Plastic Injection Molding

...manufacturing startup and management

By Douglas M. Bryce

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Preface

This book is the fourth in a series providing basic information, concepts, and ideas to those interested in, or already existing in, the world of injection molding of thermoplastics. Volume I focuses on manufacturing process fundamentals, Volume II explains material selection and product design fundamentals, and Volume III describes mold design and construction fundamentals. This volume (Volume IV) will cover the basics of starting and running an injection molding company, whether small or large. My intention was to write this book (and the others in the series) in such a way that both newcomers and old-timers would be able to obtain information that is otherwise not readily available.

The subject of this book is manufacturing startup and management. The fundamental concepts of plant layout, determining equipment needed, estimating operating costs, and operating smoothly on a day-to-day basis will be covered. In addition, we will take a look at proper staffing, determining training needs, estimating personnel costs, and comparing automatic operations to those that are manually controlled. Along the way, we will discuss secondary operations, quality control concepts, material storage and handling, and maintenance programs. We will also include a glossary and some basic terminology common to the plastics industry.

Whether you are involved in purchasing an existing company, starting a company from scratch, or simply wish to consider the possibility of going into this business, this book is for you. I enjoyed writing these books and hope that you may take the time to write and tell me about your experiences.

I would like to take a moment to thank the following for their contribution to the completion of this volume.

- *Society of Manufacturing Engineers* for providing the various resources for editing and publishing the entire series.
- The *reviewers* of this book before publication, for giving valuable advice on how to make it better.

  Jon H. Eichhoff, CEO, Ronningen Research and Development Company
  Kendall L. Miller, Owner, Fun Dimensional
  Daniel E. Woodgate, President, Gate Mold, Inc.
- *Texas Plastic Technologies*, for supporting my efforts and continuing operations smoothly during those few times when I needed to be locked up in my office writing.

- *Various company owners, presidents, chief executive officers, and management personnel*, who shared their personal experiences and ideas with me as well as their thoughts and opinions of what I was trying to do and say.

I am dedicating this fourth volume to my immediate family. They have stood by me over the past few years while I was involved in the painstaking research and writing efforts needed to complete this four-volume series. They shared in the sacrifices and pain, and I want them to share in the success of the completion. A very sincere *thank you* to my wife Linda, daughters Melanie, April, and Victoria, and to my son Christopher. Thank you for your understanding and assistance. You all made it possible, and I love you deeply.

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Georgetown, Texas 1999

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Injection Molding Concepts 1

This chapter describes the history and basic operating process of injection molding.

HISTORY

In 1868, John Wesley Hyatt developed the plastic material called celluloid and entered it in a contest created by a billiard ball manufacturer (celluloid was actually invented in 1851 by Alexander Parkes, but Hyatt perfected it). The contest was held to find a substitute for ivory, which was becoming more expensive and difficult to obtain. He used celluloid to replace the ivory used for making a billiard ball and won the contest's grand prize of $10,000 (a rich man's sum in those days). Unfortunately, after the prize was won, some billiard balls exploded on impact during a demonstration because of the instability and high flammability of celluloid. Undaunted, new improvements were made allowing its use in commercial ventures and the plastics industry was born. John Wesley Hyatt and his brother Isaiah patented the first injection-molding machine that made celluloid plastic parts in 1872. During the next 40 to 50 years, others began to investigate this new process and used it for manufacturing items such as collar stays, buttons, and hair combs.

By 1920, the injection molding industry was even more popular and during the 1940s, the plastic injection molding industry grew tremendously because World War II created a demand for inexpensive, mass-produced products. New materials and technical advances resulted in improved applications and even more use.

From its birth in the late 1800s, to recent developments and applications, the injection molding industry has grown at a fast and steady rate. It has evolved from producing combs and buttons to molding products for all production fields, including automotive, medical, aerospace, construction, and consumer goods, as well as toys, plumbing, and packaging.

Table I-1 shows some of the important dates in the evolution of the injection molding industry.

PROCESS DESCRIPTION

Injection molding is a process that softens a plastic material with heat and causes it to flow into a closed mold. Then, the material cools and solidifies, forming a

Table I-1. Evolution of Injection Molding

1868	John Wesley Hyatt injection-molds celluloid billiard balls.
1872	John and Isaiah Hyatt patent the injection molding machine.
1937	Society of the Plastics Industry founded.
1938	Dow invents polystyrene (still one of the most popular materials).
1940	World War II events create huge demand for plastic products.
1941	Society of Plastics Engineers founded.
1942	Detroit Mold Engineering, Inc. (DME) introduces stock mold base components.
1946	James Hendry builds first screw injection-molding machine.
1955	General Electric begins marketing polycarbonate.
1959	DuPont introduces acetal homopolymer.
1969	Plastics land on the moon.
1972	The first parts-removal robot is installed on a molding machine.
1979	Plastic production surpasses steel production.
1980	Apple uses acrylonitrile-butadiene-styrene (ABS) in the Apple IIe computer.
1982	The JARVIK-7 plastic heart keeps Barney Clark alive.
1985	Japanese firm introduces all-electric molding machine.
1988	Recycling of plastic comes to age.
1990	Aluminum molds introduced for production injection-molding.
1992	Metallocene catalysts give impressive properties to polyolefins.
1994	Cincinnati-Milacron sells first all-electric machine in U.S.

specific product. The action that takes place is much like the filling of a jelly donut. A hypodermic-style cylinder and nozzle injects the heated plastic into the opening of a closed container (mold). The material is allowed to harden again, a finished part is ejected, and the cycle is repeated to produce the total number of pieces required, as shown in Figure 1-1. This description oversimplifies the actual process because there are more than 100 parameters that must be controlled to ensure production of a good low-cost part. These parameters are discussed in *Volume One* of this series, *Plastic Injection Molding—Manufacturing Process Fundamentals*, and should be reviewed for more information. To better understand the relationship between the process and proper material selection, some of the parameters must be well understood.

Categorizing the Parameters

Although there are many parameters to control, they can be detailed within the confines of four major categories. These are *temperature, pressure, time, and distance,* as shown in Figure 1-2.

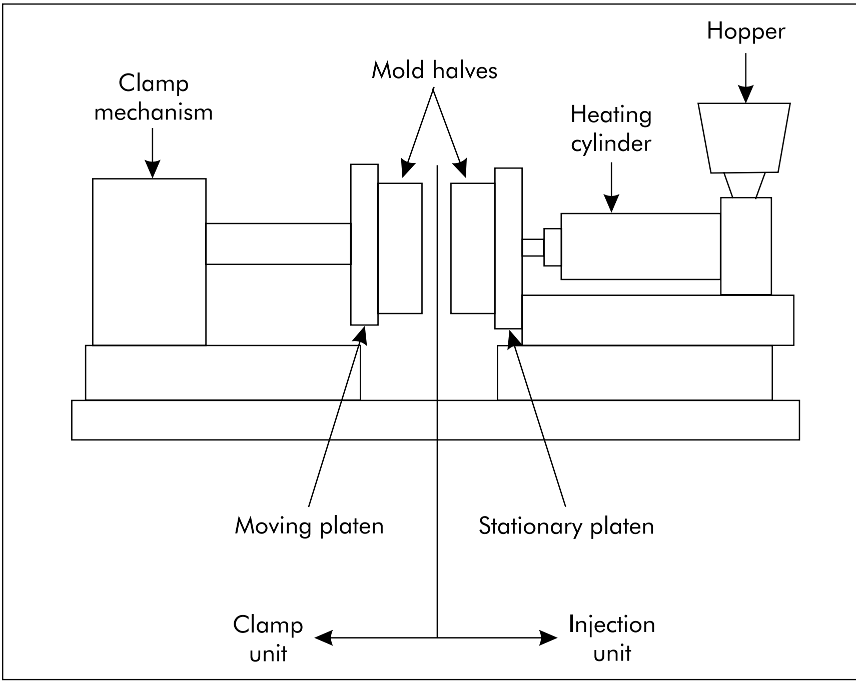


Figure 1-1. The injection molding process.

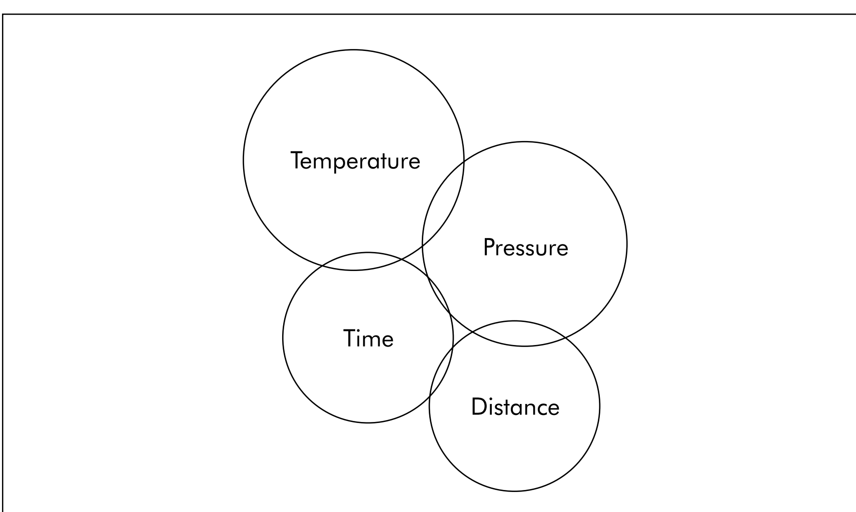


Figure 1-2. Categories of parameters.

Note that the circles in Figure 1-2 are interconnected and of different sizes. The interconnections show that each parameter is affected by, and affects, other parameters. A change in one may have a major effect on another. The different circle sizes represent the order of importance placed on each set of parameters. For example, temperature and pressure normally are more important to the process than time and distance.

Temperature

The level of heat or cold is a factor affecting the material, mold, and oil used.

Temperature of the material. The primary concern is the amount of heat that the plastic material must have for proper injection into a mold. All materials have a range of the most efficient injection temperature to maintain maximum physical properties. For amorphous materials, this range is rather broad, while for crystalline materials this range is fairly narrow (the differences between amorphous and crystalline materials are discussed in Chapter 2). However, with both types of materials there is a temperature point that the plastic flows the best and still maintains proper physical properties. This is called the *ideal melting point* and must be attained through trial-and-error activities. While this may seem primitive, it is required as a fine-tuning adjustment after a specific production run is initiated and as part of establishing particular process specifications for specific products.

The guessing process actually begins by setting the heating cylinder temperature so that the injected material is at the recommended temperature. The temperature of the plastic is measured as it leaves the heating cylinder to determine if it is within the proper range. Then, it is adjusted up or down depending on cycle times, pressure requirements, mold temperature, and other parameters. These adjustments are made during the pilot run of the process and until acceptable parts are produced. Then, a setup sheet is created, which lists parameter values that are stored for running the job again. Table I-2 shows the recommended melt temperature for some common materials. This is the temperature that should be found when measuring the material, as shown in Figure 1-3.

The softening (or melting) of the plastic is achieved by causing the individual molecules within the material to go into motion. This is accomplished by applying heat to the molecules. Generally, the more heat that is applied, the faster the molecules move. This is true until too much heat is applied. At that point, the plastic material starts to degrade and break down into its main constituents.

Heat is applied by using electrical heater bands wrapped around the outside of the injection molding machine's heating cylinder, as shown in Figure 1-4. The heater bands, which resemble hinged bracelets, are assembled with individual groups of three or four bands to control the temperature of a single zone. There are three basic temperature zones for the heating cylinder: rear, center, and front. Each zone is monitored by a thermocouple, which is connected to a temperature controller. The thermocouple determines whether or not the zone is at the correct

Table I-2. Suggested Melt Temperatures for Various Plastics

Material	Temperature, °F (°C)
Acetal (copolymer)	400 (204)
Acetal (homopolymer)	425 (218)
Acrylic	425 (218)
Acrylic (modified)	500 (260)
ABS (medium-impact)	400 (204)
ABS (high-impact and/or flame retardant)	420 (216)
Cellulose acetate	385 (196)
Cellulose acetate butyrate	350 (177)
Cellulose acetate propionate	350 (177)
Ethylene vinyl acetate	350 (177)
Liquid crystal polymer	500 (260)
Nylon (Type 6)	500 (260)
Nylon (Type 6/6)	525 (274)
Polyallomer	485 (252)
Polyamide-imide	650 (343)
Polyarylate	700 (371)
Polybutylene	475 (246)
Polycarbonate	550 (288)
Polyetheretherketone (PEEK)	720 (382)
Polyetherimide	700 (371)
Polyethylene (low-density)	325 (163)
Polyethylene (high-density)	400 (204)
Polymethylpentene	275 (135)
Polyphenylene oxide	385 (196)
Polyphenylene sulfide	575 (302)
Polypropylene	350 (177)
Polystyrene (general purpose)	350 (177)
Polystyrene (medium-impact)	380 (193)
Polystyrene (high-impact)	390 (199)
Polysulfone	700 (371)
PVC (rigid)	350 (177)
PVC (flexible)	325 (163)
Styrene acrylonitrile (SAN)	400 (204)
Styrene butadiene	360 (182)
Tetrafluorethylene	600 (316)
Thermoplastic polyester (PBT)	425 (218)
Thermoplastic polyester (PET)	450 (232)

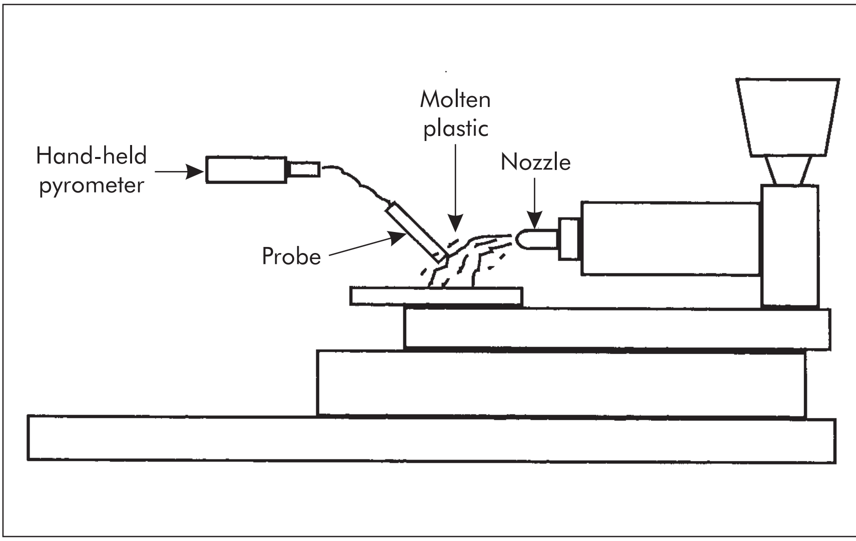


Figure 1-3. Measuring plastic temperature.

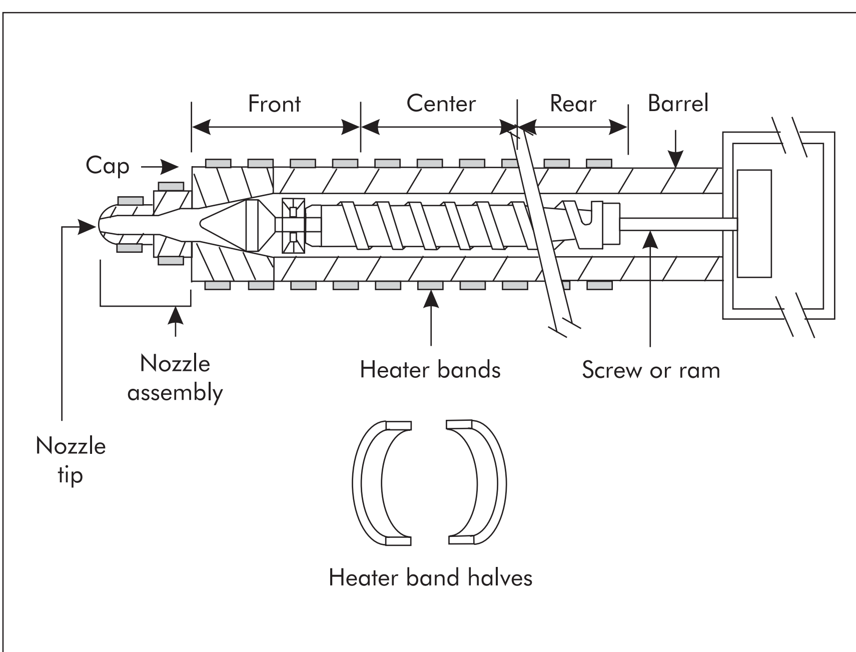


Figure 1-4. The heating cylinder.

temperature and, if more heat is required, signals the controller to supply more electricity to the heater bands in that temperature zone.

In addition, the machine nozzle (mounted at the front end of the heating cylinder) has at least one heater and is considered an additional zone, called the *nozzle zone*, as shown in Figure 1-5. As with the heater bands, heat is generated in the heating cylinder by the turning action of the feed screw located within the cylinder, as shown in Figure 1-6. The screw, which is shaped like an auger, turns to move fresh material into the heating cylinder from the hopper. Also, the turning action is utilized to squeeze the plastic, thus creating friction, which results in heat. The amount of friction is controlled by many items. This includes the rotating speed of the screw, the distance between the outside diameter of the flights, and the body diameter of the screw (which changes along the length of the screw).

Temperature of the mold. Mold temperature is another concern because the mold forms the injected plastic into a specific shape while the plastic cools and solidifies. The plastic product is then ejected from the mold and a new cycle begins.

The rate at which the plastic cools can be an important factor in determining how strong its physical properties are—especially with crystalline materials. The reason is that when the material starts heating up, the molecules are disconnected from each other, allowing them to move freely. As the material cools down, these molecules must attach to each other again to regain maximum strength. If they

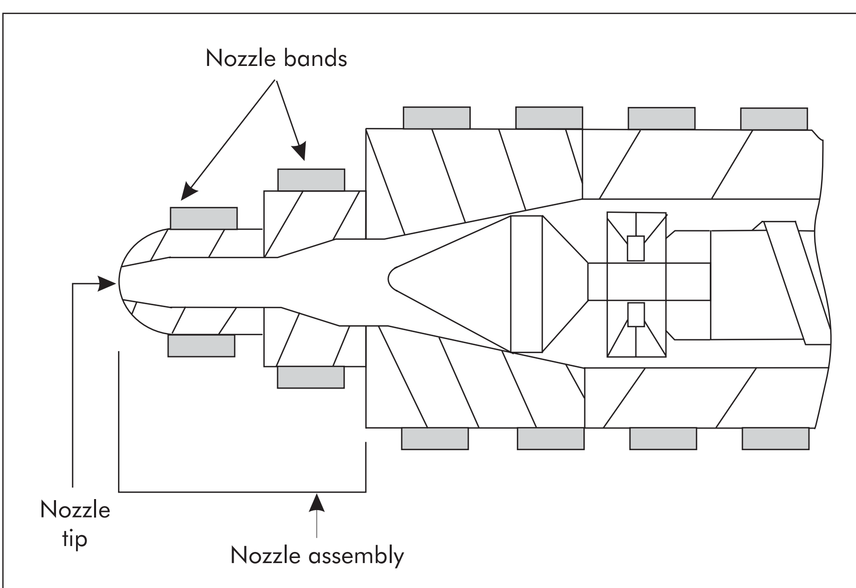


Figure 1-5. Nozzle heater zone.

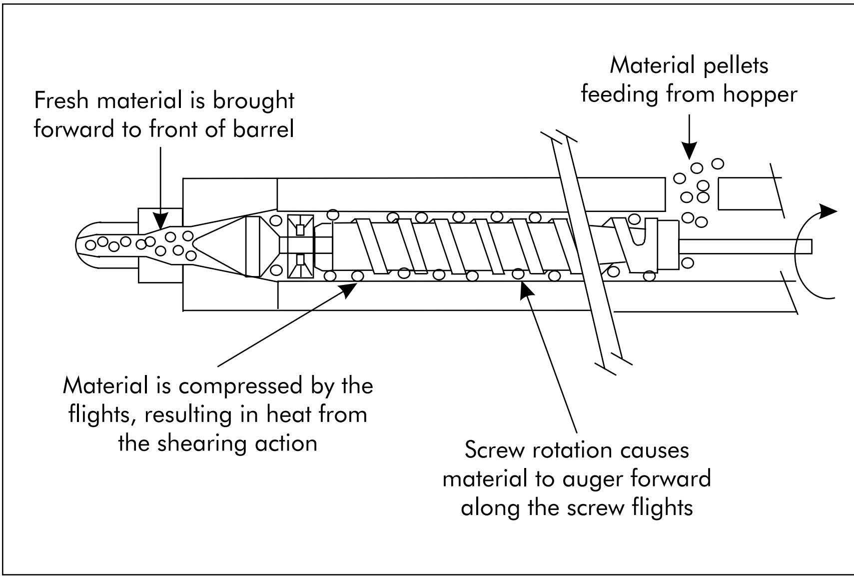


Figure 1-6. Cylinder section showing screw action.

are cooled down too quickly, they stop moving before being fully connected and the result is less physical strength. So, it is important to cool the plastic down at a rate that is slow enough to allow the material to reach proper physical strength, but fast enough to minimize cycle time (and total cost). Table I-3 shows recommended mold temperatures for some common plastics.

Running water is the normal method for controlling mold temperature. Specially designed channels are machined into the mold, usually consisting of a series of holes drilled through specific plates that make up the mold. These holes are connected by use of high-temperature hosing to a temperature control unit that supplies the correct amount and flow of hot or cold water to maintain a selected temperature, as shown in Figure 1-7.

When hotter temperatures are required, such as at startup time, the temperature controller cycles the water through a heating device until the proper temperature is reached. When cooler temperatures are required, the unit causes the circulating water to drain and refill with cool water from the input source. In this manner, the unit is capable of maintaining the temperature of the water circulating through the mold to within 2 or 3° F (1 or 1.6° C).

Temperature of the oil. With the exception of the all-electric model introduced in the U.S. by Cincinnati-Milacron, most molding machines operate through the use of hydraulic systems. These systems provide energy for turning

Table I-3. Suggested Mold Temperatures for Various Plastics

Material	Temperature, °F (°C)
Acetal (copolymer)	200 (93)
Acetal (homopolymer)	210 (99)
Acrylic	180 (82)
Acrylic (modified)	200 (93)
ABS (medium-impact)	180 (82)
ABS (high-impact and/or flame retardant)	185 (85)
Cellulose acetate	150 (66)
Cellulose acetate butyrate	120 (49)
Cellulose acetate propionate	120 (49)
Liquid crystal polymer	225 (107)
Nylon (Type 6)	200 (93)
Nylon (Type 6/6)	175 (79)
Polyallomer	200 (93)
Polyamide-imide	400 (204)
Polyarylate	275 (135)
Polybutylene	200 (93)
Polycarbonate	220 (104)
Polyetheretherketone (PEEK)	380 (193)
Polyetherimide	225 (107)
Polyethylene (low-density)	80 (27)
Polyethylene (high-density)	110 (43)
Polymethylpentene	100 (38)
Polyphenylene oxide	140 (60)
Polyphenylene sulfide	250 (121)
Polypropylene	120 (49)
Polystyrene (general purpose)	140 (60)
Polystyrene (medium-impact)	160 (71)
Polystyrene (high-impact)	180 (82)
Polysulfone	250 (121)
PVC (rigid)	140 (60)
PVC (flexible)	80 (27)
Styrene acrylonitrile (SAN)	100 (38)
Styrene butadiene	100 (38)
Tetrafluorethylene	180 (82)
Thermoplastic polyester (PBT)	180 (82)
Thermoplastic polyester (PET)	210 (99)

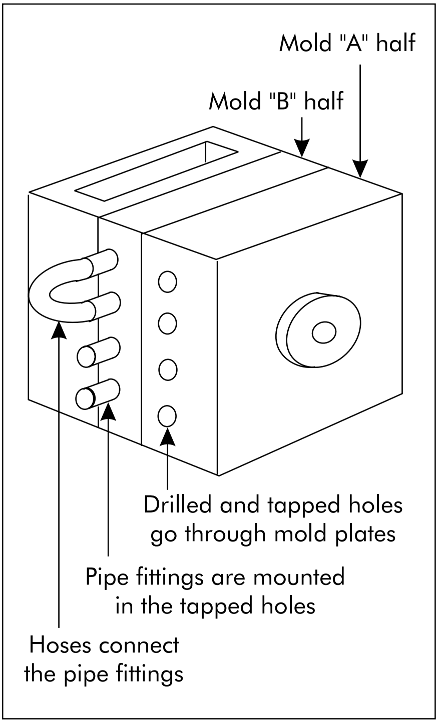


Figure 1-7. Controlling temperature of mold.

the screw, opening and closing the clamp (even in toggle machines), and actuating ejector systems. During these operations and even when the machine is running at idle, the oil temperature in the hydraulic system rises. This is due to friction created by the oil flowing through the machine, and by oil being compressed to provide pressure.

Oil temperature must be controlled to allow it to function properly. If the oil is too cold, it will be thick and will not flow easily. This may cause valves to operate sluggishly or not at all. If the oil is too hot, it will degrade and create a thin liquid filled with chunks of additive materials. These will clog passageways and interrupt operation of the hydraulic mechanisms within the system.

The temperature of the oil is controlled by using a heat exchanger. This unit circulates the oil over copper (or other highly conductive metal) tubing that weaves back and forth inside the unit. This tubing is connected to a water inlet source and the temperature of the oil is monitored. When the oil is cold, the heat exchanger does not circulate the water in the tubes.The water absorbs heat from the oil as it flows through the hydraulic system. Eventually, the oil becomes too hot and the heat exchanger opens the water inlet valve to allow water to circulate through the copper tubing. The circulating water draws heat from the oil until the oil temperature reduces to the proper value. Then, the water is shut off again until needed. In this way, the heat exchanger can maintain the proper oil temperature at approximately 120° F (49° C), plus or minus 5° F (2.7° C).

Pressure

There are many reasons for using pressure in the injection molding process. The hydraulic oil system within the molding machine, and a series of control valves, regulators, and directional valves within that system provide the needed pressure. The system normally provides a primary "line" pressure of 2,000 psi (13.8 MPa), which is then adjusted up or down by the control components of the system to provide whatever pressure is needed for a particular application. For example, the injection pressure can be adjusted from approximately 500 psi (3 MPa) for fast flowing plastic, up to 20,000 psi (138 MPa) or more, for highly viscous materials. The specific requirements for the various pressure applications, such as injection, holding, and clamp pressure, are discussed next.

Injection pressure. Injection pressure is the primary pressure used for the injection molding process. It can be defined as the amount of pressure required to produce the initial filling of the mold cavity image. The *cavity image* is the opening in the mold that will be filled with plastic to form the product being molded. Initial filling represents approximately 95% of the total filling of the cavity image.

The amount of pressure that is required will range from very low (500 psi [3 MPa]) to very high (20,000 psi [138 MPa]). The viscosity and flow rate of the injected plastic determines how much pressure is used. Of the more than 20,000 plastic materials available for selection today, most will fall within a pressure range requirement of approximately 5,000-15,000 psi (34-103 MPa). And, most of these will have a flow index rating of between 5 and 20.

The *flow index* rating (properly referred to as the *melt index*) is a value designating the amount of material (in grams) that flows in a 10-minute period from a specially designed rheometer. The melt index test is performed per the official American Society for Testing and Materials (ASTM) standard D-1238 with a rheometer as shown in Figure 1-8.

The melt index (MI) test is a good reference test to determine the relative resistance to flow (viscosity) of a plastic material. Materials with an MI value of around five indicate a very viscous material and will require very high molding pressures. In contrast, materials with an MI value of 20 will be easy to mold and will require low pressures. The materials data sheet supplied by the manufacturer will indicate the range of melt index values for specific materials.

Note that the melt index also indicates the properties of the plastic material being tested. Table I-4 shows the relative importance of increasing or decreasing the melt index value. A customer can request an increase or decrease from the material supplier as long as the requested value is within the range for that specific material. In most cases, a stiffer material may be

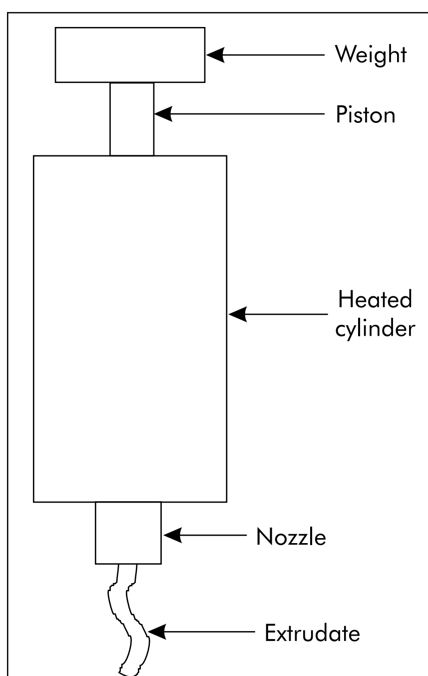


Figure 1-8. Melt index rheometer.

Table I-4. Effect of Viscosity on Physical Properties

As melt index value *decreases:*	
Stiffness	Increases
Tensile strength	Increases
Yield strength	Increases
Hardness	Increases
Creep resistance	Increases
Toughness	Increases
Softening temperature	Increases
Stress-crack resistance	Increases
Chemical resistance	Increases
Molecular weight	Increases
Permeability	*Decreases*
Gloss	*Decreases*

Note that permeability and gloss actually *decrease* as the melt index value drops.

preferred, but it will be more difficult to process because it will require higher injection pressures. A major drawback, other than cost, is the introduction of stress caused by using the higher pressures. This will be discussed in a later chapter, but be aware that stress is created in every part. However, the degree of stress can be controlled and should be minimized whenever possible to eliminate product defects and field failures.

Holding pressure. Holding pressure is applied at the very end of the primary injection stroke and is used for the final 5% filling of the cavity image. It is called *holding pressure* because pressure is held against the cooling plastic that is in the cavity image while the plastic solidifies. Molding with a uniform pressure and controlled shrinkage helps to ensure that a dense part is made. Holding pressures are usually in the range of 50% of the primary injection pressure. So, if a plastic material requires 10,000 psi (69 MPa) for primary injection pressure, the holding pressure should be applied at approximately 5,000 psi (34 MPa). Holding pressure must be applied against a pad of extra material called a *cushion*. This will be discussed in more detail in the "Distance" section later in this chapter.

Clamp pressure. *Clamp pressure* can be defined as the amount of pressure required to hold the mold closed against injection pressure. The clamp unit of a molding machine can be mechanically or hydraulically activated to apply pressure against the mold that forms the plastic product. The degree of pressure applied must be at least equal to the amount of pressure applied by the injection unit. If 10,000-psi (69 MPa) injection pressure is used, then at least 10,000 psi (69 MPa) clamp pressure must be used. In fact, a safety margin of additional pressure equal to approximately 10% above the initial clamp pressure should be used to ensure that the clamp stays closed if the injection pressure drifts upward slightly.

If the clamp pressure is too low, the mold will blow open during injection, flash will occur, and the cavity image will not fill with plastic. *Flash* is the thin, extra material that is forced into the parting line between the mating mold surfaces during a molding operation that remains attached to the molded product. If the clamp pressure is too great, the mold may collapse from the total force being applied.

Time

The duration for injecting, cooling, and clamping is considered next.

Injection time. The amount of time required for injection depends on how much material is being injected, the viscosity of the material, and the percentage of the machine's barrel capacity being utilized. The total amount of injection time required is divided into two separate phases: initial injection and holding injection.

Initial injection time. When the mold closes completely, either a limit switch or pressure buildup (or both) signals the injection screw to push forward and inject the molten plastic into the closed mold. The screw does not turn at this point, but acts only as a plunger to force the material into the mold. Initial injection is performed using the highest practical pressure for the specific application (normally 10,000-15,000 psi [69-103 MPa]) in the fastest practical amount of time. In most cases, this is less than 2 seconds and rarely more than 3 seconds. Sometimes, depending on machine design, this initial action is divided into two or three smaller actions, or *stages*. In those cases, the total amount of injection time normally does not exceed 4 to 5 seconds. The initial injection time is controlled through use of a timer. If a "booster" injection time is available, it will be included in the first stage of the initial injection time. When a booster phase is utilized, the injection machine's entire hydraulic system (injection and clamp) is combined to push a large volume of oil through the system. This can greatly increase the speed at which the material is injected into the mold.

Injection hold time. On most machines, the timer for initial injection time (also called injection forward time) controls the total amount of time that the injection screw is pushing forward. The initial injection time is the first part of that time and injection hold is the latter part. On some machines, the hold time and initial time are on separate timers.

The hold time is the amount of time that the injection screw maintains pressure against the plastic after it has been injected into the mold. This pressure is applied against the "cushion" or "pad" and is applied long enough for the gate to *freeze off* (solidify). When the plastic is injected into the mold, the molten plastic enters the mold cavity image through a gate. This gate is the first point at which the plastic moves into the cavity image. After all the required material goes through the gate and packs the cavity image, the plastic is allowed to cool under hold pressure until it solidifies. But, because it is normally the thinnest part of the cavity image, the gate is the first portion to solidify. At this point, pressure is not applied because the plastic in the cavity lies beyond the solidified gate and the pressure from the injection unit no longer has any effect on it. So, the length of time required to hold pressure against the gate is only long enough for the gate to freeze (solidify). In most cases, this is only a matter of a few seconds. A gate with a thickness of 1/16 in. (.060 in. [1.59 mm]) would take approximately 6 seconds to solidify.

Cooling time. This is probably the most important amount of time in the entire injection process. The *cooling time* is the amount of time required for the plastic material to cool and solidify, allowing the plastic part to be rigid enough to withstand the ejection process. The *ejection process* occurs when the finished molded product is pushed out of the mold after the entire cycle is completed. Even though the plastic may cool down enough to solidify, it may not be rigid enough to eject. This is because the cooling process actually takes as long as 30 days to finalize.

The initial cooling is rapid, and 95% of the total cooling takes place in the mold However, the other 5% takes place outside the mold. If the outer skin of the plastic product is solidified to a sufficient depth, the remaining cooling will not have an appreciable effect on the molded part. But if the skin is too thin, the remaining cooling will cause shrinkage stress to build up and the molded part may warp, twist, blister, or crack. The key to minimizing these problems is to keep the part in the mold for a sufficiently long time, but no longer than necessary because time is money and long cycles are expensive. Most material suppliers are more than happy to share cooling time requirements for their specific materials at varying thicknesses (the thicker the part, the longer the cooling time required). On average, a 1/16 in. (.060 in. [1.59 mm]) -thick wall should take approximately 9-12 seconds to solidify (depending on material) to the point at which it can be ejected from the mold without undue distortion.

Clamp time. Clamp time (or "Mold Closed" time) is the amount of time that the mold halves stay closed, or clamped together. It begins when the mold first closes and continues until the mold opens up again. The entire injection and material preparation phases, and cooling time take place during the clamp time. The clamp time is the greatest amount of time involved in injection molding because it encompasses most of the operations that take place during the injection molding process.

Distance

The final parameter for investigation is distance. Although it is the last item on the list of parameter priorities, control of distance is critical for producing high quality products at reasonable cost. This is primarily because excessive distance requires excessive time, and, as stated earlier, time is money. Because distance is so closely related to time, much of the discussion is basically the same as for time, with the addition of a few other items.

Mold close distance. There are two phases that comprise mold close distance. The first is the "initial close" and this describes the major portion of the closing process. The second is "final close" and this defines the last portion of the closing process.

The amount of distance covered by the initial mold closing moves the mold halves to within approximately .25-.5 in. (6.4-12.7 mm) from touching. This closing distance is normally traveled under high speed and is done to get the mold closed as soon as possible to minimize overall cycle time. But, if the mold halves should slam together under high speed, they will eventually crack and break. Also, if there is an obstruction in the mold (such as a broken piece of plastic), it can cause damage if the mold is allowed to close on it. Therefore, the mold should close quickly, but under very low pressure, until the mold halves are close to touching. This distance is measured from the point at which the mold begins to close, as shown in Figure 1-9, to the .25-.5 in. (6.4-12.7 mm) gap mentioned earlier.

After the initial close, the rate at which the mold closes is drastically reduced, but high closing pressure is used. This occurs for the entire .25-.5 in. (6.4-12.7 mm) distance of travel, until the mold halves are closed tightly against each other. If a foreign object is caught in the mold, the closing action can be stopped at this point and the object can be removed without causing damage. If the clamp should close under high pressure on any foreign object, the object will be crushed and damage the mold. After traveling the final .25-.5 in. (6.4-12.7 mm), the mold is fully closed under full clamp tonnage and the injection phase is allowed to begin.

Injection distance. As mentioned earlier, the injection process is generally broken into two phases. They are determined by the initial injection distance and

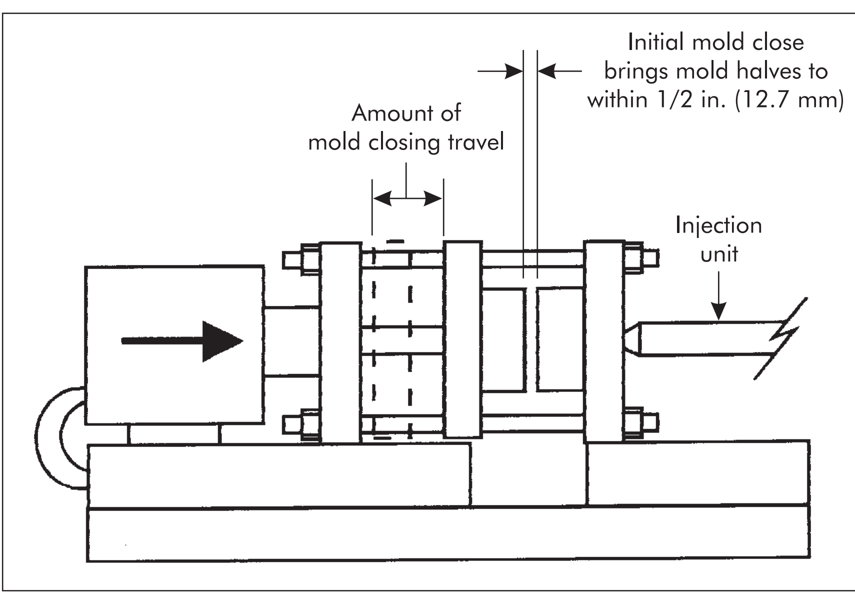


Figure 1-9. Mold closing distances.

injection hold distance, as shown in Figure 1-10. Note: the *initial injection distance* is determined by subtracting the injection hold distance from the total injection distance.

Initial injection distance must be set to ensure that approximately 95% of the intended material is injected. This distance varies depending on how big the machine is and how much of the barrel capacity is being injected for one shot. The ideal shot size is 50% of the barrel capacity. For example, if the machine is rated as having a 6-oz (170-g) barrel capacity (in styrene), the ideal single shot size is half the capacity or 3 oz (85 g). In this case, the limit switch governing that shot size would be set halfway back on the measurement scale. This scale is usually physically located on the injection barrel, but is sometimes part of the electronic control system. In any case, the scale is incremental and can be adjusted anywhere between 0 and 100% of the barrel capacity.

Holding distance. After the initial injection setting allows about 95% of the required material to be injected, the machine switches to holding pressure. This finishes filling the mold and holds pressure against the material that was injected. The point where the hold pressure begins is near the stroke end of the injection screw.

Cushion (pad). There should be a pad, or cushion, of material left in the barrel for the hold pressure to be applied against. This cushion should be approximately .125-.25 in. (3-6 mm) thick, as shown in Figure 1-11.

The amount of cushion is established by creating a total shot size that is slightly larger than that required to fill the mold. For example, if the amount of material

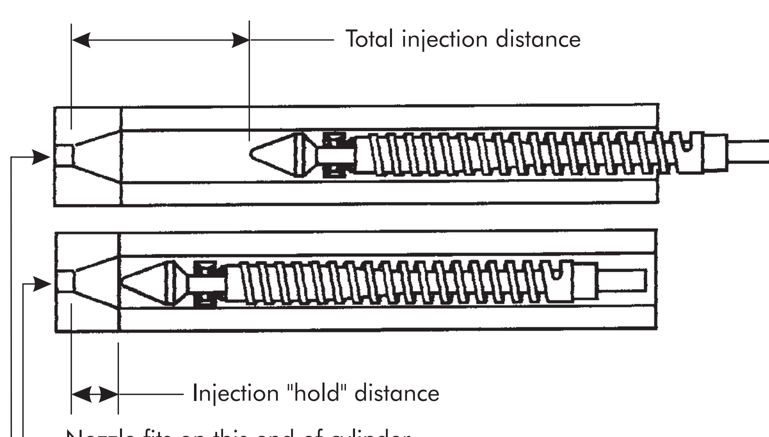


Figure 1-10. Injection hold distance.

required to fill the mold is 2.9 oz (82 g), the total shot size would be established at approximately 3 oz (85 g).This would then be adjusted (increased or decreased) during setup until the .125 in. (3 mm) cushion is developed. Changing the set point for the screw return makes this adjustment.

The thickness of the cushion is critical and must not be less than .125 in. (3 mm). Anything less is difficult to accurately control and there is a good chance that the cushion will randomly go to zero due to inconsistencies in the specific gravity of the melt. If the cushion does go to zero (or “bottoms out”), there will be no pressure held against the material in the mold and the molded part may warp, crack, or nonfill due to lack of holding pressure. Also, the shrinkage will vary and the part may not be dimensionally acceptable. On the other hand, if the cushion is more than .25 in. (6 mm) thick, the plastic in the cushion might cool down and begin to solidify due to all the steel surrounding it. This can cause a blocked nozzle, resulting in slow flowing material or no flow at all.

Mold open distance. To break the vacuum that was created in the cavity image during the injection process, the mold must be opened slowly. After the mold has opened .25 in. (6 mm) or so, the vacuum on the stationary side is relieved and the mold can be allowed to open at a faster rate. The faster rate is desired so that the cycle can be completed quickly and the next cycle started.

If a mold contains “actions,” such as slides or cams, there may be a requirement to open the mold slowly for a longer distance. This might range from the original .25 in. (6 mm) to 2 or 3 in. (5 or 8 cm) or more.

After the mold has opened enough to break the vacuum (and far enough to clear the actions) it may be allowed to open fully. The total distance that a mold opens should not be more than absolutely necessary because it takes time for this to happen—and time is money. So, how much is necessary?

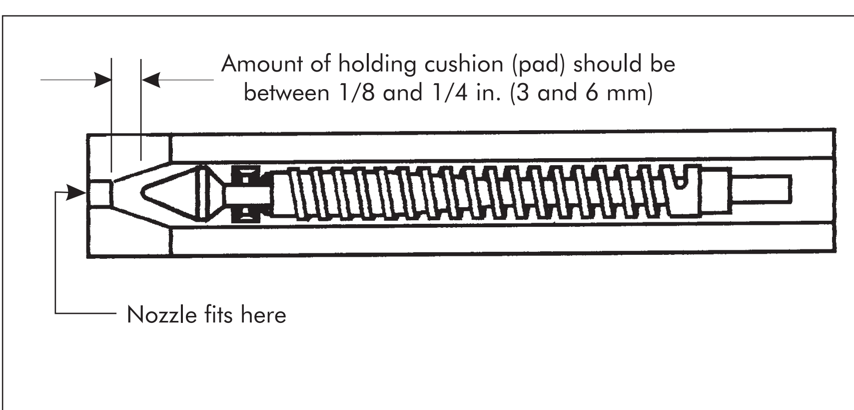


Figure 1-11. Cushion.

The mold should open a total distance equal to twice the depth of the molded part. For example, if the part being molded is a square box with a depth of 6 in. (15 cm), the mold should be allowed to open no more than 12 in. (30 cm). If possible, this dimension should be made smaller. There needs to be only enough open space to allow the finished part to fall clear of the mold after ejection, or for the operator to reach in and remove the ejected part, as shown in Figure 1-12.

If the mold is running with an operator who must physically remove the part from the ejector system, the mold open distance should be adjusted to whatever level is necessary for safety and comfort, and enough room for manipulating the part. In most cases, this will not exceed 2-1/2 times the depth of the part.

Ejection distance. The required amount of ejection is only that amount which will push the part free from the mold. The only area of the part that is ejected is the portion confined in the moving half ("B" half) of the mold If those areas have a maximum depth of 1 in. (2.5 cm), then theoretically only 1 in. (2.5 cm) of ejection is required. If more is used, it takes additional time, and time is money. If

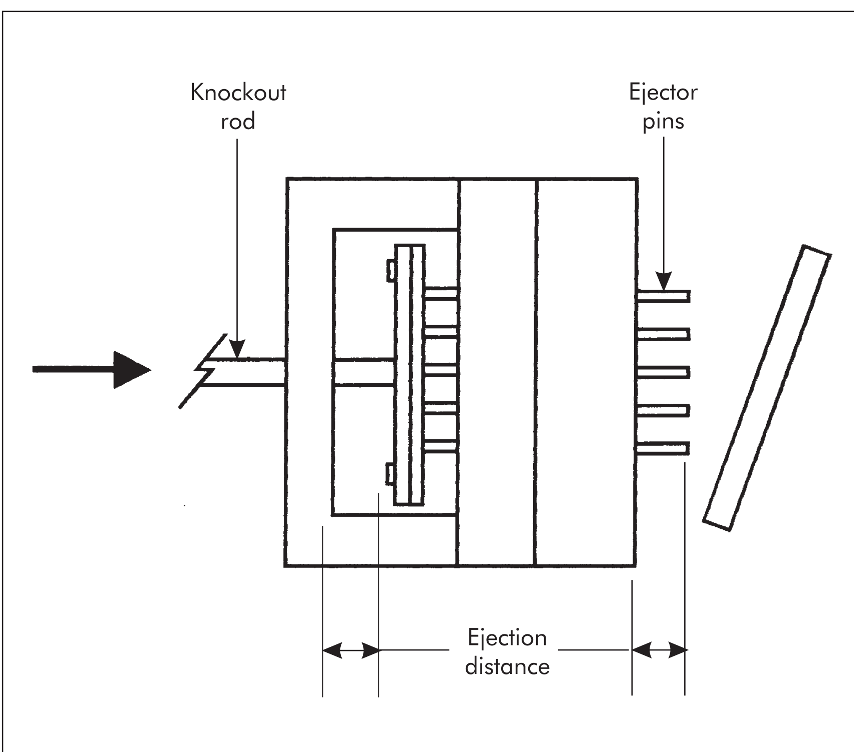


Figure 1-12. Ejection of finished part.

less is used, the part will probably not fall free and will get stuck, causing damage if the mold closes on it. It is a good practice to measure how much ejection is required and then add .125-.25 in. (3-6 mm) to make sure the part is well clear of the mold surface.

Horizontal versus Vertical Molding

The standard method of injection molding utilizes a machine that opens and closes the mold along a horizontal path, as shown in Figure 1-13. The injection unit is on that same horizontal path.

A vertical molding machine is one in which the mold opens and closes along a vertical path, as shown in Figure 1-14. The injection unit stays on the horizontal path.

There are advantages to both methods.

Advantages of Horizontal Molding

- Horizontal molding is the most common method used for injection molding. Therefore, there are large numbers of personnel available who are accustomed to the method.
- Training videos, handbooks, and troubleshooting media are readily available.
- Ejected parts fall freely from the mold because gravity assists them in the horizontal position.
- The molds' sprue bushing can stay in contact with the injection unit, thus maintaining heat stabilization.

Advantages of Vertical Molding

- Machinery takes up less floor space area because the clamp unit is vertical.
- Vertical molding is normally used for shuttle molds where one set of parts is molded while another is being prepared with inserts or overmolded parts, thus minimizing gate-to-gate cycle times.

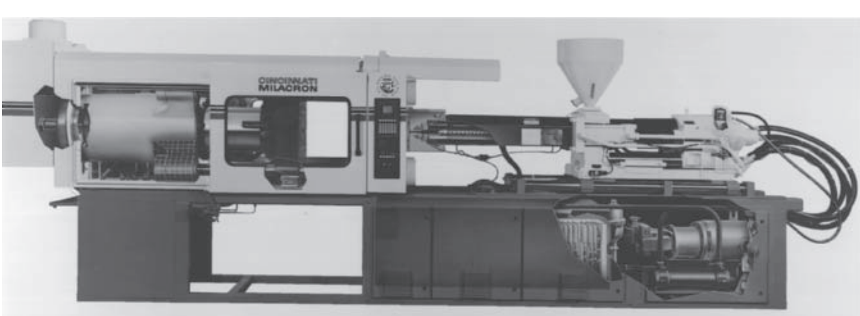


Figure 1-13. Horizontal injection-molding machine.

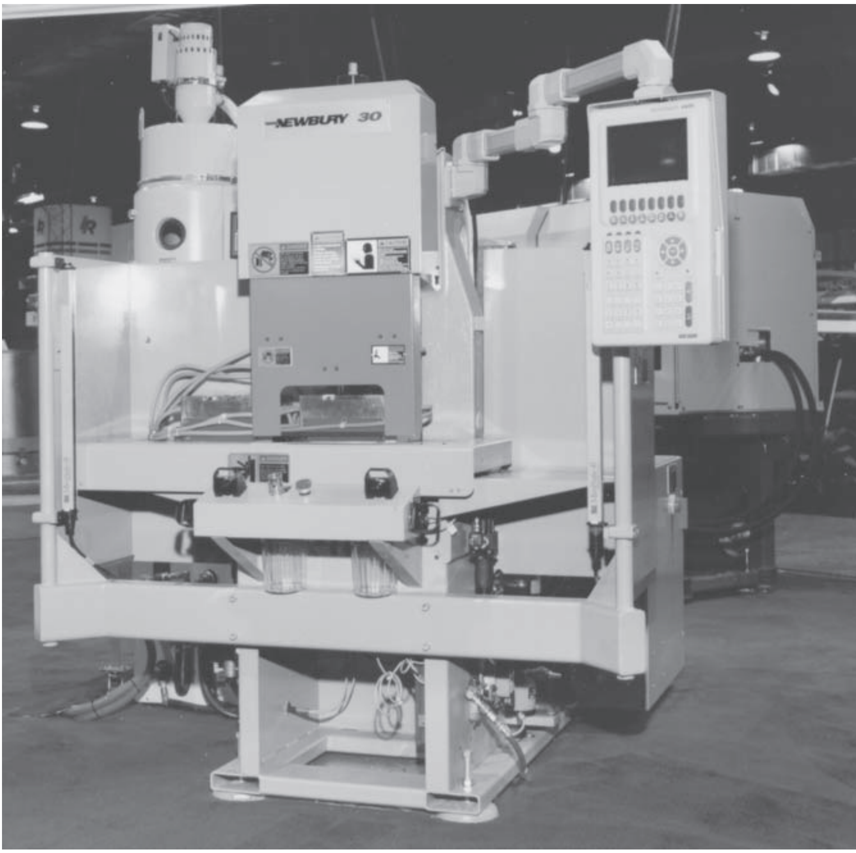


Figure 1-14. Vertical injection-molding machine.

- Vertical molding allows operators easy access to molded parts. This can be important when molding fragile products that should not be allowed to fall freely as in horizontal molding.
- Vertical molds are normally less complicated than horizontal molds and can be made less expensively.

Process Controls

To take advantage of injection molding's numerous benefits, it is necessary to control as many process parameters as possible. Actually, controlling parameters can be fairly simple. But is it really necessary? Should valuable resources (time, money, personnel, and space) be allocated to this end? The answer to both questions should be a resounding "Yes!" The reason for this is that any successful method of controlling the quality and the cost of a product depends heavily on the consistency of the process used to manufacture that product. Consistency can only be achieved by tightly controlling as many parameters as possible during the manufacturing process. This does not mean that adjustments cannot be made after the job is running. It means that proper control allows for accurate, meaningful adjustments, when they are necessary. If proper control of parameters is attained, consistency follows. This consistency takes the form of increased part quality and lowered part cost.

Part Quality

Part quality requirements are usually determined through joint discussions and agreements between the owner of the product design and the manufacturer of the product. This may be the same person (or group), or may be two individual entities, and in some cases, the owner of the product design may define the requirements without any discussion with anyone else. In any case, a set of requirements is established for how the finished product will respond to a given set of circumstances. These requirements include:

- Mechanical.
- Physical.
- Aesthetic.
- Thermal.
- Other values.

Tolerances are placed on each of the values, if practical. For example, the product designer may wish to have a product that withstands high temperature exposure for extended periods of time. Or, there may be a requirement that states the product should be a specific length. Both of these requirements must have a value placed on them. The temperature requirement might be listed as 160° F (71° C), and the length requirement might be 10 in. (25.4 cm). Reasonable tolerances are placed on these values and the manufacturer (molder) then understands the relative importance of the requirements. For example, the 160° F (71° C) becomes 160 ±10° F (71 ±5° C), and 10 in. becomes 10 ±.05 in. (25.4 ±0.13 cm).

Understanding the importance of the requirements dictates to the molder how much control is needed to obtain the necessary level of consistency and the most efficient and economical level of manufacturing. For example, the molder knows that the 10-in. (25.4-cm) length dimension can be made slightly larger if high injection pressures are used, or slightly smaller if low injection pressures are used. But the molder must be aware that as the tolerances are made tighter, greater control must be exercised over the pressure parameter. This does not say that all parts must be molded to extremely high quality levels. It states that after the level of quality required is understood, it can be met and maintained through proper control of molding parameters. *The lower the level of quality required, the easier it is to control the processing parameters.*

Part Cost

The cost to mold a part is determined in many ways and the methods are discussed in Volume 1 of this series, *Manufacturing Process Fundamentals*. After cost is estimated (and successfully quoted), it becomes the responsibility of the molder to ensure that the cost is not exceeded. Actually, the molder should try to reduce the true cost if possible, and this reduction can be passed on to the customer, kept as additional profit by the molder, or shared equitably by both. Proper control of the process parameters will allow that cost target (or reduction) to occur.

It must be stated here that someone buys every part molded, whether good or bad. The customer buys the good parts, and the molder buys the bad parts. So, it makes good sense for the molder to strive for a zero-defect situation, and to keep the manufacturing costs to a minimum. This is true whether the molder is making inexpensive flowerpots or precision-molded electronic devices. It is necessary to produce consistently acceptable products, at the lowest possible cost. This can be achieved by maintaining consistent processing cycles through consistent parameter control.

PARAMETER EFFECTS

Table I-5 shows some examples of the property values that can be adjusted by a plus or minus change in some of the more common molding parameters. Notice how some properties are changed in the same way by different parameters. For instance, less shrinkage can be attained by either increasing injection pressure or increasing mold temperature, and less degradation can be achieved by lowering back pressure as well as lowering melt temperature. These examples are shown to demonstrate the fact that the basic molding parameters work closely together, and that changing a parameter in one area may affect a value of some property in another area. By understanding this relationship, it is possible to minimize the number of adjustments required when it is necessary to make a correction due to an unexpected change in some variable of the process.

Table I-5. Parameter Change versus Property Effect

Parameter	Property effect
Injection pressure (+)	Less shrinkage, higher gloss, less warp, harder to eject
Injection pressure (–)	More shrinkage, less gloss, more warp, easier to eject
Back pressure (+)	Higher density, more degradation, less voids
Back pressure (–)	Lower density, less degradation, more voids
Melt temperature (+)	Faster flow, more degradation, more brittle, flashing
Melt temperature (–)	Slower flow, less degradation, less brittle, less flashing
Mold temperature (+)	Longer cycle, higher gloss, less warp, less shrinkage
Mold temperature (–)	Faster cycle, lower gloss, greater warp, higher shrinkage

Determining Suitable Parameter Values

The best setting for the injection pressure, back pressure, melt temperature, mold temperature, etc., depends on the molding material and the mold type used, as well as the status of the injection machine and environmental conditions.

Setup Sheet

In most molding facilities, it is common to have a setup sheet that lists many common parameters and the value for each. This is commonly used to start up a mold at the beginning of production. A typical setup sheet format is shown in Figure 1-15. Notice in the areas identified as "Temperature," "Timer Settings," "Pressure Settings," and "Miscellaneous," that there are two columns shown for listing values. The first column is marked "Startup" and the second column is marked "Actual." This form acknowledges that there should be one group of settings for startup, and another group of settings used for long-term production. Two sets of values are required because the parameters that are set for the initial parts will begin affecting each other immediately after starting up. They will stabilize after approximately 6-8 hours, affecting the molding material differently and varying from the initial startup parameter values. For example, if the barrel rear temperature is set to 475° F (246° C) at the beginning of a run, it takes approximately 45 minutes for the material inside the barrel zone to get close to that setting. Then, the temperature controller begins to cycle off and on to maintain the proper temperature. This results in an even temperature distribution along the barrel. In the meantime, the material moves through the zone, but the temperature will vary depending on the batch. The first mass of material is heated to approximately 450° F (232° C), the next few batches are heated to approximately 460° F (238° C), and the final batches are heated to approximately 470° F (243° C). Subsequent material batches are heated to the correct temperature setting, which is 475° F (246° C). This holds true even if the material remains in the barrel for thirty minutes before beginning the run.

After the run starts, all the parameters begin the stabilization process. While this process is occurring, the major parameters are adjusted to accommodate the original batches of material. This is to ensure that a parameter, such as injection pressure, is set high enough to inject the material into the mold. After a few minutes, when the next few batches come through (at a higher temperature), they flow easier and may tend to flash if the injection pressure is still held at the higher setting. When the properly heated batches start flowing, they will create flash. At this point, injection pressure is reduced to accommodate the hotter material. So, by the time everything stabilizes, which may take 6 hours or more, most of the parameters have to be reset to different values from those set at the beginning of the process. This explains the reason for maintaining two separate setup sheets or, at least, two separate columns of data on a single setup sheet.

ABC MOLDING COMPANY **SETUP SHEET** **JOB#** __________
Customer Name _______________ Part Number __________ Date ___________

Machine Data

Preferred Machine _______________
Clamp Tonnage Required _________
Clamp Stroke ___________________
Misc. Equipment Req'd ___________
____
____
____
____

Mold Data

Mold Number ___________________
Part Description ________________
No. of Cavities _________________
Shut Height ____________________
Mold Open Distance _____________
Runner Type ______ Clamp _______
Nozzle Type ____________________
Ejection Stroke _________________
Special Requirements ____________
____
____
____

Temperature

Area	**Startup**	**Actual**
Feed Throat	_______	________
Barrel Rear	_______	________
Barrel Center	_______	________
Barrel Front	_______	________
Nozzle	_______	________
Mold "A" Half	_______	________
Mold "B" Half	_______	________

Hot Runner Zone Settings
1 _____ 2 _____ 3 _____ 4 _____
5 _____ 6 _____ 7 _____ 8 _____
9 _____ 10 _____ 11 _____ 12 _____

Material Description _____________
Material Number _______________
Total Shot Weight _______________

Timer Settings

☐ Automatic ☐ Semiautomatic ☐ Manual

Area	**Startup**	**Actual**
Mold Open	________	________
Injection Delay	________	________
Injection Fwd	________	________
Injection 1st	________	________
Injection 2nd	________	________
Injection Hold	________	________
Mold Close	________	________
Decompress	________	________
Ejectors Fwd	________	________
Air Blow Off	________	________

Pressure Settings

Area	**Startup**	**Actual**
Accumulator	________	________
Back Pressure	________	________
Injection 1st	________	________
Injection 2nd	________	________
Injection Hold	________	________
Ejection	________	________

Miscellaneous

Area	**Startup**	**Actual**
Overall Cycle	________	________
Cushion (in.)	________	________
Screw RPM	________	________
Clamp Speed	________	________
Ejector Speed	________	________
_____________	________	________
_____________	________	________
_____________	________	________
_____________	________	________
_____________	________	________
_____________	________	________

Prepared by ______________________
Date ____________________________
Approved by ______________________
Date ____________________________

Figure 1-15. Typical setup sheet. (Courtesy Texas Plastic Technologies)

Controlling Shrinkage

All materials have a specific shrinkage rate value assigned to them by the material manufacturer. The use of the term "rate" is a misnomer because it implies that the shrinkage occurs as a function of time, which is not true. Regardless of this inaccuracy, the term is used because it has become accepted throughout the industry. *Shrinkage rate* is a value that can be used to predict how much difference there will be in the plastic product from when it is first molded to after it has cooled to room temperature, as shown in Figure 1-16.

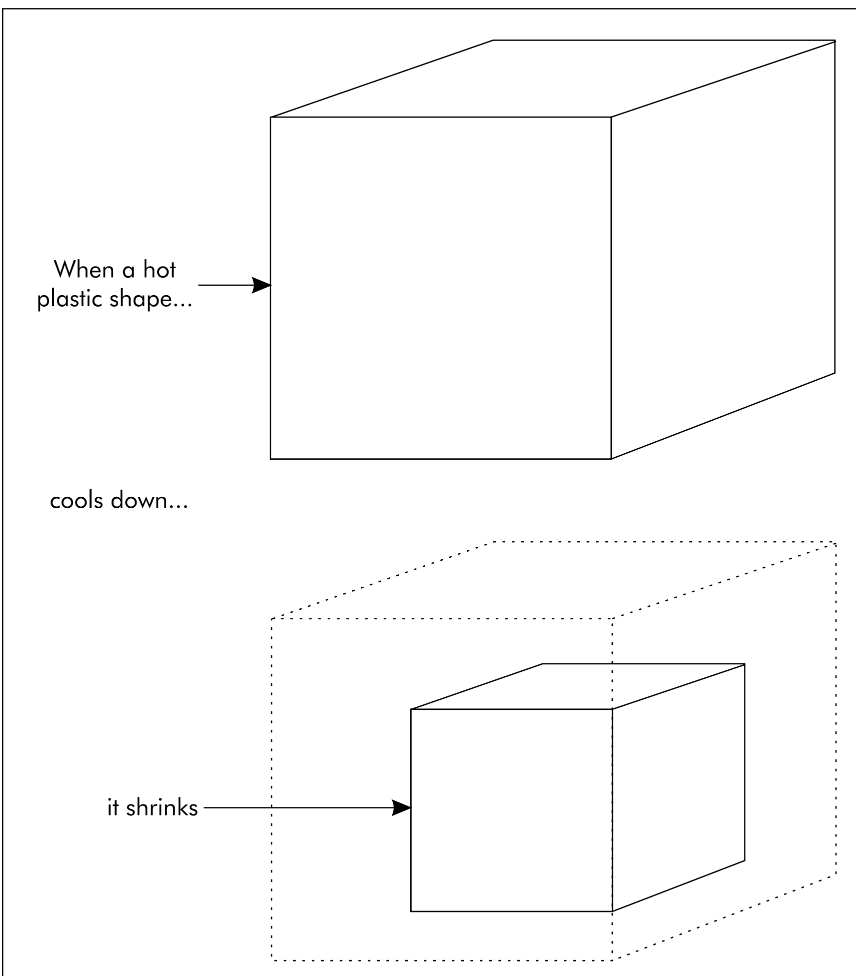


Figure 1-16. Shrinkage rate.

Everything (except water) expands when it is heated and shrinks when it is cooled. Plastic material is no exception. Each plastic material has a distinct value for how much it will shrink after it is heated and then allowed to cool. The shrinkage rate is listed as a unit value of in./in. This means that for each linear dimension of the plastic product, the material will shrink a certain amount. Usually, these materials shrink somewhere between .000 in./in. up to approximately .050 in./in. Shrinkage also can be thought of in terms of percentage. A part that has a .010 in./in. shrinkage will shrink a total of 1%, one with a shrinkage rate of .020 in./in. will shrink 2%, and one with a .005 rate will shrink 1/2 of 1%. Note: inch per inch shrinkage is proportional to millimeter/millimeter shrinkage. Therefore, dual dimensions will not be given in this section.

Taking a shrinkage factor of .010 in./in., the effect is seen on a part that is 6 in. long. The shrinkage factor is multiplied by 6 in. That gives a total of .060 in. of shrinkage for that single dimension (.010 × 6). When a moldmaker builds the cavities that will form the finished plastic product, he or she must allow for that shrinkage. So, the moldmaker will make the steel that will form the 6-in. dimension 6.06 in. Then, when the material cools, it will shrink down to the desired 6-in. dimension, as shown in Figure 1-17. This figure shows that the mold cavity dimension for the length of the plastic ruler product is 6.06 in. and the width is .505 in. If shrinkage is the same in all directions, the plastic that fills that cavity will shrink to 6 in. × .500 in. when it cools, because it has a shrinkage rate of .010 in./in.

All plastics are generally categorized as having low, medium, or high shrinkage rates. Shrinkage is considered low if it is within a range of .000 to .005 in./in. Medium shrinkage is within a range of .006 to .010 in./in. High shrinkage is anything over .010 in./in.

It is important to understand the relationship between shrinkage and amorphous versus crystalline materials. Amorphous materials tend to have low shrinkage rates and the shrinkage occurs equally in all directions. This is called *isotropic* shrinkage. Crystalline materials tend to have high shrinkage rates, and the shrinkage is greater in the direction of flow than across the direction of flow. This is called *anisotropic* shrinkage, as shown in Figure 1-18. An exception to this anisotropic rule exists when using reinforced materials. These will shrink less in the direction of flow and more across the direction of flow. This is due to the linear orientation of the reinforcement fibers.

Because of the inherent differences between amorphous material shrinkage and crystalline material shrinkage, there is a greater range of shrinkage control for amorphous materials. Crystalline materials have a tendency toward higher shrinkage rates in general, and have much less response to processing parameter changes for shrinkage control. The following information, while general, applies more for amorphous materials than crystalline types.

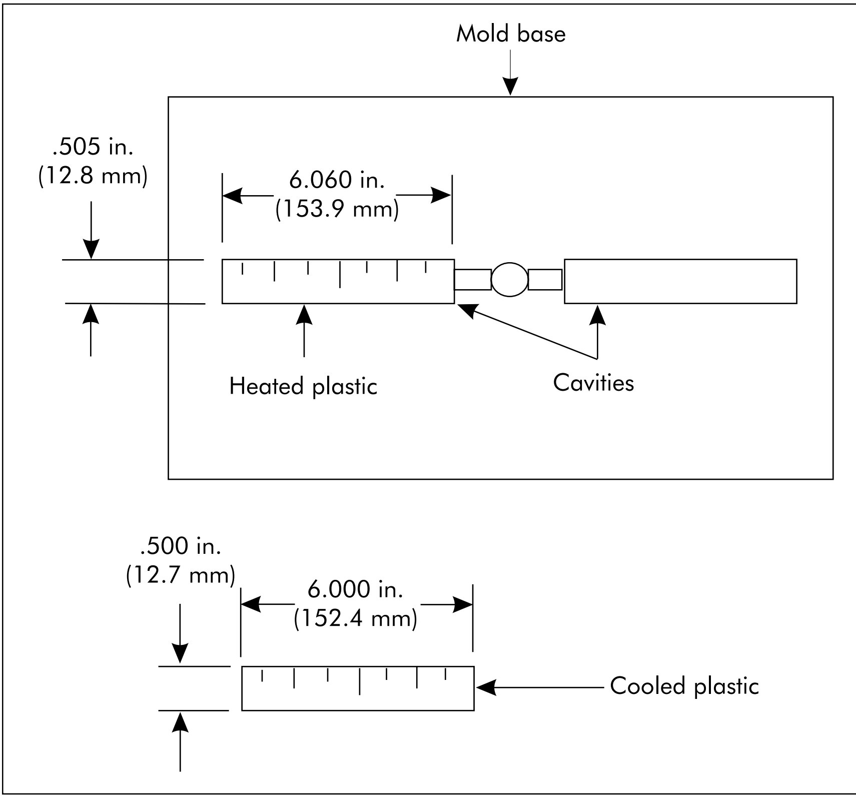


Figure 1-17. How shrinkage affects dimensions.

Temperature Adjustment Effects

One method that can alter the amount of shrinkage for a specific product or material is to adjust the temperature of the plastic while it resides in the barrel. In general, the higher the plastic temperature, the greater the amount of shrinkage. This is because of the activity of the individual plastic molecules: as the temperature rises, these molecules expand and take up more space. The higher the temperature, the greater the expansion. The reverse of this is also true: the lower the temperature, the lower the degree of expansion, therefore the lower the amount of shrinkage as the plastic cools.

A general reference is that shrinkage rates can change 10% by adjusting barrel temperatures 10%. Thus, if a material exhibits a shrinkage rate of .005 in./in. at a barrel temperature of 500° F (260° C), it can be lo wered to .0045 or raised to

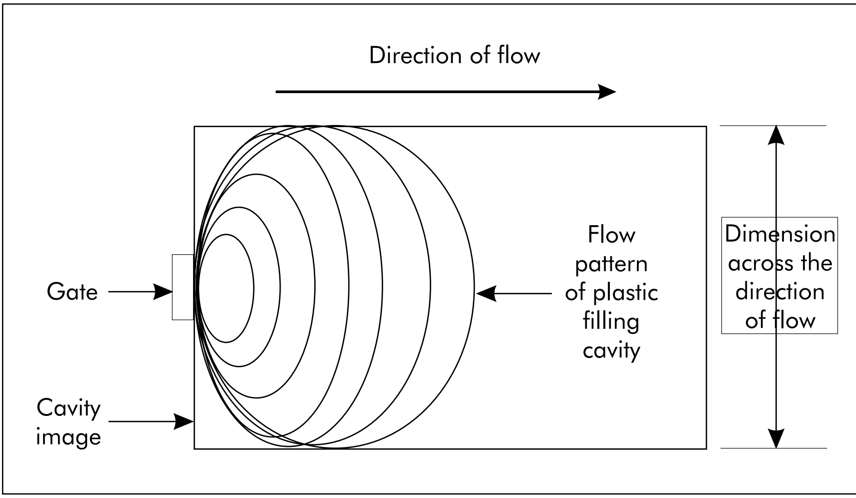


Figure 1-18. Amorphous versus crystalline shrinkage.

.0055 by altering the barrel temperatures to 450 or 550° F (232 or 288° C), respectively. These are extreme changes and may not be practical for other reasons, but they represent the 10% example.

Shrinkage also can be adjusted by altering mold temperatures. A hot mold will create less shrinkage than a cold mold. This is because the cold mold solidifies the plastic "skin" sooner than a hot mold, resulting in a shrinking of plastic before full injection pressure is applied. A hot mold, unlike a cold mold, allows more molecular movement. In addition, the injection pressure can reduce the volume of plastic before solidifying. This results in less shrinkage because the molecules are not allowed to move as much after solidifying. In this case, a 10% change in mold temperature can generally result in a 5% change from the documented shrinkage rate.

Pressure Adjustment Effects

Injection pressure has a direct affect on shrinkage rate. The higher the injection pressure, the lower the shrinkage rate. This is because the injection pressure packs the plastic molecules together. The higher the pressure, the tighter the molecules are packed. The more they are packed, the less movement they are allowed as they cool. This lower movement results in lower shrinkage. Generally, a 10% change in pressure can cause a 10% change in shrinkage rate. Of course, the shrinkage is controlled only for as long as the pressure is applied. As long as the pressure is applied until the plastic has cooled and solidified, the shrinkage will be controlled. If the pressure is relaxed before that point, the shrinkage will increase because the molecules have been allowed to move again.

Postmold Shrinkage

There is a constant battle between maintaining the quality of a molded product and reducing the cost of molding that product. Controlling the shrinkage is only a part of that battle, but it should be understood that the lower the desired amount of shrinkage, the longer the cycle, and the higher the cost. Of course, the opposite is also true. In fact, under certain molding conditions, after the part is out of the mold, it may continue to cool and shrink for up to 30 days. The first 95% of the cooling and shrinking takes place within the first few minutes after removal from the mold, but that last 5% can take up to a month to stabilize and complete. Even if the shrinkage is controlled to achieve that first 95% through molding parameter adjustments, the theoretical cycle time could evolve into 10 minutes for a part that should normally run at a 30-second cycle. One way to minimize cycle time is to control the shrinkage after the product is ejected from the mold. The cycle time can be reduced, which in turn reduces the cost of molding. This is what postmold cooling and shrinking is all about.

Restraining the molded product in a fixture while it cools normally controls postmold shrinkage, as shown in Figure 1-19. Notice that the product is being

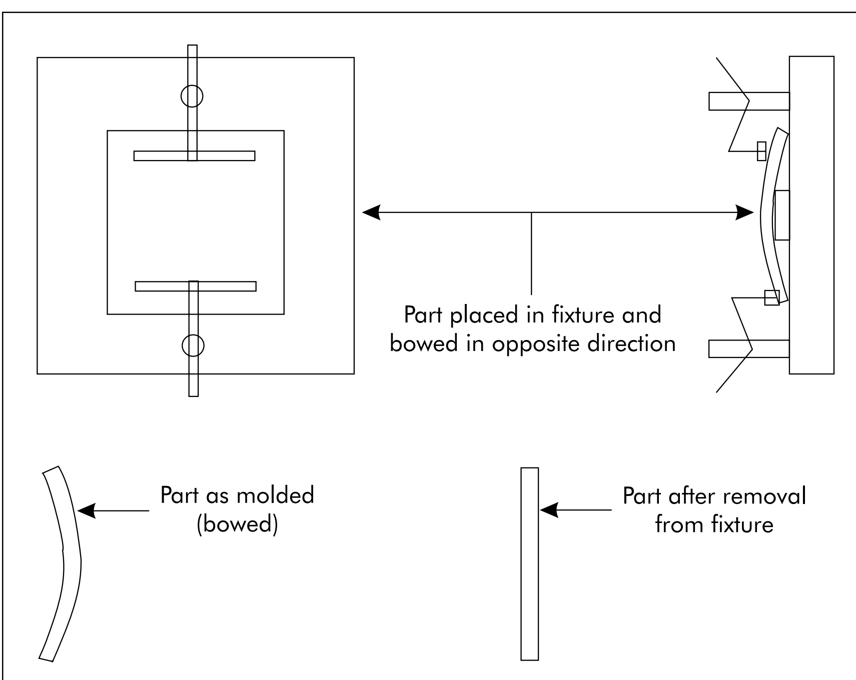


Figure 1-19. Postmold shrinkage control through use of a fixture.

deliberately bent and bowed in directions opposite of the normal shrinking and cooling patterns that develop when a part cools. The bending process overcompensates for shrinkage so that the part will spring back after cooling to a shape that is desired. This must be done through trial-and-error measurement of cooled parts to determine the optimal fixture adjustment.

When using postmold cooling/shrink fixtures, the cooling product should be left in the fixture for the equivalent time of approximately six full cycles. Therefore, it is necessary to have at least six fixtures, or "stations" in place at all times. Forcing air over the parts helps stabilize them.

Another method of postmold cooling is to drop the molded parts in a container of cold water. The temperature of the water must be maintained at below room temperature (approximately 60° F [16° C]). There is no advantage to having it lower than that because after the entire plastic mass drops to a temperature below its melting point or glass transition point, it will not continue to shrink. The postmold cooling is done to cool the center portions of the walls, which take longer to attain solidification than the external skin of the walls.

There is a danger in using any method of postmold shrinkage control because the practice induces varying degrees of mechanical stress to the molded product. Forcing the molecules into unnatural positions causes this stress. When this is done, stress is concentrated on the molecules that are being stretched and compressed (discussed in the next section). Stress is maintained as the part cools and it is set in after the part has fully cooled and shrunk. Then, if it is ever exposed to extreme temperatures or mechanical abuse, the product may fracture, crack, or shatter depending on how much stress was introduced during control of postmold shrinkage.

MINIMIZING MOLDED-IN STRESS

Other than contamination, the single most significant cause of field failure of an injection-molded product is molded-in stress. *Stress* is defined as a resistance to deformation from an applied force, as shown in Figure 1-20. Simply put, if a force is applied to an object, the object resists having its shape changed. The amount of resistance that is present can be identified as stress. It is possible to understand molded-in stress by visualizing what happens during the injection molding process. A plastic material is heated to a temperature at which it assumes the consistency of warm honey and is ready to inject into a mold. During this heating phase, the molecules of the plastic begin to move around. This is what causes the material to soften or melt. After the material is ready, a plunger device (screw) injects the material by pushing it forward through the machine and into the mold. This pushing action causes the molecules to align or orient in a linear fashion. It is similar to pushing a fork through a plate of cooked spaghetti; the pasta strands (molecular chains) start to line up neatly next to each other in the direction that the fork is traveling.

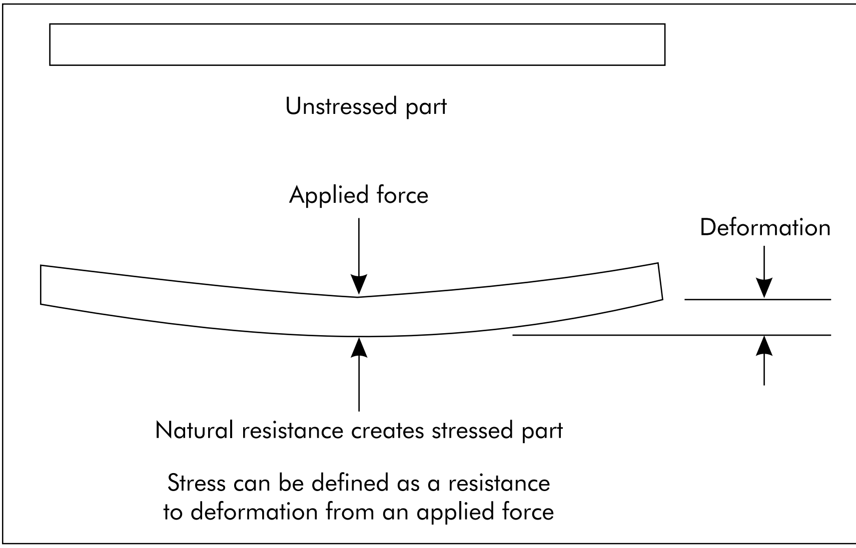


Figure 1-20. Molded-in stress.

In the molding process, these molecular chains are injected into a mold where they are then cooled while still being held under high pressure. Because they are kept from relaxing back to their original state, they are solidified under stress. It is like stretching a rubber band, and then freezing (solidifying) it in that stretched out position. If the rubber band thaws, it will snap back toward its original state. That happens because stress is being released. The same thing happens in an injection-molded part. If the part is allowed to relax after solidifying, the stresses that were molded-in can be released, and warpage, cracking, twisting, crazing, or even shattering can result due to elevated end use temperatures or even being knocked sharply against the edge of a desk. To minimize the possibility of any of these things occurring in the molded part, it is ideal to minimize the amount of stress that is molded in. Although it may not be possible to eliminate it all, it is possible to minimize stress. This can be done through product design as well as mold design, proper material selection, and control of processing by adjusting and maintaining molding parameters.

SUMMARY

The injection molding industry started in 1868 with the invention of the injection molding machine and process by John and Isaiah Hyatt. It did not become widespread until the 1940s. Then, with the advent of World War II, the government sought new, fast, inexpensive methods and materials for producing products of all kinds.

Injection molding is a process where a plastic material is softened sufficiently by heat to allow it to flow into a closed mold. Then, the material cools and solidifies, forming a specific product.

There are more than 100 parameters that must be controlled for an acceptable molding operation. These can be placed into one of four categories: time, temperature, pressure, and distance.

The softening (or melting) of the plastic is achieved by causing the individual molecules within the plastic material to go into motion. This is accomplished by applying heat to the molecules. There are four heating zones found in a molding machine-heating cylinder: nozzle, front, center, and rear.

Injection pressure is used to primarily fill the mold (95%) with molten plastic. Clamp pressure is used to keep the mold closed against the injection pressure of the incoming molten plastic. Total cycle time of the injection molding process consists of adding up the individual times required for many activities, including (among others) injection time, cooling time, and machine closing and opening time.

Insert molding and overmolding (a form of insert molding) are usually performed on a vertical-molding machine. This allows loading and unloading actions to be performed while another set of parts is being molded, thus reducing operating costs substantially.

Material property values can be altered significantly by adjusting molding parameters.

Setup sheets are vital documents needed for successful operation of a molding machine in production. It is important to understand that a molding process will take up to 8 hours to stabilize and a setup sheet should contain data for both the startup phase and subsequent stabilization phase of the process.

All materials have a specific shrinkage rate value assigned to them by the material manufacturer. The shrinkage rate is a value that can be used to predict how much difference there will be between the plastic product when it is first molded compared to after it has cooled to room temperature.

QUESTIONS

1. In what year did John Wesley Hyatt start the injection molding industry off by winning a contest for inventing the process?
2. In what year did John and Isaiah Hyatt receive a patent for the first injection-molding machine?
3. Why were the 1940s instrumental in creating an explosion of interest and growth in the plastic injection molding industry?
4. In what year did plastic production surpass steel production in the United States?
5. Describe the injection molding process as it is defined in Chapter 1.

6. How many parameters must be controlled during the injection molding process?
7. How many categories are required to list all the parameters noted in question number six?
8. What is the recommended melt temperature for a liquid crystal polymer material?
9. What causes the plastic material to melt (or soften)?
10. Not counting the nozzle, name the heating zones present in the injection heating cylinder.
11. What is the recommended mold temperature for a liquid crystal polymer material?
12. What device is used to control the temperature of the hydraulic oil in a molding machine?
13. What are the three primary types of pressure found in the injection molding process?
14. What is the reason for obtaining a melt index value for a specific material?
15. Define the term *clamp pressure*.

Materials 2

In this chapter, definitions are provided for the various terms that are unique to plastic materials. They are important to know for selecting the proper material or family of materials with required properties for a specific product and process.

THE DEFINITION OF PLASTIC

The term *plastic,* when used to describe molding materials, is defined as any complex, organic, polymerized compound capable of being shaped or formed. Generally speaking, the terms "plastic" and "polymer" are used interchangeably, although strictly speaking a polymer is a plastic, but a plastic does not have to be a polymer. Plastics can be in the form of liquids or solids or something between the two.

Plastics are created by refining common petroleum products; crude oil and natural gas are the main building blocks. Figure 2-1 shows how these blocks are utilized to make some of the more common plastic materials available today. Experimental work is currently underway to create plastic materials from sources other than petroleum. There has been limited success in creating primary materials from such products as vegetable oils and coal.

POLYMERIZATION

When we discuss plastics, we are usually referring to compounds that have been created by way of a process called *polymerization*, a reaction caused by combining a monomer with a catalyst under pressure, and with heat.

A *monomer* is a single unit composed of molecules. In the polymerization process we combine many single units of plastic into many combined units of plastic, known as *polymers*. Therefore, the process used to produce these polymers is called *polymerization*. Polymers are used for molding and are formed by combining a series of monomers.

BASIC MOLECULAR STRUCTURE

With a very powerful microscope capable of seeing molecules, a plastic molecule can be seen as a whirling ball of motion. A bunch of elemental atoms would be spinning and vibrating around a central location. If the activity were stopped, the

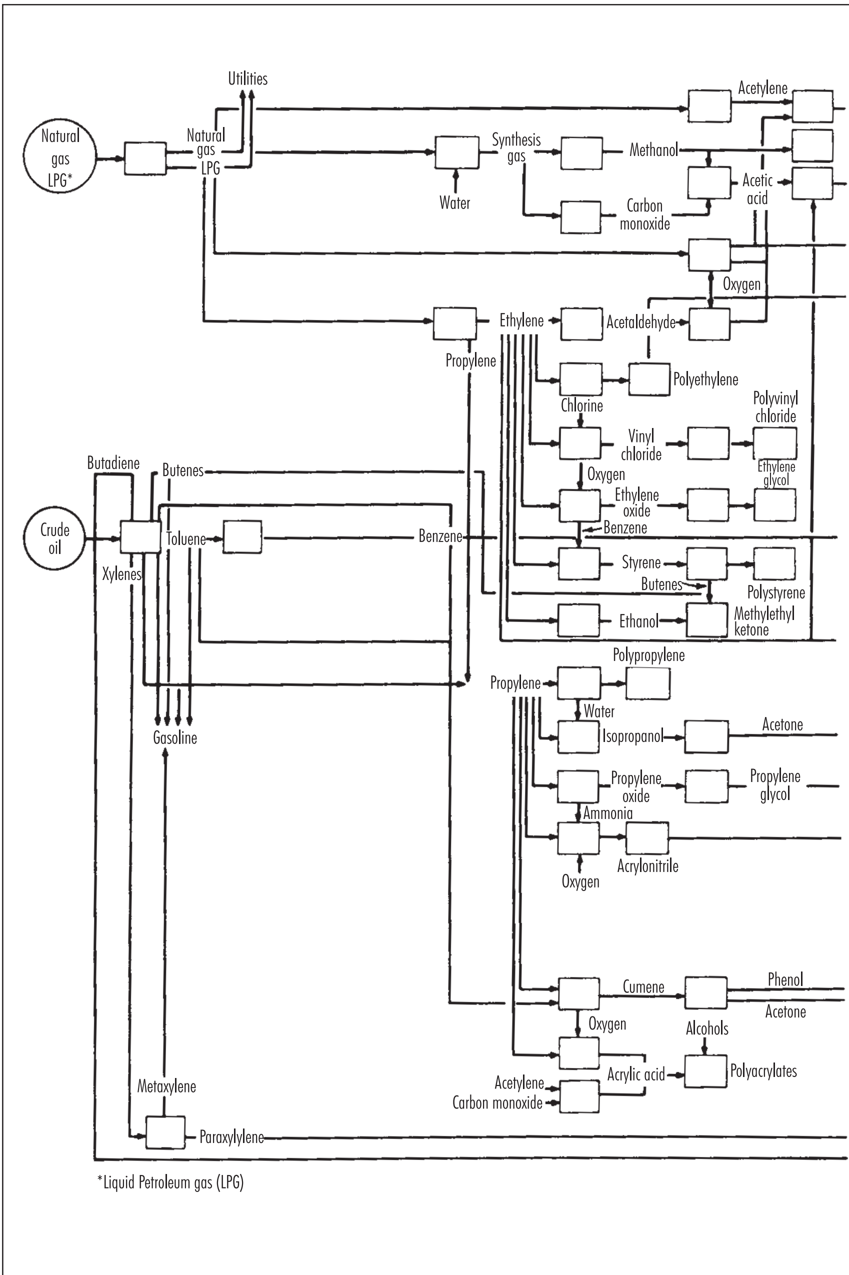
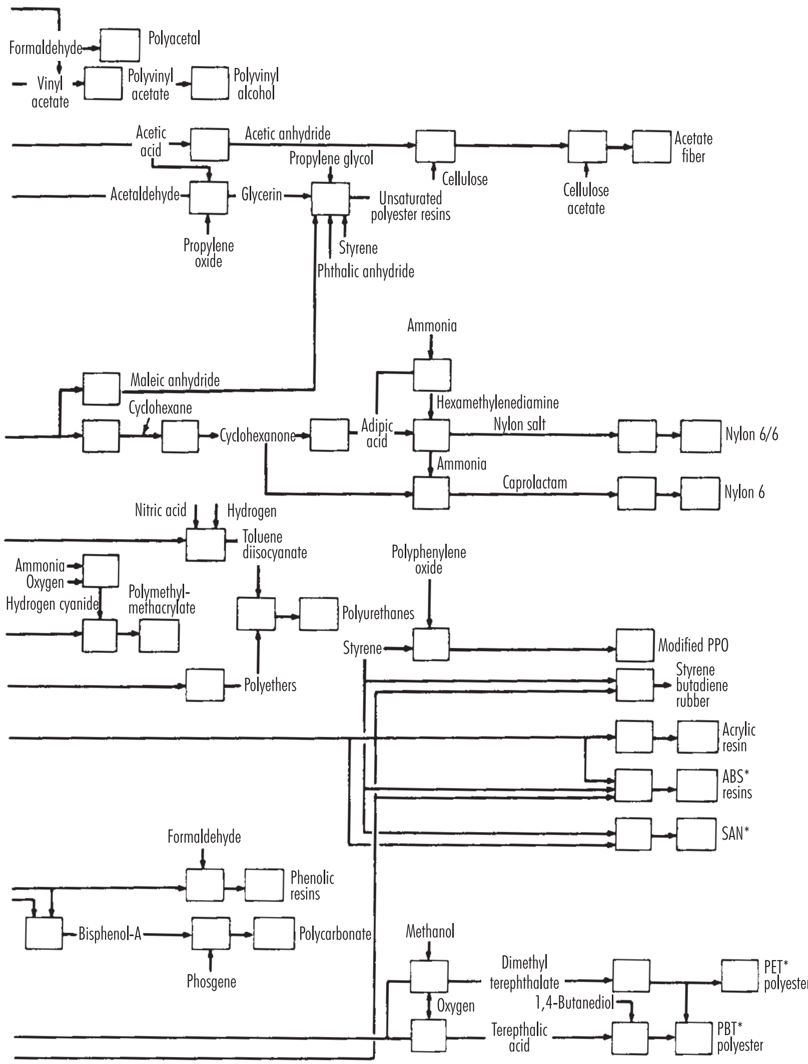


Figure 2-1. Petroleum sources for common plastic materials. (Courtesy Celanese Plastics Company)



Key: acrylonitrile-butadiene-styrene (ABS) styrene-acrylonitrile copolymer (SAN)
polyethylene terephthalate (PET) polybenzothiazole (PBT)

atoms would appear to be held together, but there would be no strings or lines connecting them. They appear to be held together by an invisible force of attraction. This phenomenon is graphically represented by drawing atoms connected by lines, as shown in Figure 2-2 for an ethylene monomer molecule.

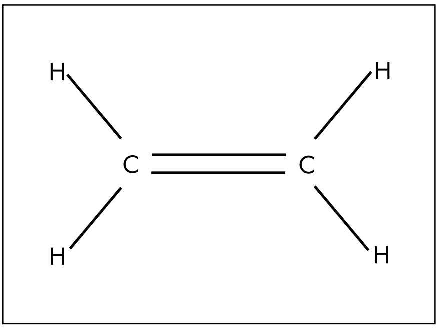


Figure 2-2. Ethylene monomer molecule.

Atoms in Figure 2-2 are represented by the element identifiers, H for hydrogen, and C for carbon. Lines represent the forces that connect the atoms from all directions, but in reality there are no actual visible connections. The double lines shown between the carbon elements represent an area of the molecule used to form bonding sites during the polymerization process. When a polymer is formed, the process temporarily breaks down a series of monomer molecules and then connects them in one large polymer molecule formed by linking the monomer molecules together at specific "bonding sites." Prior to this polymer formation, the multiple monomer molecules look like those shown in Figure 2-3.

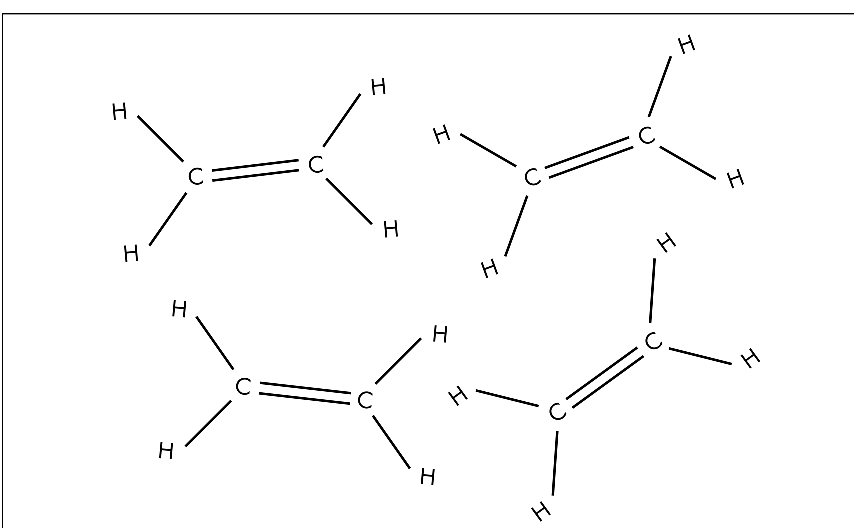


Figure 2-3. Multiple monomer molecules.

Note that all the ethylene monomers look the same, but they are not connected to each other. They can be thought of as loose railroad cars, all on different tracks in a train yard. To become a polymer of ethylene, the monomers must be connected to each other in a specific way. This is accomplished by exposing them to the polymerization process. When the polymer has formed, the line representation looks like that shown in Figure 2-4.

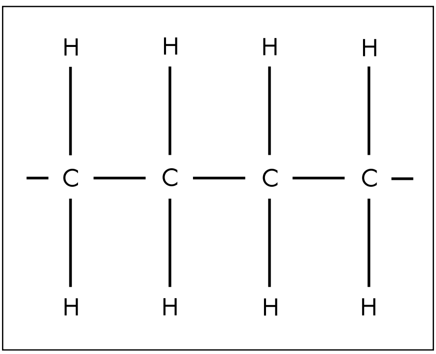


Figure 2-4. Polymerized ethylene monomers (polyethylene).

The monomers are all now connected to form a polymer of ethylene. This is known as a plastic called *polyethylene*. Note that the double lines between the carbon elements have been separated into single lines found on both sides of the carbon elements. These are the bonding sites. The result is a chain of ethylene molecule units tied together to form the single ethylene polymer. In the case of polyethylene, approximately 1,000 monomer units are tied together to form a single polymer unit. Laid end-to-end, it would take approximately 100,000 of these polymer units to equal 1 in. (2.5 cm) of length.

Therefore, while a monomer is a single unit of plastic, a polymer is many units of plastic connected together. This is accomplished through the polymerization process that mixes monomers with a catalyst and adds pressure and heat to complete the connecting process.

COPOLYMERS

To create copolymers, it is necessary for different groups of monomers to come together. For example, a monomer of styrene reacts with a monomer of acrylonitrile and a monomer of butadiene to form the familiar acrylonitrile-butadiene-styrene (ABS) copolymer, as shown in Figure 2-5.

Altering the amount of each monomer will create totally different property values. Copolymers can be produced using any of several polymerization techniques (these are discussed later in this chapter under "How Plastics are Made").

ALLOYS AND BLENDS

In addition to polymers and copolymers, many basic plastic formulations also are available as alloys and blends. An *alloy* is a material formed by mixing two (or more) basic plastics to form a "new" plastic. This new plastic is a homogenous mixture of the basic plastics, usually exhibiting improved properties over the

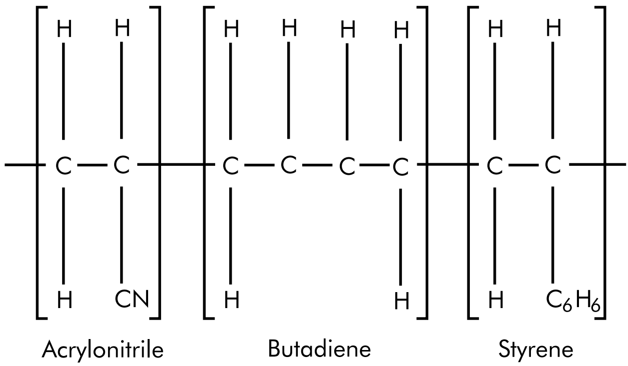


Figure 2-5. Copolymer molecular structure (ABS).

original plastics. A *blend* is also a mixture of two (or more) basic plastics, but the resultant mixture is not homogenous and merely exhibits an average of the property values of the original plastics. When discussing alloys and blends with material suppliers, it is important to understand the difference and to make sure the distinctions of both are understood.

THERMOPLASTICS VERSUS THERMOSETS

While there may be many different ways to classify the approximately 20,000 plastic materials available today, the first classification is usually the one that defines the material as either a thermoplastic or thermoset.

A *thermoplastic* material can be defined as plastic material which, when heated, undergoes a physical change. It can be reheated and reformed, over and over again. Examples of thermoplastic materials include ABS (used for such applications as TV cabinets and computer housings) and polyethylene (used for milk jugs, food wrap, etc.).

A *thermoset* material can be defined as a plastic material, which when heated, undergoes a chemical change and "cures." It cannot be reformed, and reheating only degrades it. Examples of thermoset materials include phenolic (for automotive distributor caps) and melamine (for plastic dinner plates).

There is a common perception that thermoset materials cannot be recycled because they "cure" when processed. However, curing only means that they cannot be melted down again, as can thermoplastics. Molded thermosets can be ground into a powder and used as filler for making other thermoset compounds or even thermoplastic compounds. They should never be discarded to a landfill.

The focus of this book and other volumes in this series is on thermoplastic materials because of their current popularity (approximately 80% of all plastic products today are made from thermoplastic materials). Thermoplastics are available in a wide variety of primary formulations as well as many blends and alloys. They are easily processed and require heating, forming in a mold, and cooling. Thermoplastics are like water because they can change repeatedly from a solid to a liquid without altering their chemical makeup during the heating and cooling process. But, unlike water, they are identified in one or the other of two distinct categories: amorphous or crystalline.

AMORPHOUS VERSUS CRYSTALLINE STRUCTURED MATERIALS

The two major categories of thermoplastic materials are amorphous and crystalline. While some materials are available in either category, and some materials are actually combinations of both, in our discussion we classify them as either amorphous or crystalline. There are some major differences between the two.

Amorphous Materials

Amorphous (am-OR-fuss) materials are those in which the molecular chain structure is random (as shown in Figure 2-6) and becomes mobile over a wide temperature range. This means that these materials do not literally "melt," but rather "soften," and they begin to soften as soon as heat is applied to them. They get softer and softer as heat is absorbed, until they degrade as a result of absorbing excessive heat. It is common and acceptable to refer to amorphous materials as "melting" and we do so in our discussion.

Crystalline Materials

In *crystalline* (CRISS-tull-in) materials, the molecular chain structure is well ordered (as shown in Figure 2-7), and becomes mobile only after the material is heated to its melting point. This means these materials do not go through a softening stage, but stay rigid until they are heated to the specific point at which they immediately melt. They will degrade if excessive heat is absorbed.

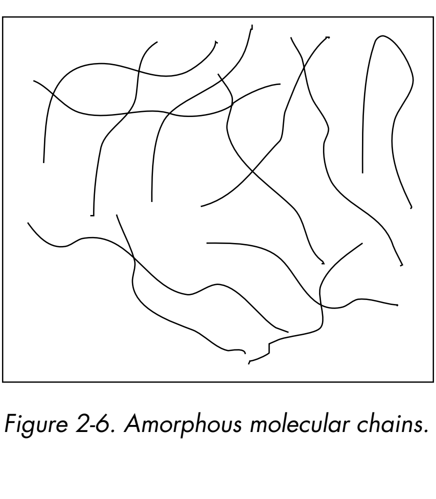


Figure 2-6. Amorphous molecular chains.

Comparison of Amorphous and Crystalline Molecular Chains

Because of the unique molecular structure of these two types of materials, their physical properties are also distinctly different. In fact, they are just

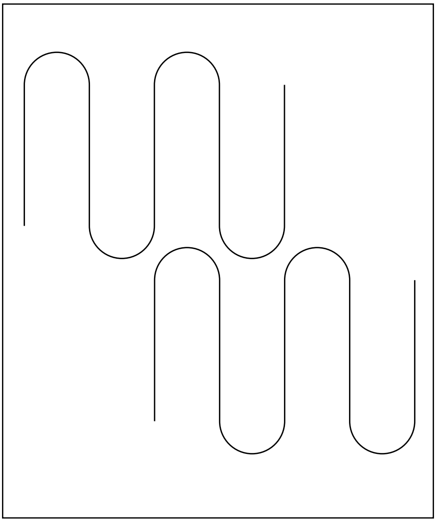


Figure 2-7. Crystalline molecular chains.

about directly opposite of each other. For example, products molded from these materials would have the properties shown in Table II-1.

However, for each rule there is an exception, and this also holds true with plastics. For example, though acrylonitrile butadiene nitrile (ABS) is an amorphous material, it is not clear, but translucent. Generally, the comparisons stated are true. Some materials (such as nylon) are available in *either* amorphous or crystalline formulations. Semicrystallines, in contrast, have characteristics of *both* formulations. Table II-2 shows the classifications of some of the more common plastics.

Table II-1. Amorphous versus Crystalline Properties

Amorphous	Crystalline
• Clear	• Opaque
• Low shrinkage	• High shrinkage
• Softens (no melting)	• Melts (no softening)
• High impact	• Low impact
• Poor chemical resistance	• Good chemical resistance
• Poor lubricity	• Good lubricity

ELASTOMERS

Elastomers are polymers that exhibit a wide spectrum of elastic or rubber-like properties. Typical elastomeric materials are shown in Table II-3.

HOW PLASTICS ARE MADE

Plastic molding materials are created through polymerization. Within the process are three common ways of polymerizing materials. The first is called *addition,* a simple combination of molecules occurring without the generation of any

Table II-2. Examples of Amorphous and Crystalline Materials

Amorphous Materials	Crystalline Materials
• ABS	• Acetal
• Acrylic	• Cellulose butyrate
• Cellulose propionate	• Liquid crystal polymer (LCP)
• Polyamide-imide	• Polyamide (nylon)
• Polyarylate	• Polyester (PBT)
• Polycarbonate	• Polyetheretherketone (PEEK)
• Polyetherimide	• Polyethylene
• Polyethersulfone	• Polyethyleneterephthalate (PET)
• Polyphenylene oxide	• Polyphenylene sulfide
• Polystyrene	• Polypropylene
• Polyurethane	• Polyvinyl chloride (PVC)

Table II-3. Typical Elastomers

• Acrylates	• Butyls	• Chlorosulfonated polyethylene
• Fluorocarbons	• Fluorosilicones	• Polysulfides
• Polyurethanes	• Neoprenes	• Nitriles
• Silicones	• Styrene butadienes	

by-products. Actually, addition polymerization can be achieved in several different ways, but the most common involves chemical activation of the molecules, which causes them to combine with each other in a chain reaction. This is the method used for creating ethylenes.

A second type of polymerization, called *condensation*, involves removing specific atoms of each molecule, thereby allowing the molecules to link together. In this process, certain by-products are created that must be removed from the reacting polymers so that further polymerization is not inhibited. This method is used for making some nylons and phenolics.

Combining the addition and condensation polymerization processes gives us the third type, *combination*. In this method, a polymer is first formed using the condensation method. Then, this still active polymer is exposed to an addition polymerization process, which causes further reaction to form larger polymers with a third ingredient. This is the process by which “cross-linking” polyesters are made.

MOLECULAR WEIGHT AND DISTRIBUTION

The physical properties of any given polymer are controlled by many factors. The most important are generally the polymer's molecular weight (MW) and the molecular weight distribution (MWD).

Molecular weight is the average weight of the molecules that make up the polymer. Polymers with higher average molecular weight tend to be tougher and more chemically resistant, while those with lower average molecular weight tend to be brittle and weak. However, the higher the molecular weight, the more difficult it is to process the material during molding operations.

Molecular weight distribution is defined as the relative proportions of molecules of different weight within a polymer. It is a measurement of the ratio of large, medium, and small molecular chain lengths found in the material. If the material is made up of molecular chains that are mostly near the average length, it is called *narrow-range*. If it is made up mostly of chains of a much wider variety of lengths, it is called *broad-range*. Generally speaking, the narrow-range polymers have better mechanical properties than the broad-range polymers, but they are much more difficult to process.

INFLUENCE OF TIME AND TEMPERATURE

Exposing it to varying time and temperature processes can alter the molecular structure of any given polymer. For example, heating a crystalline polymer above its melting point and then quickly quenching it will create a material that is more amorphous in nature. This is because quenching interferes with the ability of the molecules to reform normal crystals found in crystalline materials. Thus, the quenched product will exhibit properties more closely related to amorphous materials than crystalline materials. Slower cooling will enable the crystals to form, resulting in a product with properties associated with crystalline materials.

Given enough time, heated polymer molecules will migrate to find their ideal "preferred" equilibrium structure. Increasing the temperature allows the molecules to accomplish this equilibrium in a much shorter time, but reducing the temperature minimizes the degree of equilibrium achieved. Thus, the property values of a polymer may vary widely, depending on how much time was allowed for the molecular structure to equilibrate.

SUMMARY

A simple definition for *plastic*, as it is used in this book, is any complex, organic, polymerized compound capable of being shaped or formed. Usually, the terms "plastic" and "polymer" are used interchangeably, although strictly speaking, a polymer is a plastic, but a plastic does not have to be a polymer.

Refining common petroleum products creates plastics. Crude oil and natural gas are the main building blocks for plastic materials.

Polymerization can be defined as a reaction caused by combining monomers with a catalyst, under pressure, and with heat applied.

A monomer is a single molecular unit, while a polymer is made up of combined monomers.

Many basic plastic materials are also available as alloys and blends. An alloy is a material formed by mixing two (or more) basic plastics together to form a "new" plastic that is totally homogenous, while a blend is two (or more) plastics mixed together without becoming homogenous.

Thermoplastic materials are those which, when heated, undergo a physical change and can be reheated and reshaped over and over again.

Thermoset materials are those which, when heated, undergo a chemical change and actually become something new. They cannot be reformed by being reheated.

Amorphous materials are those in which the molecular chain structure is random and becomes mobile over a wide temperature range. Crystalline materials are those in which the molecular chain structure is very orderly and becomes mobile only after applying enough heat to reach the melting point.

Plastics are polymerized using one of three basic methods referred to as addition, condensation, and combination.

The most important factors in controlling the physical properties of any polymer are molecular weight and molecular weight distribution.

Given enough time, heated polymer molecules will migrate to find their ideal natural equilibrium structure. Increasing the temperature allows the molecules to accomplish this equilibrium in a much shorter time, but reducing the temperature minimizes the amount of equilibrium achieved. Thus, the property values of a specific polymer may vary widely depending on how much time was allowed for the molecular structure to equilibrate.

QUESTIONS

1. What is the definition of *plastic* as it is used in this book?
2. Define the term *polymerization*.
3. What naturally occurring products are the main building blocks of plastics?
4. What is necessary to create copolymers?
5. What is the major difference between an alloy and a blend?
6. Define *thermoplastic*.
7. Define *thermoset*.
8. What are the two major classifications of thermoplastic materials?
9. Define *amorphous* materials.
10. Define *crystalline* materials.
11. List three properties of typical amorphous materials.
12. List three properties of typical crystalline materials.

Determining Primary Equipment Needs 3

Before deciding what size and type of primary equipment is needed, get information about the type of products that will be manufactured in the molding facility. Then, choose the primary equipment needed while considering the following:

- The type of industry served.
- A description of the family of plastic materials that will be processed.
- The approximate minimum and maximum physical sizes of products.
- The availability of electric power.
- The degree of intended automation.
- A comparison of new versus used equipment.
- The use of multiple screws and barrels.
- The type of clamp mechanism needed.
- The cycle times needed to make the part.
- How other molding facilities are producing the same type of parts.
- The approximate annual volume to be produced.
- The level of education and expertise expected from production personnel for producing the targeted product lines.

INDUSTRY TYPES SERVED

Injection molded products are used by virtually every industry that exists today. The level of sophistication ranges from low-level products, such as disposable flower pots, to high-level medical and electronic products. Each industry creates a list of special demands for its injection molded products. A molder specializing in the respective area can meet these demands best. A molder possessing equipment capable of molding miniature electronic connectors cannot be competitive when it comes to molding disposable plastic forks. Likewise, a molder specializing in recycled plastic flower pots does not have the sophisticated equipment and clean-room environment needed for producing high-quality medical implant devices.

While it is certainly acceptable for a molder to target more than one type of industry, it is advisable to treat each group of similar industries separately. That means specific equipment should be segregated and used only for specific applications. For example, thin-walled, high-volume products, such as disposable drinking cups, require fast cycling equipment with state-of-the-art controls to allow competitive pricing. CD manufacturing, on the other hand, must be done in a more sophisticated facility and demands higher quality standards and closer process monitoring. One thing these products have in common is the need for fast cycling that can be provided by toggle-style molding machines. These machines utilize a mechanical clamping system that is capable of opening and closing the mold rapidly, resulting in fast cycles.

On the other side of the coin are large, loose tolerance products, such as laundry baskets and chair shells. These products must be molded on large equipment and usually rely on the stability and structural strength of hydraulic clamp machines. These are slower-acting than toggle machines, but are more suited to moving large molds.

Many machine manufacturers provide equipment designed for clean-room environments. These are especially designed to minimize contamination caused by molding compounds, machine hydraulics, operator contaminants, and common dirt and dust. This equipment is more expensive than machinery of the standard design and the extra charges must be absorbed in overall manufacturing costs.

A thorough understanding of the industry(ies) being served is necessary. Their requirements will dictate the degree of accuracy and quality desired, as well as the expected price range and level of service needed for specific product lines. Many industries are now seeking vendors capable of providing "full service" activities. This means the customer wants a single vendor to be responsible for all the activities involved in the total production of a product. These activities may include not only the injection molding operation, but also some secondary operations, mold design and manufacture, tooling fabrication, special packaging and/or drop shipping, and even long-term storage of the finished goods. Other industries may prefer for the vendor to supply the molds (and sometimes the materials). It is wise to investigate and analyze a variety of industry standards to determine the specific equipment requirements needed to service each industry.

PLASTIC MATERIAL FAMILIES

There are over 20,000 plastic materials to choose from today. When including all of the filler combinations and various grades of plastics, this number quickly climbs to 100,000 choices. Each plastic requires very specific processing parameters and material handling standards. As shown in Chapter 2, there are some major differences between processing amorphous materials as compared to crystalline materials. The result is that certain families of plastic materials tend to be classed together regarding processing methods and procedures. The molding facility must be capable of providing the tools and expertise needed for processing the specific material families required for particular products. A molder cannot possibly possess the expertise and equipment for processing all the various types of plastic material families that exist. Therefore, choices must be made. These choices determine the material families for which the molder must possess the processing expertise and equipment knowledge to produce the proper finished products.

After the families have been selected, the molding facility can procure the proper equipment and tooling for manufacturing products. One of the primary choices to make is the screw design. There are a variety of screw designs available for various types of material. While any basic molding machine is provided with a standard screw design, some materials are more efficiently processed using specially designed screws. A consultation with a screw manufacturer or machine supplier can help determine which design(s) to incorporate.

PHYSICAL SIZE OF PRODUCTS

Some industries, such as electronics, inherently produce small and/or miniature product designs. These products can be molded on smaller presses than products such as furniture (chair shells) or automotive panels. There are many differences in setting up a facility to incorporate small presses versus one designed to utilize large presses. These differences include electrical utility hookups, water consumption and control, depth of concrete footings for machine installation, and floor space requirements.

ELECTRICAL POWER AVAILABILITY

A facility with more than a few small molding machines will probably require the installation of an electrical substation on the premises. This is necessary to provide the amount of power that will be required not only for the molding machines, but also for auxiliary equipment, the tool room, air conditioning, water temperature control, etc. The average molding facility, consisting of 10, 300-ton (91,629 kN) molding machines and the necessary support and auxiliary equipment, will consume approximately 1,500 kVA (kilovolt-amps). Adding a 25% safety factor for power requirements dictates the need for at least 1,875 kVA. This means the facility should install a 2,000 kVA substation. If future expansion is planned, additional kVA should be added at the time of initial substation installation. In a later chapter, the average power consumption requirements of primary and secondary equipment will be explained. For now, just understand that larger equipment requires greater power availability than smaller equipment. This must be a determining factor when selecting a site, as well as the size of equipment to be purchased. The machine sizes will be dictated by the size of the products to be molded, and the number of cavities to be molded at one time.

DEGREE OF PLANNED AUTOMATION

Automation requirements range from a labor-intensive scenario, where every aspect of the production facility is controlled to some degree by human intervention, to a lights-out operation requiring no human intervention at all. Deciding on the amount of automation required will aid in determining the brand, type, style, placement, and cost of the primary molding equipment. Highly automated facilities require highly sophisticated equipment. Labor-intensive facilities require equipment with much less sophistication.

Generally speaking, automation requires space. Robots, material movers, pick-and-place units, etc., take up more space than their human counter parts. Room must be left around and between equipment to allow access for adjustments, maintenance, and repair. This results in an overall larger facility with higher associated manufacturing costs.

NEW VERSUS USED EQUIPMENT

When considering purchases of expensive items, such as molding machines, inevitably the question arises as to whether or not it makes sense to consider used equipment. When considering the original cost, it would appear that a used machine would be less expensive than a new one. For example, if the cost of a new, average, 300-ton machine is about $200,000, the same machine, used, might be as low as $80,000, depending on age and condition. It seems there is a lot of money to be saved. The purchasing decision must be made based on the specific facility requirements. The advantages and benefits of both new and used equipment must be compared side-by-side to decide which conditions or combinations are right. The following are some items of concern:

- Does the older equipment have the level of computer-controlled parameters required? Much of this is determined by the expertise of the operating personnel. Employees who are new to the industry may not be able to run older equipment that is not computer controlled. Likewise, older employees may not have been exposed to the new computer controls. While the level of expertise of employees should not be the only factor to consider, it must be included in the final decision.
- What is the maintenance record of the older equipment? If this is not known, or unavailable, avoid it. If the information is available, study it closely. Often, a long list of small repairs indicates a bigger problem that was never resolved.
- Why is the equipment available? Did the previous owner wish to upgrade, or is it being dumped because it costs too much to keep running? If the name of the previous owner is available, call and ask questions. The answers may save a bundle of cash.
- Is it better to buy from a broker? Ask five molders and you will get six answers. In most cases, a broker will provide a money-back guarantee for a short period of time, if the machine does not meet advertised standards. Make sure these standards are understood before purchasing the equipment. If it is a lease, there may be a problem. Many lessors will not pay in

advance for used equipment, and many equipment brokers will not release equipment without prepayment. One danger is the lack of a clear title to the equipment. If equipment is bought from an individual, a title search may need to be performed to make sure there is no lien on the equipment. If there is, and it is purchased anyway, the money will be lost. This search is time consuming and expensive. If the equipment is bought from a broker, they have already made the search and guarantee free title.
- What is the condition of the equipment? How is it known? Is the expertise available to inspect, operate, and determine the operating condition? A consultant may need to be hired to analyze the situation. Some brokers will stand behind their equipment when it comes to unforeseen problems, but this can be a sensitive issue. It is better to approach the purchase of used equipment much like purchasing a used car. Try it out and get a good mechanic to look it over. Try to buy from reputable companies and large captive molders. They tend to spend the money and take the time to properly maintain and upgrade their equipment.

An alternative to new or used is refurbished equipment. Refurbished equipment will cost about 50% of the price of brand new equipment and will have recent controllers and computerized interfaces employed. There are many companies specializing in this area, so check their references and ask plenty of questions. For a little more time and money, a lot more refurbishing than what is standard can be negotiated. Even the paint color can be customized.

- Is standardization preferred? If so, there may be problems with used equipment. Unless all the same age range and brand names are purchased, a larger supply of spare parts will have to be maintained to accommodate a wider variety of standards. When buying new equipment, there is the luxury of specifying precise options and standardizing to extremes. This limits the number of spare parts and assemblies that must be kept on hand because one item will fit many machines. In addition, customers like to see machines that are all the same brand, and all the same color. This imparts a sense of uniformity and consistency to the molding facility and provides a warm, comfortable feeling to the customer. Of course, the same results can be accomplished through purchase of used equipment, but the logistics involved cause the costs to become higher and negate much of the intended savings.
- How much time is available? New equipment takes awhile to manufacture, especially if specialty items and options are required. Delivery schedules for new equipment at the time of this writing are in the area of 16 weeks (4 months). Some machines take as long as 8 months to procure. If a machine is needed faster than that, used or refurbished equipment may suffice.

MULTIPLE SCREWS AND BARRELS

Whatever injection molding equipment is purchased, consider additional screws and barrels for each machine. This will provide the flexibility to produce a wider variety of products on a limited number of machines.

There is a range of barrels and screws available for a specific clamp size of machine. Generally speaking, the combination of barrel (shot) size to clamp size is shown in Table III-1. These values are general in nature. Because the machines are manufactured in a modular method, a wide range of barrel sizes can be ordered for a specific clamp size. For example, a 300-ton clamp machine can be supplied with an 8, 16, 20, 30, or 40-ounce shot size barrel. Due to the thermal degradation problems that occur when molten plastic stays too long in the barrel, the average barrel size (30-ounce) may be too large for products requiring the 300-ton clamp force. An extra barrel and screw assembly could be purchased for approximately 25% of the cost of another 300 ton machine. This would give the flexibility of providing processing capability for what amounts to two separate machines, without the accompanying expenditures in money and available floor space. In fact, it would be wise for a custom molding shop to purchase two or three varying barrel and screw assemblies for each molding machine in the facility. If three units were provided for each machine, a 10 machine shop would have the potential processing capability of a 30 machine shop, limits of time not withstanding. Quick-change assemblies would allow changeovers in less than one hour, during the normal mold changeover and setup operation.

Table III-1. Clamp Tonnage versus Shot Size

Clamp Size, tons	(kilo Newtons)	Shot Size, oz	(g)
10	(88.9)	.5	(14.2)
25	(222)	2	(56.7)
50	(445)	4	(113.4)
100	(890)	8	(226.8)
200	(1,779)	16	(453.6)
250	(2,224)	20	(567)
300	(2,669)	30	(851)
450	(4,003)	60	(1,701)
750	(6,672)	120	(3,402)
1,000	(8,891)	200	(5,670)
2,000	(17,792)	450	(12,757)
4,000	(35,584)	900	(25,515)

HYDRAULIC, TOGGLE, ELECTRIC, OR HYBRID?

A question that must be addressed is "What type of clamp mechanism is needed?" There are four styles available and each has advantages and disadvantages. A thorough understanding of each type is necessary. Try talking with various suppliers to obtain this information. Ask each of them for the obvious benefits of their own design, and also the disadvantages of the competition's design. This will provide a good bank of data to help make the decision. And, do not be locked into one style over another. Two or three different types in the same facility may be preferred. That is fine, as long as the limitations of each type are understood. The following highlights some of the advantages and disadvantages of each type of machine.

Hydraulic

Generally, hydraulic machines are specified as being necessary for applications requiring clamp tonnage in excess of 500 tons (4,448 kN). Hydraulic machines employ easy, finite, adjustment of clamp force. This force is monitored directly through gage readout. Once set, the clamp force is maintained throughout the molding process, even with mold thickness variations caused by heating and cooling of the mold.

The primary disadvantages of the hydraulic machine are the slower clamping action and the fact that oil leaks are always present. They also tend to take up more space than toggle machines.

Toggle (Mechanical)

Toggle machines are ideal for applications requiring fast cycle times, especially when cycles are less than 10 seconds total. These machines tend to take up less floor space than hydraulic machines and are usually less expensive for a specific clamp size. The linkage mechanism provides an inherent slowdown to the clamp closing action that eliminates the need for added controls for this parameter.

The primary disadvantages of a toggle machine are the inability to obtain finite adjustment of clamp tonnage, and vibration that can cause loosening of machine components. In addition, the link mechanism requires frequent lubrication to minimize wear from friction.

Electric

Electric machines are fairly new to the injection molding industry. They are basically mechanical in nature, using gears, stepping motors, and mechanical leverage to attain the clamping forces required. Their popularity threatens the domination of hydraulic machines when considering equipment of 800 tons (7,117 kN) clamp force or less.

Electric machines are fast and clean. There is no oil used, so oil leaks are nonexistent. This makes them ideal for clean-room environments. Over 50% of all electric machines are being purchased for their speed, while approximately

25% are purchased for their cleanliness. The noise level of electric machines is extremely low, and vibration is minimal.

The main disadvantages of electric machines are their cost per ton of clamp, the relatively small sizes available, and the small vendor base available.

Hybrids

Some machine manufacturers have developed hybrid equipment. These machines combine many of the benefits of hydraulic operation with those of the electric machines. Hybrid machines usually contain electric servo drives to perform some of the functions that hydraulic systems would normally perform. The electric systems are more energy efficient and provide faster action than their hydraulic counterparts.

The primary disadvantage of a hybrid machine is the cost. Usually, the machine is produced using standard technology, then retrofitted to provide the degree of hybrid specified. A hybrid machine can be built with either an electric screw drive (an additional $40,000 on average), a variable-speed drive on the hydraulic pumps (an additional $25,000 on average), or both.

ESTIMATING CYCLE TIMES

Usually, when considering starting up an injection molding operation, there are already a few products in development but not commercially available. These could be captive product designs (for an in-house operation), custom designs (for a specific outside customer), a product design that is still in the concept stages, or combinations of these. Another scenario suggests weighing the benefits of molding products in-house versus contracting to outside vendors.

In all of these situations, it is important to understand how much molding (in time values) is actually required. To know that, it is necessary to compile cycle time requirements and what is known as *cavitation* (how many cavity images are created in the mold to run at one time). That will determine the maximum hourly production capabilities of the facility. It will also determine how many machines (and what sizes) will be required to produce a given volume of product over a specific fiscal period.

If there is existing molding of products similar to those to be molded in the new facility, the cycle times could be measured. If this is done, make sure the entire cycle is timed. This is known as the *gate-to-gate cycle* and works by starting the timing at a specific point in one cycle and ending it at the exact same point in the next cycle. Everything that takes place during this specific amount of time is included. If the luxury of being able to time actual cycles does not exist, the cycle times must be estimated. This can be a simple process or extremely sophisticated and time consuming. Here, the simple method is chosen and only general estimates are required. Table III-2 shows some cycle time estimates for generic materials. Note that it is based on wall thickness and is concerned with the thickest section of the part. These cycle times are average. If the mold is complicated (such as an unscrewing mold), or large, the cycles may be much longer due to extended open and close portions of the cycle.

Table III-2. Cycle Times versus Wall Thickness

Wall Thickness, in. (mm)	Overall Cycle Time, seconds
.060 (1.5)	18
.075 (1.9)	22
.100 (2.5)	28
.125 (3.2)	36

Cooling Time versus Cycle Time

Figure 3-1 shows the average cooling time curve for generic materials at varying wall thicknesses. Note that the figure does not demonstrate a straight-line curve. This is because the plastic cools from the outside first. As solidified skin forms, it becomes an insulator and keeps the heat in the center from easily be conducted out by the mold. As the wall thickness is increased, the cooling time is also increased.

Determining Number of Cavities

After the overall cycle has been determined, the ideal number of cavities in a given mold must be calculated. This number can be established by understanding the total number of parts required in a year (annual volume) and the desired length of time that will be used to produce the parts. For example, if the total annual requirement is 1,000,000 parts with an estimated cycle time of 30 seconds, and all parts are run over a 3-month period, the following formula can be used to determine the correct number of cavities:

$$N = V \div [(XM) \div C] \tag{1}$$

where:

N = number of cavities
V = annual volume requirements
X = number of months desired for running parts
M = number of seconds available per month
(516 hours a month × 60 seconds = 30,960 seconds, which assumes a 24 hour day, 5 days a week)
C = estimated total cycle time in seconds

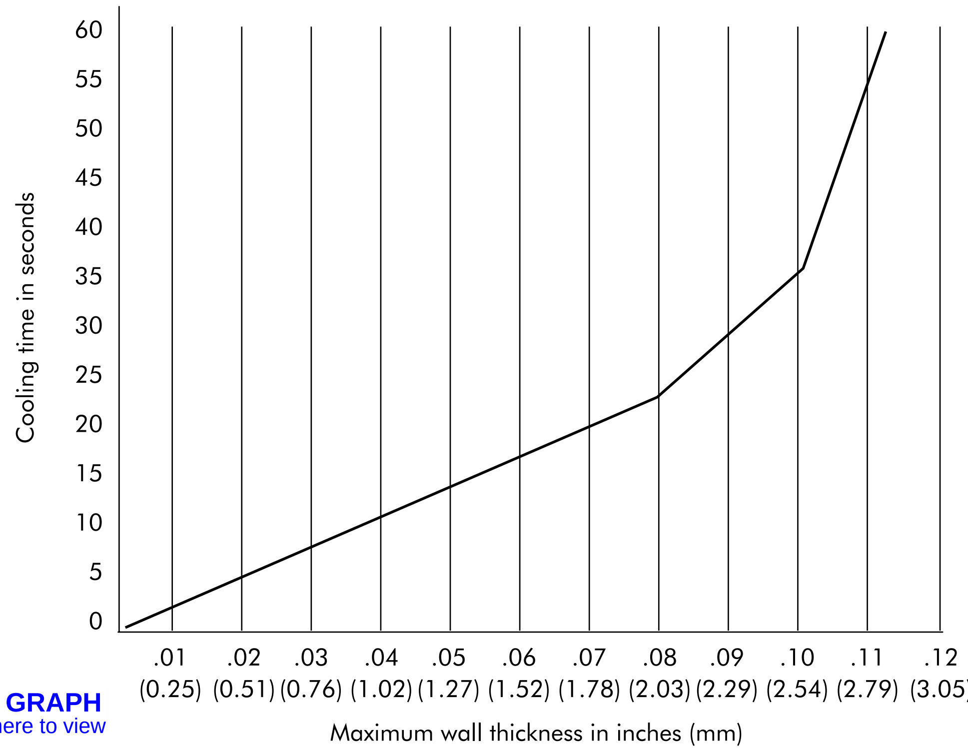


Figure 3-1. Cooling time versus wall thickness.

So,

$$N = 1{,}000{,}000 \div [(3 \times 30{,}960) \div 30]$$
$$N = 322.997 \text{ or } 323$$

From this example, a single mold with 323 cavities is desired. This may not be practical, depending on the size of the molded part. If 32 cavities were planned for a mold, then it would take 10 molds continuously running on 10 machines for the full 3-month period to produce 1,000,000 pieces. Alternatively, 20 molds could be run each with 16 cavities, on 20 smaller machines to achieve the same results. Generally, a single cavity can produce approximately 60,000 parts a month, when running 5 days a week, 24 hours a day, 50 weeks a year, if there is not any scrap, defects, or downtime.

The preceding situation reflects how a custom molder may approach quoting a specific job for a customer. For an in-house operation, the approach may be different in that the time desired for running out the production would probably extend to a full 12-month period. In that case, the number of cavities would shrink to one-fourth of that required for a 3-month run. It is common for in-house operations to accommodate molding equipment dedicated to specific products, while a custom molder must attempt to run a large variety of products through a given number of machines.

The final decision on cavities must consider the amount of clamp tonnage of the machines available for producing the parts. Large tonnage machines will accept larger molds, and small tonnage machines are limited to smaller molds. Thus, it becomes a matter of trade-off to determine the machine size for purchasing. Analyze the size of products to be molded, the annual volume requirements, the length of time desired for producing the annual volume, the approximate cycle time, and the amount of clamp tonnage required to hold a given mold closed. This information must then be manipulated until a reasonable solution is achieved.

How Much Clamp Tonnage?

Clamp tonnage requirements are determined by the viscosity (melt flow index) of the material being molded. The melt flow index is determined by using a plastometer and performing a test in accordance with the ASTM standard D-1238. A material that is stiff will require a greater amount of injection pressure, and thus a greater amount of clamp tonnage to hold the mold closed against the injection pressure. After the viscosity of the intended plastic is understood, *projected area* (as shown in Figure 3-2) must be estimated, against which the injection pressure and clamp tonnage will be directed. Visualizing the shadow of the part as if it was viewed with a strong light behind it does this. It also can be considered as the length × width footprint, and does not consider the depth dimension unless it is more than 1 in. (2.5 cm) deep. If so, a 10% factor is to be added to the clamp tonnage requirement for each inch of added depth.

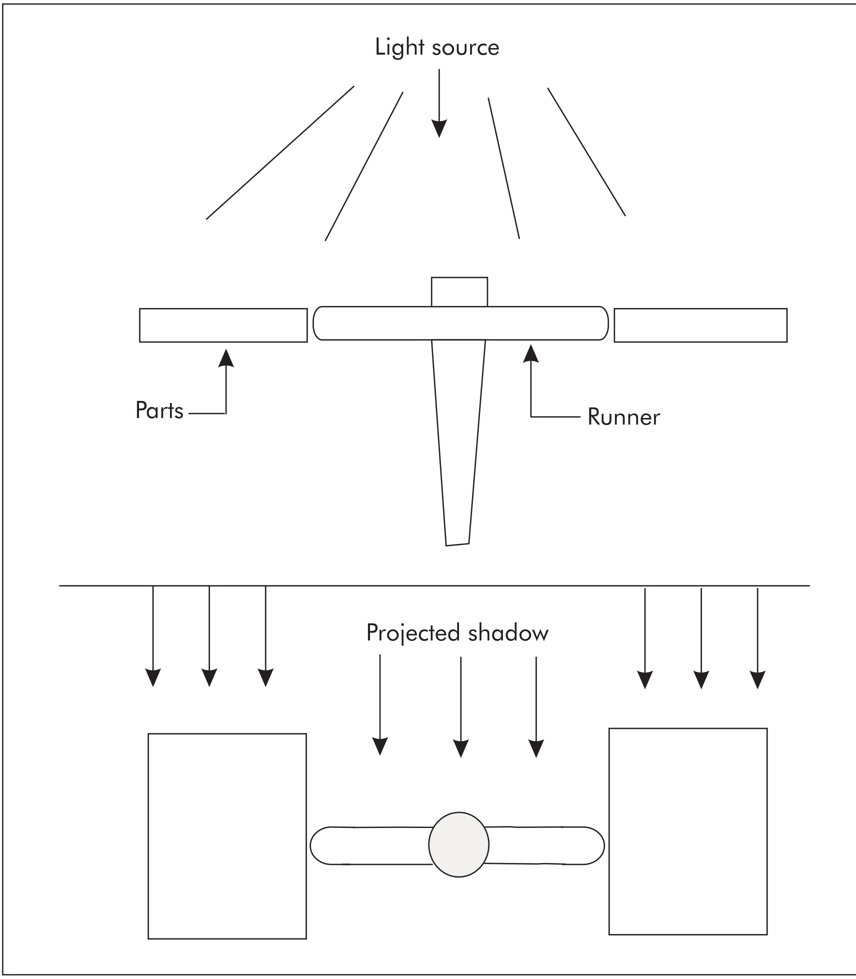


Figure 3-2. Projected area of part to be molded.

The projected area is multiplied by a factor from 1–5 tons/in.^{2} (13.8–69 MPa) to determine the total amount of clamp tonnage required. The exact number depends on material viscosity, with the easy flowing materials needing only 1–3 tons/in.^{2} (13.8–41 MPa) and stiffer materials needing between 2.5–5 tons/in.^{2} (34–69 MPa). The final tonnage requirement assumes a .25–.5 in. (6–13 mm) -wide shutoff land exists around the cavity image to allow the clamp tonnage to focus only in that area. Without that shutoff land, the clamp tonnage requirement may increase by four or five times. Note: the press capacity is the amount of force needed to keep the mold closed. However, determining the pressure (force per area) first must derive this capacity. Force uses units of tonnage or Newtons. Pressure uses units of psi or Pascals.

The following is an example of how to determine proper clamp tonnage in U.S. customary units. The part to be molded is a square plaque that is 6 × 6 in. and .060 in. thick. The projected area of that plaque would be found by multiplying length times width, or 6× 6 in., which equals 36 in^2. If the molding material is nylon, which is very easy flowing, the lower range number of 2 tons per in.^{2} could be used—36 in.^{2} × 2 tons = 72 tons required to keep the mold closed against necessary injection pressures. If the molding material were a stiffer flowing resin, such as polycarbonate, the projected area would need to be multiplied times a factor of five, instead of two. That would yield a total clamp tonnage requirement of 36 × 5, or 180 tons.

After the total amount of tonnage is determined, 10% should be added as a safety factor, and a machine that provides clamp tonnage closest to that number should be used. For instance, in the polycarbonate case noted earlier, there was a need for 180 tons clamp tonnage. Adding a 10% safety factor brings that number to 198 tons. Ideally, a 200-ton machine would be used. A 225 or 250 ton machine also could be used. However, do not run a mold in a machine that is much larger than required because of the potential of creating excessive clamp tonnage that can break the mold. Also, excessive tonnage means additional cost-to-manufacture and is a waste of resources.

SUMMARY

Before deciding what size and type of primary equipment is needed, get information about the type of products that will be manufactured in the molding facility. Then, choose the primary equipment needed while considering the following: the type of industry served, a family description of plastic materials that will be processed, the approximate minimum and maximum physical sizes of products, the availability of electric power, the degree of intended automation, a comparison of new versus used equipment, the use of multiple screws and barrels, the type of clamp mechanism needed, the cycle times needed to make the part, how other molding facilities are producing the same type of parts, the approximate annual volume to be produced, and the level of education and expertise expected from production personnel for producing the targeted product lines.

While it is certainly acceptable for a molder to target more than one type of industry, it is advisable to treat each group of like industries separately. This means specific equipment should be segregated and used only for specific applications.

A thorough understanding of the industry(ies) being served is necessary. Their requirements will dictate the degree of accuracy and quality desired, as well as the expected price range and level of service needed for specific product lines.

Many industries are now seeking vendors capable of providing "full service" activities.

The average molding facility, consisting of 10,300-ton molding machines and the necessary support and auxiliary equipment will consume approximately 1,500 kVA (kilovolt-amps). Adding a 25% safety factor dictates the need for at least 1,875 kVA.

Refurbished equipment will cost about 50% of the price of brand new equipment and will have recent controllers and computerized interfaces employed.

Whatever type of equipment purchased, consider additional screws and barrels for each machine. This will provide the flexibility to produce a wider variety of products on a limited number of machines.

In estimating cycle time, remember that if the mold is complicated (such as an unscrewing mold), or large, the cycles may be much longer due to extended open and close portions of the cycle. A reference to consider is that, on average, a single cavity is able to produce approximately 60,000 parts a month when running 5 days a week, 24 hours a day, 50 weeks a year, not providing for any scrap, defects, or downtime.

QUESTIONS

1. What must be known to determine the size and type of primary equipment needed?
2. What type of equipment is required for producing thin-walled, high-volume parts?
3. Many industries are now seeking vendors capable of providing ____________ activities.
4. What does "full service" mean?
5. What is the number range of how many plastic materials are available today?
6. Including the safety factor, how many kilovolt-amps of electricity are required for the average molding facility?
7. Generally speaking, what does automation require?
8. What is the major advantage of buying used equipment from a broker?
9. Why should additional screw and barrel sizes be considered for each machine?
10. What does the term *gate-to-gate cycle* mean?
11. On average, how many parts can a single cavity mold produce in one month?
12. How is the amount of clamp tonnage determined for a specific part?

Determining Auxiliary Equipment Needs

4

WHAT IS CONSIDERED AUXILIARY?

In the injection molding business, the injection machine is considered the *primary* piece of equipment. Anything else required for assisting the primary equipment while producing the molded part is considered *auxiliary*. Therefore, items such as a granulator for grinding defective or excess material, a mold temperature controller, and a hopper loader would be considered auxiliary. These should not be confused with items such as printing machines, assembly equipment, and packaging systems, which are thought of as *secondary* equipment rather than auxiliary, because they are not needed for the molding production itself. Robots are considered auxiliary equipment if they are utilized at the molding press. The next sections discuss auxiliary equipment selection.

GRANULATORS

The molding process inevitably produces defective parts and molded material that can not be used (in the form of runners, etc.). Rather than discharge this waste to a landfill, a machine known as a *granulator* reduces the material to a size resembling the original virgin pellets for reuse in future products.

There are granulators available for all thermoplastic parts ranging from film and products that are soft and pliable, to those that are hard and nonflexible. While there are various designs and concepts used by granulator manufacturers, the basic system consists of rotating blades that continue to cut the molded material into smaller and smaller chunks, until they will fall through a screen with appropriately sized openings, as shown in Figure 4-1. These reduced-size particles (called *regrind*) are then collected in a container for future use, or immediately transferred back to the machine hopper to be mixed with virgin pellets for continuous molding.

Regardless of which machine type is chosen, all granulators work on the principal of shearing action to reduce the particle size. This action is very dependent on blade sharpness and contact angle with the anvil. Proper maintenance of these

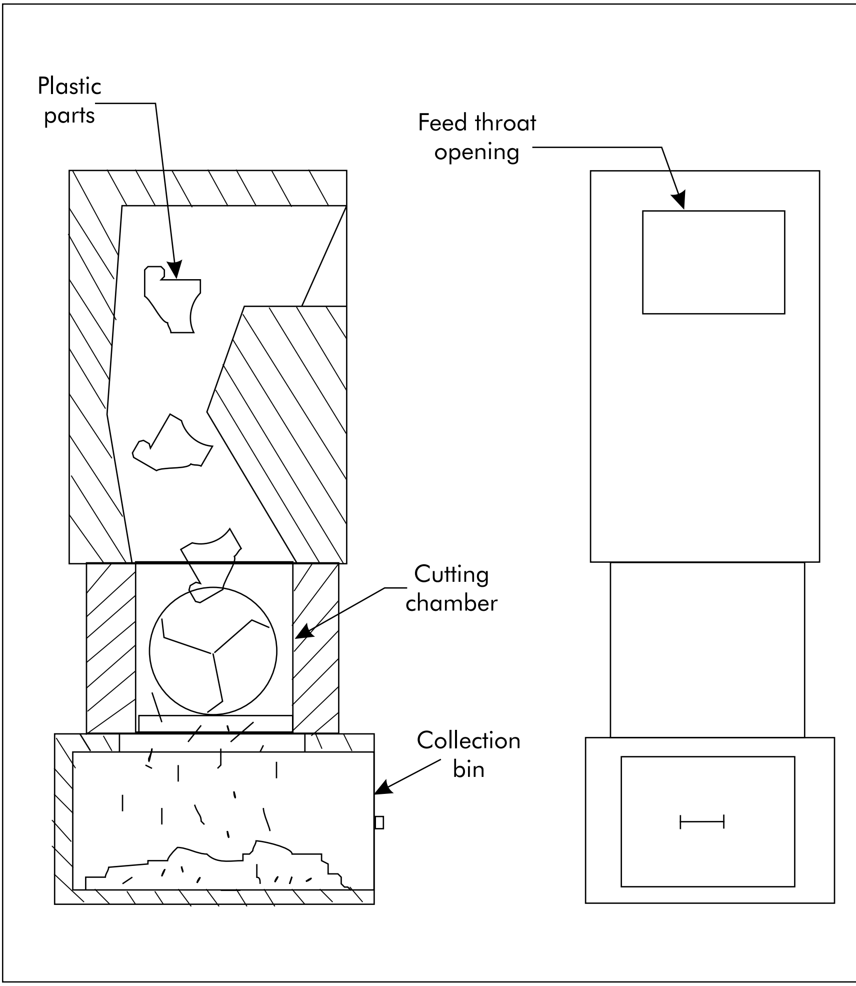


Figure 4-1. Granulator concept.

areas is critical to successful granulating. However, even with proper maintenance, granulating produces a fine, dusty material (called *fines*) along with the usable particles. These fines can interfere with normal molding conditions and should be discarded before using the regrind in future molding. Fortunately, due to static electricity charges, fines tend to build up on the walls of the granulator's storage container and are easy to access for removal purposes.

Granulators are usually specified by the size of the cutting chamber. This is the area in which the material is reduced or ground. These chambers are normally rectangular in shape. A typical chamber would be approximately 10 × 12 in. (25 × 30.5 cm), but chambers are also available in sizes from about 3 × 6 in. (7.6 × 15 cm) up to around 30 × 50 in. (76 × 127 cm). The feed throat, through which uncut material is fed into the cutting chamber, is normally covered with a flap to minimize "blow-back" of the material being ground.

Sizing screens are available in many opening sizes. The usual approach is to use a screen size that will produce the smallest possible particle to improve blending with the virgin material. However, as the regrind particle is made smaller, more undesirable fines will be produced. This is wasteful and should be avoided by determining the most acceptable fines level for the product.

Granulators tend to be noisy and must contain some type of sound-deadening material around the outside or within the wall construction of the entire unit. This is mandatory for meeting federal regulations regarding human decibel level exposure limits. Even then it is advisable for employees to utilize hearing protection when operating granulators.

When it comes to size, many different granulators may be purchased. If only small parts are being molded, then only small granulators are required. If large parts are being molded, large granulators are needed. The larger the grinder, the higher the cost to purchase, operate, and maintain. Therefore, proper planning should be involved before making final decisions on what type and size machine should be purchased. Involving representatives from several different granulator manufacturers will provide good information to help make the decision. Lowest price is not always the determining factor.

Granulators are available in many styles ranging from under-the-press to beside-the-press, to centrally located stations. When molding identical materials on many molding machines, it is usually advisable to use a single, central station to granulate parts and materials from all the molding machines in one location. This reduces the number of personnel required, as well as the overall purchase cost for the granulator system. It also provides for closer controls of regrind quality, and allows controlled and accurate mixing and blending of regrind-to-virgin for future molding. Elaborate systems can be developed, using the central location concept, which can predry, blend, and transfer compounds directly back to the machine hoppers.

Under-the-press granulators utilize a flat design to allow them to be placed directly under the mold. They can be used to capture runner systems as soon as the mold opens. These can then be ground and fed directly back to the hopper to allow continuous molding of regrind-virgin mix without having to dry the regrind.

Beside-the-press granulators are the most common. As the name implies, they are placed in immediate proximity of the molding machine, where a press operator is responsible for feeding the material to be ground. Although it is normal to provide a single granulator for each molding machine, it is sometimes possible to have a single granulator service two or more molding machines if they are molding identical materials.

Two-stage granulators are utilized when the parts to be ground are very large. In these systems, there are two separate cutting chambers. The first is used to cut the large part into smaller, more easily handled parts. These are then allowed to travel into the next cutting chamber, which finishes the reduction operation.

DRYER UNITS OVERVIEW

Dry material is essential to successful injection molding. There are three main methods of drying material: ovens, hopper dryers, and floor dryers. Vented barrels are built into specific brands of molding machines and are not considered as auxiliary equipment, so they will not be covered here. However, it should be noted that vented barrels and hopper dryers cannot remove all of the moisture necessary to ensure proper molding, and they should be used only in conjunction with one of the other drying methods.

After material has become dry enough to mold, it will stay dry for approximately 2 to 3 hours, only if adequate methods are utilized to maintain that dryness. Therefore, it is not practical to dry material much more than 2 hours ahead of the time it will be used. In fact, most machine hoppers are designed to hold approximately 2 hours worth of material for that very reason. The use of hopper dryers will extend that time because the hopper dryer unit has an extended size hopper that continuously maintains the dryness of the material within it. The following describes how a typical hopper dryer unit works.

Hopper Dryers

Hopper dryers are the most common units for drying and maintaining dryness of plastic materials prior to molding, as shown in Figure 4-2. They work on the principal of circulating warm, dry air through a mass of plastic pellets. The dry air absorbs moisture from the pellets and is taken away, back to the dryer unit where the moisture is deposited into a bed of granular, absorbent material called a *desiccant*.

Common desiccants are calcium chloride and silica gel. After a few hours use (6 to 8), the desiccant, saturated with moisture, is removed and regenerated by placing it in a high-temperature oven that dries off the moisture and freshens the desiccant for reuse. This activity can be built right into the main system and performed automatically. Normally, a bank of desiccant containers is utilized so one can be regenerating while another is in use.

Hopper dryers will not usually properly dry material. They are intended only to maintain material that is already dry. The material must be dried by other methods before being placed in the hopper dryer. One of those methods is the floor drying system, as shown in Figure 4-3.

Floor (Central) Dryers

Using dryers on every press can become expensive for a molding operation with a large number of molding machines. An alternative is to use a central drying

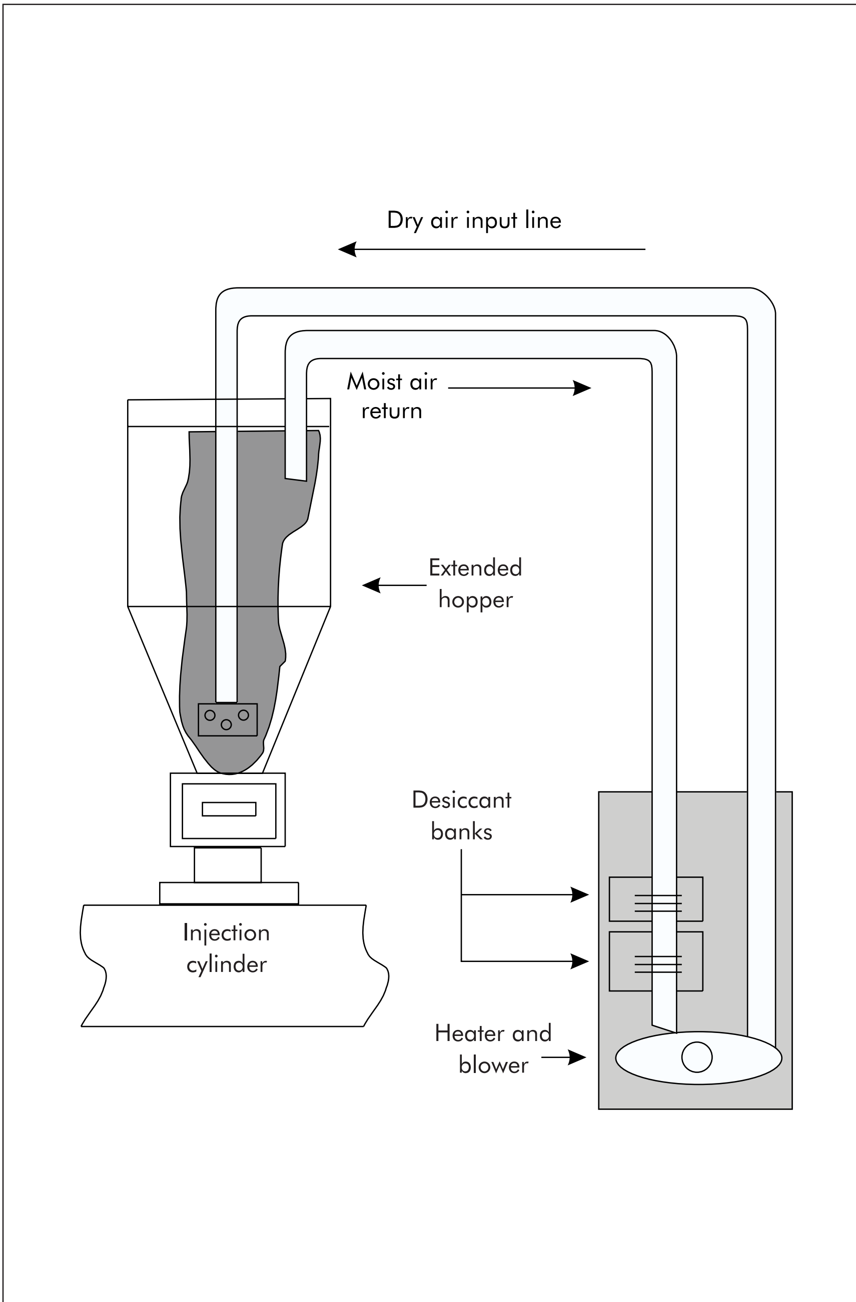


Figure 4-2. Typical hopper dryer operation.

Figure 4-3. Floor dryer unit. (Courtesy AEC)

system, commonly referred to as a floor dryer. This is similar in operation to the hopper dryer, but one central unit feeds many machines. Commonly, a single central dryer can serve four to six machines. There are some very large units for a larger number of presses, but they are expensive and usually cost-prohibitive for most operations.

Floor drying units operate by one of two basic methods: drying and transferring material, or drying and transferring just air. The first method preheats and dries the material in a central spot and then feeds the warm, dried material, as needed, directly to the machine using it. In this way, small storage hoppers can be utilized for each machine, holding enough material to last approximately 30 to 60 minutes of process time. This minimizes the tendency for the material in the hopper to pick up moisture. Such a system is practical only if the same material type and color is being molded on all the machines fed by the dryer unit. The second method provides a central supply of dry air that is pumped to each machine. Extended hoppers are used, which store enough material to last 2 to 4 hours. Using this system, many materials can be dried at the same time. In this case, the dry air is not heated and a preheater is required at the hopper of the machine.

Oven (Drawer or Tray) Dryers

Oven dryers were the original drying units, dating back to the 1920s. These units consist of a series of trays (drawers) mounted on a rack within a closed chamber, as shown in Figure 4-4. The chamber contains a method of forcing hot, dry air over the trays. The trays are filled with plastic pellets to be dried and usually hold approximately 25–50 lb (11–23 kg) each. The pellets are poured into each tray to a depth of 1.5–2 in. (3.8–5 cm).

As the dry air is forced over the trays, it picks up any moisture present and returns it to a desiccant bed. There, the moisture is pulled from the air by the desiccant, and the dry air is returned to the chamber for another pass. Like other drying units, oven dryers require the desiccant to be regenerated on a timely basis (usually every 8 hours).

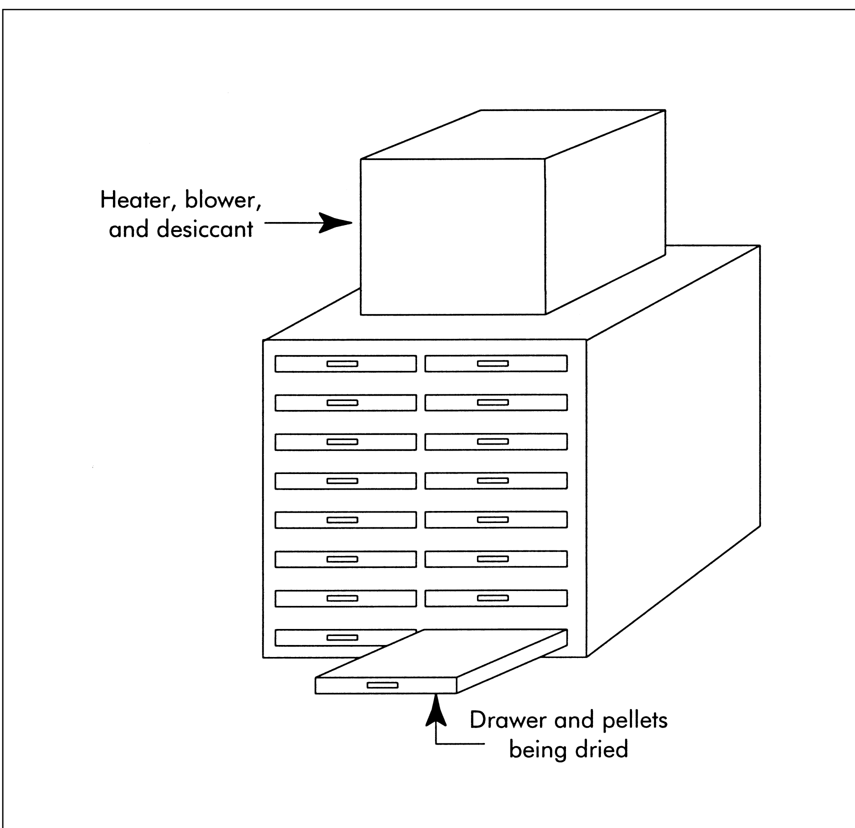


Figure 4-4. Typical oven-type dryer.

Defining Dryness

Each plastic material (whether hygroscopic or not) requires a specific amount of drying, at a specific temperature, and for a specific amount of time to achieve an acceptable level of moisture content, usually around 1/10 of 1%. For example, ABS material must be molded with a maximum moisture content of .10–.15%, by weight. This can be achieved by drying at 200° F (93° C) for a period of 2 hours in a standard dehumidifying dryer environment. However, some nylons may require up to 24 hours drying at 190° F (88° C) to achieve acceptable moisture levels. This information may be obtained directly from the material supplier.

Do not accept the response from the material supplier that some materials do not require drying. Hygroscopic materials absorb moisture directly from the atmosphere and, therefore, must be dried before molding. The most common of these hygroscopic materials are ABS, polycarbonate, and nylon. Other materials that are not hygroscopic (such as polypropylene and polyethylene) may still require drying if condensation is present or local humidity levels are high enough to create moisture content above 1/10 of 1%. But, how can you tell if the right moisture level is present?

Dew Point Measurement

The *dew point* is the temperature at which the plastic material is considered dry, when using a dehumidifier. This can be measured using a special dew point meter (available from molder supply houses) that indicates the dew point temperature. The meter attaches to the hopper outlet and measures the dew point of the material just before molding. Most plastics must fall in the range of between 10° F (–12° C) and –45° F (–43° C) dew point. The actual requirement for a specific material may be obtained from the material supplier. The dew point meter is used as a monitor to ensure the plastic has been thoroughly dried before it is processed.

Moisture Testing (TVI Test)

An inexpensive and accurate method for testing materials for acceptable dryness was developed by the GE Plastics Section at Pittsfield, Massachusetts. The test, called Tomasetti volatile indicator (TVI) requires very little equipment and is performed using only six easy steps.

The equipment needed consists of an electric hot plate capable of maintaining 525° F (274° C), two standard glass microscope slides, tweezers, and some wooden tongue depressors. The procedure is as follows:

1. Place the two glass slides on the surface of the hot plate (which has been preheated to 525° F [274 °C]), for 2 minutes.
2. After 2 minutes have passed, use the tweezers to place two or three plastic pellets on top of one of the glass slides, as shown in Figure 4-5.

3. Now, using the tweezers, place the other glass slide on top of the plastic pellets, making a sandwich of two glass slides with the pellets between them.
4. Using the long edge of a tongue depressor, press the slide sandwich together until each of the pellets flatten out to about a .5 in. (13 mm), or so, in diameter.
5. Using the tweezers, remove the glass slide sandwich from the hot plate and allow it to cool approximately 5 minutes, as shown in Figure 4-6.

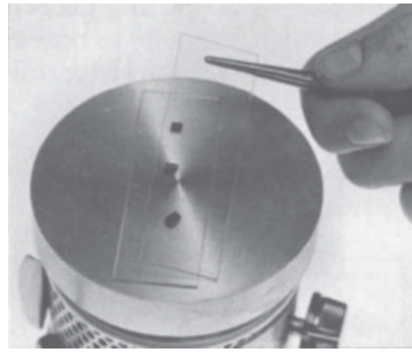


Figure 4-5. TVI test slide.

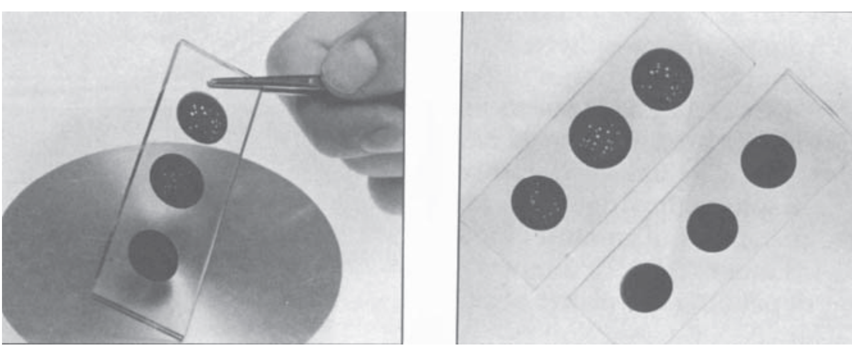


Figure 4-6. TVI procedure.

6. Perform an approximate calculation for the total area of any bubbles formed, to the area of the plastic pellets.This will give a ratio that can be interpreted as a percentage of moisture present in the original pellets.

Utilizing the TVI test will give a close approximation of moisture content for comparison to the material supplier's recommendations to determine if the material is dry enough to mold The fewer the bubbles, the dryer the material. This test is not accurate for glass-reinforced plastics, but it can still be used as a reference test for them. If only one or two bubbles are found, they may indicate trapped air instead of moisture, so the material can be considered dry.

LOADERS

Every injection-molding machine is dependent on a consistent supply of fresh plastic material during the molding process. This material must be moved from a storage container, after being dried, to the machine hopper so the machine can process it. Handling the raw plastic material, usually in pellet form, can become time consuming and labor intensive, especially as the number of molding machines increase. So, this material handling phase of the molding process tends to be performed by machinery whenever possible. The choice of material handling equipment depends on four considerations:

1. The type of material (usually pellets, but also powder).
2. The amount of material required for consistent processing.
3. The vertical and horizontal distances being covered.
4. Special functions required beyond movement (such as mixing color).

Mechanical Loaders

The most common mechanical loader is the auger type, which employs a long-pitch, spring-shaped auger, rotating within a tube. The discharge end of this tube is attached to the top of the molding machine hopper, and the pickup end is placed inside of the material shipping (or storage) container, usually placed next to the molding machine. When the system is activated, the rotating auger picks up material from the container and carries it through the tube and into the machine hopper. Activation can be initiated by a timer, level sensor, or manually. While this is an inexpensive transfer system, it is very difficult to clean and should only be considered when one specific material will be used for an extended period of time.

Another method of mechanical loading (although not commonly utilized) is the *elevator loader*. This system consists of an elevating platform, placed next to the molding machine in such a way as to raise a container of material up to the level of the hopper. At that point, the elevator table tilts and pours material from the container into the hopper. Then it lowers the container back to floor level. To be effective, this system requires an extended-size molding machine hopper and a large amount of floor space, so its use is fairly limited.

Vacuum Loaders

By far, the most popular loading system for transferring raw plastic to the molding machine hopper is the *vacuum loader*, as shown in Figure 4-7. The most common of these consists of an integral motor (or pump) unit mounted directly on top of the molding machine hopper. Tubes are connected to the unit and placed within the material container up to 50 ft (15 m) away from the machine. When activated, the unit creates a vacuum, which sucks material from the container and pulls it to the vacuum unit sitting on top of the hopper. When it arrives, the unit dumps the fresh material directly into the hopper. These systems are suitable for applications requiring material loading rates of up to 2,000 lb (907 kg) an hour.

Figure 4-7. Vacuum loader. (Courtesy Polymer Machinery)

Positive Pressure Loaders

When many machines are using the same material, or very large volumes of material are being used by various machines, it is possible to utilize large, positive pressure, loading systems that are centrally located. They are connected to each molding machine by tubes and can transfer material over great distances (up to 500 ft [152 m] or more), so the relatively high cost can be spread over a large number of machines. These systems also can be designed such that each machine can be fed a different material, or color of material, without cross-contamination. Each system can deliver approximately 15,000 lb (6,804 kg) of material an hour, and typically unload bulk railcars to silo storage.

BLENDERS

Blending may be defined as the combining of two or more types of materials to give a uniform mixture. For injection molders, this may be required to achieve proper color combinations, or to blend regrind with virgin pellets. It also can be used for adding ingredients to improve flow, reduce sticking, increase flammability resistance, or enhance the base material in many other ways.

Blending can be performed manually by stirring a measured amount of the desired ingredients into a measured batch of raw plastic pellets. Alternatively, rolling a closed barrel of the combined materials across the floor for 30 minutes can be a substitute. But the labor costs and probable inconsistent blending results of manual operations have led to the popular utilization of automated blending systems.

The most common method of automated blending is performed by a unit that is mounted on top of the hopper-loading unit on the molding machine, as shown in Figure 4-8. Some loaders incorporate built-in blending units.

Figure 4-8. Machine-mounted blender. (Courtesy AEC)

Blending units are actually metering devices that allow a specified amount of ingredient (usually pellets or powders, but also can be liquid) to be combined with a batch of plastic just before it is dumped into the molding machine hopper.

When molding a product that generates a great deal of regrind, blend the regrind with incoming virgin materials. This step will use up the regrind as it is generated. In these cases, it is ideal to connect a blender pickup hose to the storage compartment of the regrind granulator so that regrind material can be used immediately after initial molding, and before it has a chance to absorb moisture from the environment.

MOLD TEMPERATURE CONTROLLERS

For efficient, productive molding, the mold temperature must be controlled as closely as possible. This can be accomplished using either a stand-alone control unit or a centralized cooling system with manifold connections at each machine.

Stand-alone Units

Figure 4-9 shows a stand-alone unit, which is portable, on casters, and is brought to the mold. There are many sizes available, with some units at waist height and some that are floor level and easily moved from area to area. These units are electrically operated and must be plugged into a proper outlet. They also must be connected to a water supply or other coolant source.

As shown in Figure 4-10, a supply hose is connected from the stand-alone unit to one half of the mold. A return line is also required from the mold half to the unit. It is not efficient to do so, but some molders use a single unit to control both halves (A and B) of the mold. This requires one half of the molds to receive supply water from the other half. This means that the incoming water is usually hotter for the second half. This makes it extremely difficult to maintain a temperature difference of within 10° F (5.5° C) between the two mold halves, as required for efficient production. It is much more desirable to utilize two control units per mold, one for each half.

Figure 4-9. Stand-alone mold temperature control unit. (Courtesy AEC)

The operation of the unit is simple. A liquid, usually water, is circulated through the mold by the control unit. This circulation is accomplished by sending the water through a hose connected to one half of the mold. A similar hose returns the water to the control unit. The control unit senses the temperature of the water at that time and compares it to the preset temperature required for that specific mold. If the water is too hot, the unit drains some of it and replaces it with fresh, cold water until the temperature setting is matched. If the water is too cold, the unit uses an internal heater to warm it up to the temperature setting before it goes back to the mold. In some cases, the unit may not have an internal heater and will stop circulating water until it has absorbed enough heat from the mold itself. The temperature controlling process is continuous, requiring the control unit to operate in a fluctuating manner, heating and cooling the water to maintain the proper temperature.

The most common liquid used is water, but sometimes a temperature higher than 212° F (100° C) is needed (the boiling point of water). In that case, a liquid, such as mineral (or silicone) oil, is required because it has a much higher boiling point than water.

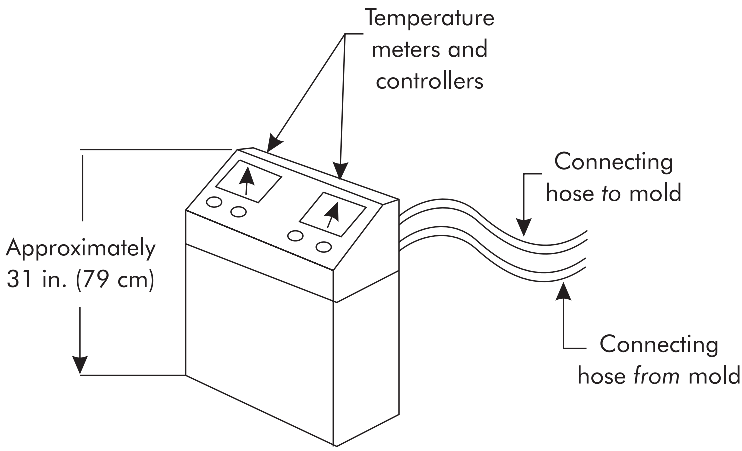


Figure 4-10. Connecting control unit to mold.

Manifold Systems

A second method of controlling mold temperature (although not as accurate as the stand-alone unit) is the manifold system. This system relies on the use of a central system of circulating water that runs throughout the entire molding facility. The circulating water is usually pumped to a cooling tower, which cools the water down. It is then pumped back to the molding operation where the cycle is repeated continuously. Along the route, taps are placed to allow hoses to be connected to the central system. These taps are called *manifolds*. Hoses from each mold half are connected to these manifolds, allowing the circulating water to enter the mold. Closing off the manifold taps until the mold removes enough heat from the incoming plastic attains temperature control. Then, the manifold taps must be opened slightly to allow fresh water circulation through the mold. This brings the temperature back down and continues until the mold is of the correct temperature. At this point, the taps are left in whatever position necessary to maintain the temperature.

Turbulent versus Laminar Flow

Regardless of what method is employed for controlling mold temperature, the flow of water (or other medium) must be turbulent while moving through the cooling channels. A turbulent flow is much more efficient than a laminar flow, as shown in Figure 4-11.

Laminar flow means that the cooling medium (usually water) flows through the cooling channel in layers, one upon the other. Only those layers closest to the outer walls of the cooling channel are actually pulling heat away from the mold. The center layers are never exposed to the heat and do not remove heat from the mold.

With *turbulent flow,* the water is constantly churning. This churning action continuously blends all the water together, mixing the water closest to the walls with that in the center of the flow. This mixing maneuver utilizes all of the water in the cooling action and creates a much more efficient cooling pattern than the laminar method.

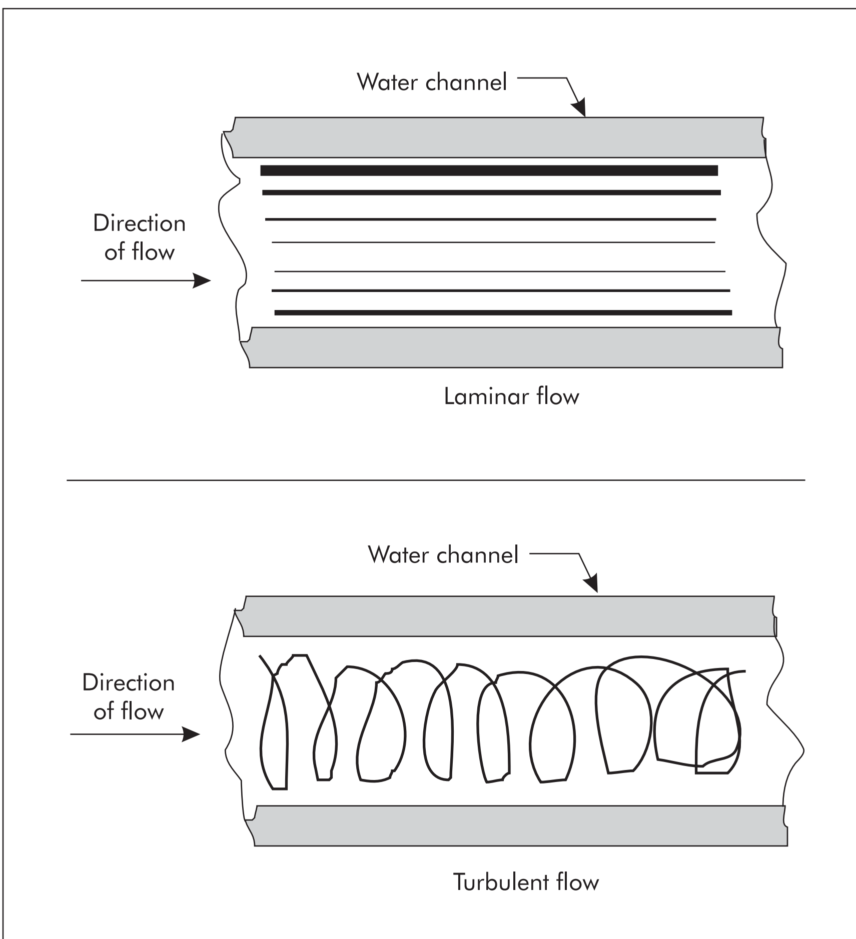


Figure 4-11. Laminar and turbulent flow.

Reynolds Number Determination

There are a few ways of determining if the water flow is turbulent or laminar. One way is to feel the hoses going to and coming from the mold If the outgoing hose is more than 10° F (5.5° C) warmer than the ingoing hose, the flow is not turbulent. This means that there is inefficient laminar flow, and there is still much more heat to be removed from the mold. If the temperatures are the same, or within 10° F (5.5° C) of each other, the water flow is turbulent and it is doing an efficient job of removing heat as fast as it is being generated.

Another, more accurate method of determining turbulence is to calculate a value known as the Reynolds number. The *Reynolds number* is a dimensionless value that can be defined as an expression of the amount of drag present in a material flowing through a channel. When it comes to water flowing through a cooling channel of a mold, a Reynolds number below 3,500 indicates a tendency for the existence of laminar flow. A number above 7,000 indicates a return to laminar flow, and numbers between 3,500 and 7,000 indicate full turbulence (a Reynolds number of 5,000 is ideal).

The Reynolds number can be calculated by using the following formula:

$$R = KQ/Dn \qquad (2)$$

where:

R = Reynolds number
K = 3,160
Q = flow rate (gpm)
D = diameter of waterline (inches)
n = water viscosity (centistokes), see Table IV-1

The most important answer to find is the gallons per minute (gpm) required to produce a specific Reynolds number. The gpm is easily variable when all other conditions are fixed. The following is an exercise to make that determination.

Table IV-1. Water Viscosity versus Temperature

Water Temperature ° F	(° C)	Viscosity (n) (centistokes)
32	(0)	1.79
50	(10)	1.30
68.4	(20.2)	1.00
100	(37.8)	.68
150	(65.6)	.43
212	(100)	.28

First, the temperature of the water entering the mold must be known. In this case, use the temperature of 50° F (10° C). Then, find the diameter of the waterline. If a 1/8-in. (3.2-mm) pipe diameter is used, the actual drilled hole-opening diameter (water passage) is 11/32 in. (8.7 mm). Because turbulent flow is desired, the specific minimum Reynolds number of 3,500 is used. Remember, the formula is: $R = KQ/Dn$. By substituting the numbers for the variables, the following is attained:

$$R = (K \times Q)/(D \times n) \tag{3}$$

where:

R = Reynolds number (in this case, 3,500)
K = 3,160
Q = flow rate (gpm)
D = 11/32 or .34375
n = 1.30

So,

$$3{,}500 = (3{,}160 \times Q)/(.34375 \times 1.30)$$
$$Q = (R \times D \times n)/K$$
$$Q = (3{,}500 \times .34375 \times 1.30)/3{,}160$$
$$Q = .495 \text{ gallons per minute (gpm)}$$

Therefore, a flow rate of .495 gpm with water temperature of 50° F (10° C) will create proper turbulence (3,500) through a 1/8-in. (3.2-mm) pipe waterline. The formula can be adjusted for determining what Reynolds numbers are used for specified waterline diameters and flow rates, or what water temperature would be needed to create a specific Reynolds number. There are variable conditions under which the ideal Reynolds number range (3,500 to 7,000) can be achieved. Strive to maintain a Reynolds number of 5,000, if possible, to ensure that proper heat transferability is provided to control the operating temperature of the mold.

ROBOTS

The use of robots in the injection molding industry has greatly increased. The main reason is not just a reduction in labor costs, but the increased ability to achieve consistency in machine cycles. Robots are unique because they do not require breaks or lunch periods and they seldom miss work due to illness. Also, it makes more sense to use a robot for tedious, repetitive, physical labor, and utilize humans for jobs requiring thought, analysis, and decisions.

The primary use of robots in the molding facility is to replace machine operators. Their consistency of operation makes them ideal as pick-and-place units for parts removal from the mold. Robots can be located to enter the molding area of the machine from many directions. The most common style is the *top entry* system in which the robotic arm comes down from the top of the machine to enter the area between the mold halves for part removal activities. Another style is the *front entry* system in which the robotic arm enters the molding area from the front, or operator side, of the molding machine. The third style is the *bottom entry* system in which the robotic arm comes up and enters the molding area from below the mold. In any of these systems, the actual robot body can be placed in the most convenient location and the robotic arm can be maneuvered to enter the molding area from the directions noted earlier.

There are two basic types of robots: flexible and rigid.

Rigid Robots

Rigid robots are those that are designed and built to perform actions associated with only one specific application. These robots actually look like sophisticated machines; they might drill holes, machine shapes, or perform similar work. They are usually bolted in place and are not designed to be moved or adjusted. Rigid robots are normally found in secondary operation roles but can be utilized as auxiliary equipment for tasks such as stacking packages, transferring molded parts from one assembly station to another at the molding press, etc.

Flexible Robots

Flexible robots are those that are designed to be moved and adjusted to perform various activities that may change from product to product. For example, robots that remove finished parts from molding machines can be moved from machine to machine and are fitted with quick-connect fittings at the end of their "arms" to receive any number of tools or grasping attachments. Sometimes, these robots are called *pick-and-place* units because their primary function is to grasp an item, move it to another location, and place it on a table, in a fixture, on a conveyor, or in a box. They also can be used to perform rudimentary operations, such as snapping two parts together.

Robotic equipment can be designed to perform virtually any physical operation that a human can perform. This allows use of robots in such operations as assembly, painting, product transfer, and even shipping. With vision control systems attached, robots can be used for inspection.

SUMMARY

Dry material is essential to successful injection molding. There are many styles of drying units available including hopper dryers, oven dryers, and floor dryers.

Although dew point measurement is a good way of testing for proper dryness, TVI moisture testing is inexpensive and extremely accurate.

Loaders are machines that are used for placing raw plastic in machine hoppers. They can be mechanical, vacuum, or positive pressure pneumatic.

Blenders are utilized to mechanically mix additives with raw plastic pellets. This can be done prior to loading the material in the hopper, or at the hopper itself.

Granulators are machines that grind up scrap and excess molded material (such as runners) to create "regrind."

To maintain the proper mold temperature, a mold temperature control system is used. This system can be stand-alone. It contains a coolant (usually water, but sometimes oil) that is circulated through the mold (the temperature of the coolant determines the temperature of the mold). Or, this system can be a manifold system, which allows individual molds to connect to a central circulating water system. Each mold is controlled by throttling the manifold connection valve taps to the proper position.

Robots are being used in the injection molding industry to perform tedious, monotonous activities, such as machine operation.

QUESTIONS

1. What are the three most common types of granulator styles?
2. What is the term for material that absorbs moisture from the atmosphere?
3. Besides dew point measurement, what is another test for determining moisture content?
4. What are the three methods employed by material loading machines?
5. How far can a vacuum loader transport plastic pellets?
6. What is the primary purpose of a blender?
7. What is a granulator used for?
8. How many stand-alone temperature controllers should be connected to a single mold?
9. Name the two common media used in mold temperature controllers.
10. What are the two basic types of robots available?
11. What type of robot is the pick-and-place robot used in injection molding?

Determining Utility Requirements

5

DEFINING UTILITIES

Utilities are nonhuman resources required for the operation of primary and secondary equipment. They include electricity, water, and compressed air. This chapter will discuss methods for determining specific requirements.

ELECTRICITY

The main resource for any molding operation, and by far the most utilized, is electricity. It is used for powering motors, energizing heater bands, heating water, operating controllers, and for providing human conveniences such as lighting, ventilation, and cooling fans. In fact, the percentage of electrical costs as part of the total manufacturing cost of a product can range from 15% to 50% or more. The cost of electricity can range from about $0.03 per kilowatt-hour to $0.15 per kilowatt-hour (and higher) across the United States (with the Northeast and West being the most expensive and South Central being the least expensive).

For small facilities with few machines, it may be possible to obtain electrical power directly from local suppliers. However, for most molding facilities, electricity is provided through a substation that is erected on the molding facility site by the local power company. The substation size is determined by the maximum amount of current that the facility will need at its peak level of operation. The total current is calculated by adding up all of the individual machine and component requirements, including a safety factor, and estimating future needs.

Determining Requirements

The total current requirements for a molding facility includes the current required for the:

- Molding machine.
- Auxiliary equipment.
- Chillers.
- Cooling towers.
- Heating, ventilation, and air conditioning (HVAC).
- Air compressors.
- Lighting.

- Molding department.
- Inspection area.
- Mold and machine maintenance areas.
- Material storage and warehouse.
- Maintenance department.
- Mold and tooling.
- Machine maintenance.
- Miscellaneous equipment.

Molding Machine

The place to start for determining electrical requirements is the molding machine. It is the greatest user of electricity and each manufacturer will list the total amount of current required for each model of machine they produce. Molding machines are typically manufactured for three-phase electrical power. The most common is the 480-volt, three-phase, 60-cycle system (U.S.). In most cases, the higher voltage is used for electrical motors; the molding machine contains a transformer that reduces the voltage to 240 V for heater bands and auxiliary equipment, and 120 V for items such as lights and fans. Table V-1 shows some average kVA requirements for common press sizes, based on clamp force.

A typical molding facility will have many sizes of molding machines available. For example, a 12-machine shop may have two each of all the sizes shown in Table V-1. To determine how many kVAs are required for the molding machines, the total kVA shown is added together and multiplied by two. This would give a total requirement of 1,020 kVA (510 × 2). This is the maximum operating demand. This demand is higher at time of startup and tapers off during production. The actual demand during production is probably 60% of this maximum, or 612 kVA.

Auxiliary Equipment

For purposes of this discussion, auxiliary equipment is considered to include scrap grinders, mold temperature control units, hopper dryers and loaders, stand-alone floor dryers, and typical conveyor systems.

Table V-1. Average kVA Requirements for Common Press Sizes

Press Size tons (MN)	Power Requirement kilovolt amps (kVA)
50 (448)	35
120 (1)	60
200 (1.8)	85
300 (2.7)	100
500 (4.5)	110
700 (6)	120
	510

In most cases, there is a scrap grinder available at each molding machine. Scrap grinders are usually sized for the job-at-hand, and require around 5–30 kVA. For the example 12-machine shop, assume there are 12 scrap grinders with an average kVA of 15 each, for a total of 180 kVA.

Two mold temperature control units should be assigned for each machine (one for each mold half). Each unit requires an average of 12 kVA for a total requirement of 2 (mold temperature units) × 12 (mold machines) × 12 (kVA for each unit) = 288 kVA.

Each machine should have a hopper dryer unit for maintaining material dryness during molding, and a loading unit for replenishing material. The dehumidifying dryer units range from 5–100 kVA. An average of 30 is used for the 12-machine shop, which makes a total of 360 kVA. The loaders are rated at approximately 1.5 kVA. Add 18 more (1.5 × 12) kVA for a final total of 378 kVA for the hopper dryer and loader combination.

Stand-alone floor dryers are used for the initial drying of raw materials. Normally, two units are required for a 10–12-machine shop. Each unit will need at least 12 kVA for a total of 24 kVA.

Conveyor systems are used for many purposes and the typical 12-machine shop will have at least two such systems. Each system requires an average of 10 kVA for a total of 20 kVA.

Chillers

Because there is so much heat generated during the molding process, some method is needed to remove the heat from the process water. This water controls both the mold temperatures and the temperature of the molding equipment's hydraulic oil. It is inefficient and costly to dump this water to a drain system, so devices are used, such as centrally located chiller units, to cool the process water through a circulating system. This circulation takes the heated water and runs it through the chillers, which cool it back to the desired temperature before sending it back through the main water system. In most facilities, there are two chillers on hand. Both are used for peak times (during hot summer months and high-demand cycles), while only one is used for maintaining temperatures during normal operation. An average 40-ton central chiller unit will have a 55-kVA requirement. Two units, then, will require a total of 110 kVA.

Cooling Towers

To maximize the efficiency of the chillers, a cooling tower arrangement can be utilized. This system is placed before the chillers so that the heated process water first goes through the cooling tower. Here, the water is cascaded through a bundle of spray arms, which spray the water through the air, and into a small reservoir. A fan pulls heat from the reservoir water and dissipates it into the atmosphere. The cooler water is then directed to the chillers where the temperature is further reduced. A large cooling tower is usually sufficient for a 12-machine shop, although it is common to use two smaller units. In either case, the total kVA required will be approximately 56 kVA.

Heating, Ventilation, and Air Conditioning (HVAC)

Geographic requirements, local environmental agency laws, and many other influences determine the HVAC of a typical molding facility. On average, ventilation is based on moving a minimum of 6,000 cubic feet per minute (CFM) (170 cubic meters per minute [CMM]) of air at a use of 1.5 kVA per 2,000 CFM (56.6 CMM). In addition, typical air conditioning (AC) has a minimum requirement of 1.5 million Btu at 1.0 kVA per 15,000 Btu. The heat recovery portion (fans and blowers) would average about 10 kVA. An average HVAC requirement would total approximately 110 kVA.

Air Compressors

For operating hand tools and special equipment, and for general cleaning and material handling, a central air compressor system is vital to the average molding operation. Usually, a 12-machine shop would utilize two compressors, each with a flow rating of approximately 150 CFM (4 CMM). In addition, there may be a requirement for one or two smaller, portable units. A requirement of approximately 30 kVA exists for each central unit and around 8 kVA for each portable unit. This totals 76 kVA.

Lighting

Plant lighting is available in many forms, ranging from basic incandescent all the way to high-pressure sodium. Each type has a specific place in the molding facility. Sodium lighting is the most efficient, while fluorescent lighting is approximately one-half as efficient as sodium, and incandescent lighting is one-eighth as efficient as sodium. For the greatest cost efficiency and most productive operation, it is recommended that the molding department and warehouse area use high-pressure sodium. Fluorescent lighting should be utilized in areas such as mold and machine maintenance, material storage, and mechanical/electrical service rooms. Incandescent lighting should be available for inspection areas.

Proper *lighting levels* are determined by the size of the lighted area, the reflectivity value of the wall surfaces, and by the ceiling height. Lighting requirements are based on watts of lighting required per ft^2 ($0.09\ m^2$) of work area, and usually are calculated at a level of 4 ft (1.2 m) above the floor.

$$L = (w/a) \times f \tag{4}$$

where:

L = lighting level
w = light wattage
a = work area
f = factor for lighting requirements

The calculations begin by assuming a basic need of 1 watt of lighting for every square foot of area being lit (or about 11 watts of light for every square meter). This number is factored by a value of one-half, one, two, or three, depending on lighting requirements. For example, because higher lighting levels are required in the inspection area, it should have a factor of three applied, while the warehouse should be factored by a value of one-half.

Molding department. Most molding areas have ceilings of about 16 ft (5 m) to help dissipate heat and fumes. Normally, the lighting fixtures are placed at a point that is 2 ft (0.6 m) below the ceiling. In a typical 12-machine molding facility of 8,000 ft^2 (743 m^2), with a basic need of one watt/ft^2 (/0.09 m^2) of area, 8,000 watts of lighting are required if high-pressure sodium light fixtures are used. If the less efficient incandescent light fixtures are chosen, then the total watts needed would increase to eight times that number, or 64,000 watts. This is because the sodium fixtures, at a 16 ft (5 m) height, will produce the required level of 1 watt/ft^2 (0.09 m^2) (when measured at 4 ft [1.2 m] above the floor), while incandescent lights will only produce .125 watt/ft^2 (/0.09 m^2) under the same conditions. Thus, although the sodium lights are more expensive to purchase, they are much less expensive to operate.

Inspection area. In the inspection area, better lighting conditions are needed because it is critical for the inspection personnel to observe finished products in the best possible light. For that reason, incandescent lighting is mounted closer to floor level. Normally, this lighting is placed 8–10 ft (2.4–3 m) above the floor, and desk lighting is added where needed. Because incandescent lighting is used, factor the watts per area requirement by eight. The 12-machine facility would probably have an average inspection area consisting of 200 ft^2 (18.6 m^2), which would thus have a total wattage requirement of 1,600 watts. Although it is less expensive, sodium lighting is not adequate for inspection areas because it produces a yellowish cast on the products being inspected and tends to distort vision. Incandescent lighting best duplicates “natural” lighting conditions for indoor applications.

Mold and machine maintenance areas. Fluorescent lighting can be used in mold and machine maintenance areas. Sodium lighting is not suited for these areas since it tends to cause vision distortion. However, the more expensive incandescent lighting is not needed in this case, and fluorescent lighting provides a cost efficient alternative. Because of its lower efficiency value, the wattage requirement should be increased by a factor of three. An average mold and machine maintenance area for a 12-machine shop has a floor space of approximately 1,800 ft^2 (167 m^2). This, then, would require a total of 4,800 watts of lighting.

Material storage and warehouse. Because lighting is not as critical in storage and warehouse areas, sodium lighting can be used with a factor of one-half when calculating wattage requirements. It is difficult to determine an average when it comes to warehouse space because it can be used for so many different items. However, when used strictly for raw materials and tooling storage, a typical warehouse for a 12-machine shop might be 6,000 ft² (557 m²). Sodium lighting, factored by one-half, would yield a total requirement of 3,000 watts.

Totals. Table V-2 shows the results of adding up all of the lighting requirements for a 12-machine facility.

Maintenance Department

The typical maintenance area is devoted to providing maintenance for molds, secondary tooling, fixtures, test equipment, and primary and secondary machines. This requires specialized equipment, usually wired for 230-volt power. A 12-machine shop, in this example, would have the following requirements.

Mold and tooling. For the mold and tooling maintenance areas providing major repairs, the equipment should consist of one or two milling machines, one or two surface grinders, a lathe, a drill press, and miscellaneous powered hand tools. The total average kVA requirement for such a facility is 70 kVA. If only minor repairs are being performed, the equipment list might consist of only powered hand tools and a drill press, which would result in a total requirement of approximately 15 kVA.

Machine maintenance. The equipment needed for machine maintenance includes all of what was mentioned earlier and a band saw, larger drill press, and welder. In addition, one or two bench grinders and buffing equipment will be needed. This will add a total requirement of approximately 60 kVA.

Miscellaneous equipment. In this category, place all the other equipment not listed so far. This would include items such as test equipment, special automated equipment, powered tools such as trim knives or degating tools, and any other electrically operated tools or equipment not listed elsewhere. An average electrical requirement for miscellaneous equipment would approximate a total of 10 kVA.

Table V-2. Total Lighting Requirements

	Area ft² (m²)	Power Requirements (watts)
Molding department	8,000 (743)	8,000
Inspection area	200 (18.6)	1,600
Maintenance area	1,800 (167)	4,800
Warehouse	6,000 (557)	3,000
Miscellaneous		600
Totals	16,000 (1,486)	18,000 (at 1 kVA for each 1,000 watts, a total requirement of 18 kVA)

Totals

Table V-3 shows a total for the electrical requirements in kVA for the 12-machine molding facility. These are only estimates, and safety factors of approximately 25% must be included. To plan for expansion, a 5-year projection of additional requirements should be added to the basic needs (assume another 50%). This gives a total startup and 5-year expansion requirement of 4,538 kVA. Now, a properly sized electrical substation can be installed for the facility with enough electrical power to run the operation, even at peak load times.

Distribution of Electrical Services

Electrical power must be distributed through a system that provides efficient partitioning in a compact and sensible manner. With a 12-machine shop, this distribution would be accomplished by utilizing a system such as that shown in Figure 5-1.

As shown in Figure 5-1, the electrical power enters the facility from the main substation as provided by the power company. From there, it is divided into segments that make up the main distribution center. From this center, the power is distributed to the specific machines or areas as needed. Along the way, transformers are required for changing the power from the 480 V, three-phase, as supplied by the substation, to other voltages and phases as needed by the machines and equipment.

It is a good practice (and required by certain local codes) for every piece of equipment to have a main disconnect switch for the electrical power that feeds the equipment. With this switch, a specific machine can be disconnected from power (for maintenance or other reasons) without disrupting power to other machines or areas.

Table V-3. Total Equipment Electrical Requirements

Equipment	Power Requirement (kVA)
Molding machines	1,020
Auxiliary equipment	890
Chillers	110
Cooling tower	56
HVAC	110
Air compressors	76
Lighting	18
Maintenance department	130
Miscellaneous equipment	10
Total	2,420

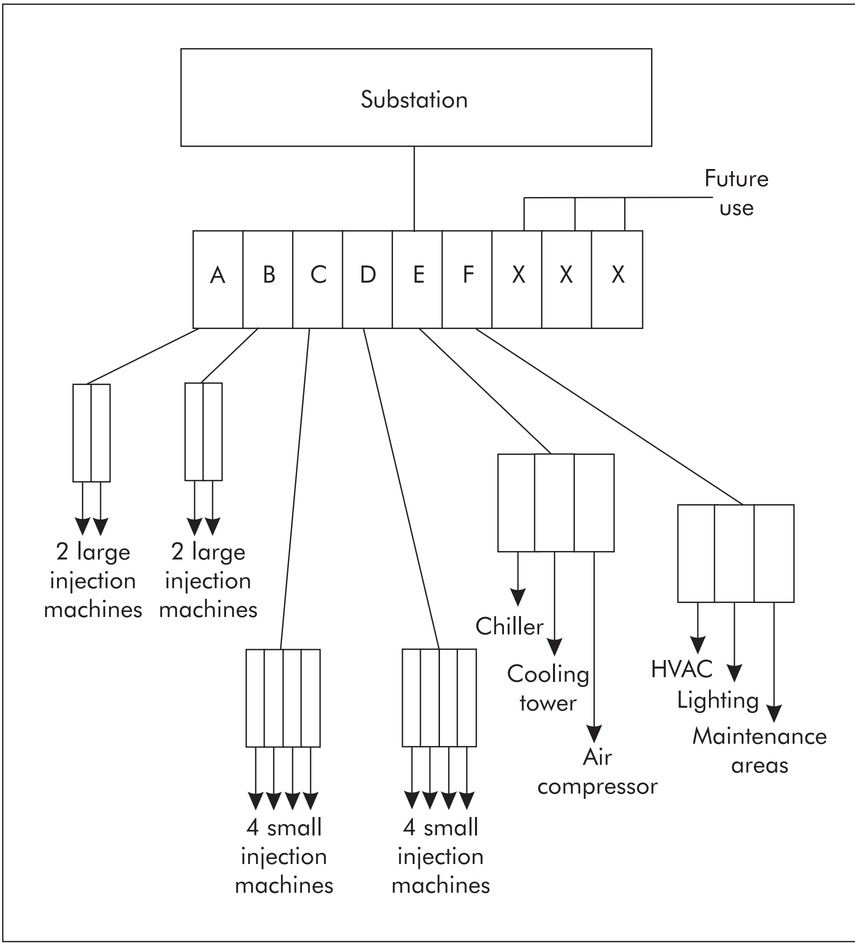


Figure 5-1. Electrical distribution for a 12-machine facility.

WATER

Water is used in many areas of the molding facility. Process water is used primarily for cooling the machine's heat exchanger (used to control oil temperature) and for circulating through the mold to maintain mold temperatures.

Determining Requirements

For controlling mold temperature, the water will require an average flow rate of 35–40 gallons per minute (GPM) or 132–151 liters per minute (LPM) for each mold. Small molds will require less and large molds will require more. The 40 GPM (151 LPM) rate will be considered average for each machine in the sample 12-machine facility.

Water flow for controlling each machine's heat exchanger temperature will be in the range of 20–30 GPM (76–114 LPM) per machine, depending on the size of machine being serviced. An average of 25 GPM (95 LPM) will be used in this example.

Based on the values listed earlier, the system must be capable of providing a constant flow rate of at least 780GPM (2,952 LPM). To that, around 10 GPM (38 LPM) is added for the air compressor after-coolers, and at least 10 GPM (38 LPM) for miscellaneous uses. That brings the need to 800 GPM (3,028 LPM)Adding a 25% safety factor for peak demand times, the system should provide a minimum of 1,000 GPM (3,785 LPM) maintained flow rate.

Because of the volume of water being used, it is not economically feasible to allow the used water to empty to a drain. Therefore, cooling towers and chiller systems are implemented in which the used water circulates and is cooled down to its original temperature before being recirculated through the system.

Distribution of Water Services

Figure 5-2 shows a typical distribution system for a 12-machine facility using a standard cooling tower and two chillers.

The distance between machines is approximately 10 ft (3 m) on the smaller machines and 12 ft (3.6 m) on the lager machines. This allows room for hookups to the waterline system and ease of access for mold setup and other installa tion procedures.

It is wise to consider placing the waterline system, along with air and electrical lines, in a trench beneath the floor of the facility . This allows much more operating space above ground. If trenches are utilized, they should be approximately 5–7 ft (1.5–2.1 m) deep and 3 ft (0.9 m) wide to allo w easy access by maintenance and setup personnel. In addition, for safety reasons, a heavy grating system should cover the trenches. Although expensive to add to an existing facility, a new facility can add trenches for little additional cost at time of initial construction.

COMPRESSED AIR

Compressed air is used in a typical molding facility for such things as ejector-assist blow-offs, cleaning dust from tables and fixtures, cooling hot parts directly from the mold, and providing power for operating hand tools, automated equipment, material handling and loading, and small core pulls. This air should be well cleaned and dried before using. Although slightly oiled air is usually provided, some devices are not suited for using this oilA 12-machine shop would probably require two such compressors, as well as one or two small, portable compressors for special requirements.

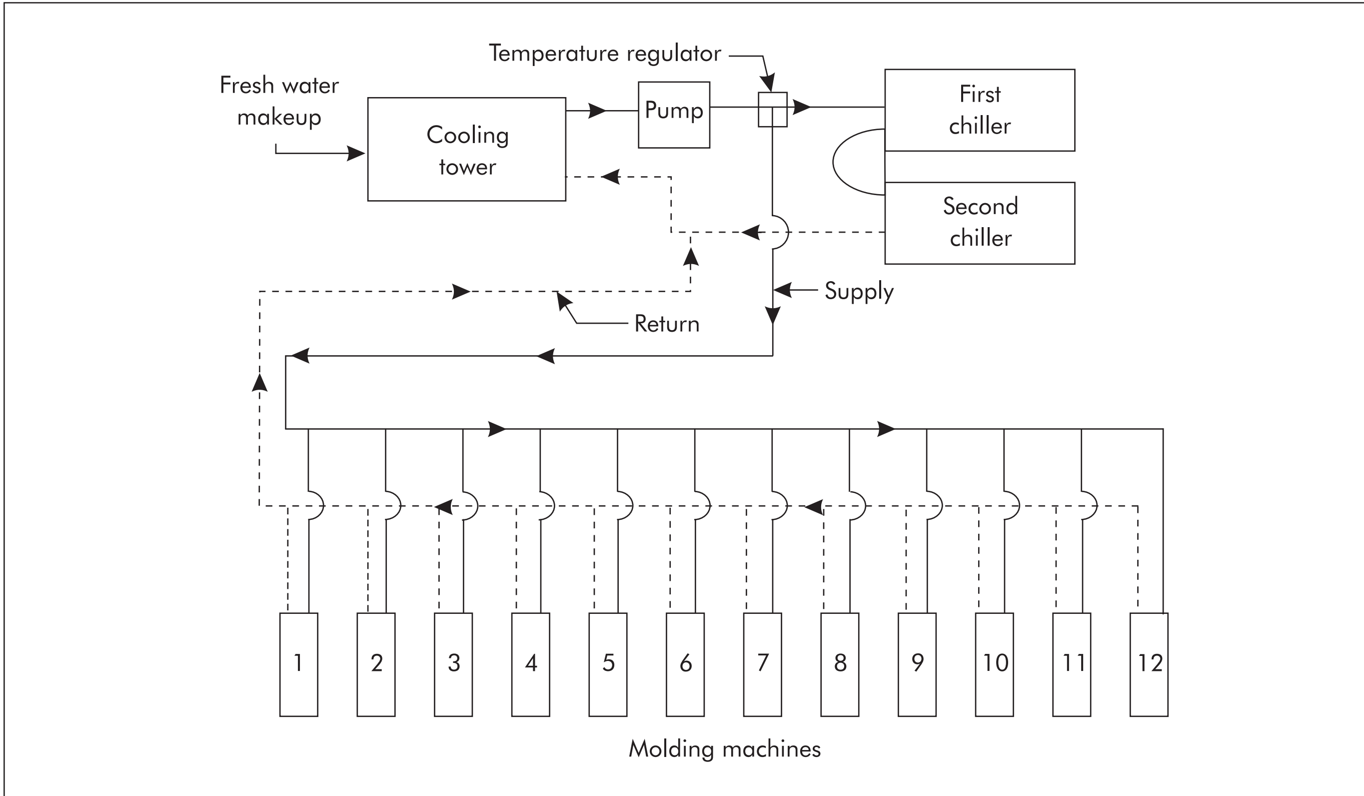


Figure 5-2. Water distribution system for a 12-machine facility.

Determining Requirements

The first thing to consider is what type of compressor should be purchased. Compressors are available in either two-stage reciprocating or rotary screw types. The two-stage compressors are common, but they do require small amounts of oil for internal lubrication. This oil will be evident in the air supply. If exceptionally clean air is required, it is better to consider a rotary screw compressor because they do not require lubrication, although they are more expensive.

The number of molding machines in the facility can determine the size of compressor required. The greater the number of machines, the lower the average amount of air required. For example, a two-machine shop will find an average requirement of 15 CFM (0.42 CMM), while a 12-machine shop will only require an average of 7 CFM (0.20 CMM). This is due to the fact that not all devices and equipment operating are calling for air supply at the exact same moment. A 12-machine shop, then, would require a total of 84 CFM (2.38 CMM) compressed air supply. This must be able to be supplied at a constant pressure value of at least 90 psi (0.6 MPa). Therefore, reservoirs are needed to keep a supply of compressed air available at all times.

Each machine requires air for the previously noted reasons, but there is also a requirement for the maintenance areas. Due to the use of many air-operated tools and devices by maintenance personnel, an additional 40–50 CFM (1.1–1.4 CMM) must be provided. This brings the total for the 12-machine plant to 134 CFM (3.8 CMM) at 90 psi (0.6 MPa).

Distribution of Air Services

Distribution of compressed air can be accomplished in many ways. The least costly is to construct a large, single main branch with small connections for each piece of equipment. The disadvantage of this system is that significant pressure losses will develop over long lengths of travel.

A better method is to construct a "loop" with both ends connected to the supply. This reduces the piping run to half that of the main branch system (which reduces pressure losses). However, it is more expensive to install.

In any case, there will be a need to calculate additional CFM (CMM) to offset the 5 to 10% loss, which will occur due to leaks. These are always present and difficult to keep repaired.

SUMMARY

Utilities are nonhuman resources required for the operation of primary and secondary equipment. They include electricity, water, and compressed air.

The main resource for any molding operation, and by far the most utilized, is electricity. It is used for powering motors, energizing heater bands, heating water, operating controllers, and for providing human conveniences such as lighting, ventilation, and cooling fans.

Molding machines are typically manufactured for use of three-phase electrical power. The most common is the 480-volt, three-phase, 60-cycle system (U.S.). In most cases, the molding machine contains a transformer that reduces the voltage to 240 V for heater bands and auxiliary equipment, and 120 V for convenience outlets to be used for items such as lights and fans.

On average, ventilation is based on moving a minimum of 6,000 CFM (170 CMM) of air per minute at a use of 1.5 kVA per 2,000 CFM (57 CMM). In addition, typical AC has a minimum requirement of 1.5 million Btu at 1.0 kVA per 15,000 Btu. The heat recovery portion (fans and blowers) would average about 10 kVA. An average HVAC requirement would total approximately 115 kVA.

The size of the area being lit, the reflectivity value of the wall surfaces, and the ceiling height determine proper lighting levels. Lighting requirements are based on watts of lighting required per ft^2 (m^2) of work area, and usually are calculated at a level of 4 ft (1.2 m) above the floor.

Although sodium lights are more expensive to purchase, they are much less expensive to operate.

Water is used in many areas in the molding facility. Process water is used primarily for cooling the machine's heat exchanger (used to control oil temperature) and circulating through the mold to maintain mold temperatures.

The number of molding machines in the facility can determine the size of compressor required. The greater the number of machines, the lower the average amount of air required.

QUESTIONS

1. Define the term *utilities*.
2. What percentage of the total manufacturing cost is electrical cost?
3. What is the most common rating for electrical power used by molding machines?
4. What is the average kVA requirement for a 300-ton molding machine?
5. What factors determine proper lighting levels?
6. What is the basic need that determines how much lighting is required?
7. How many kVA are needed for a shop with a requirement of 18,000 watts of electrical power?
8. What are the two primary uses of water in the molding process?
9. What is the biggest advantage of placing utilities in an underground trench?
10. What two basic types of air compressors are found in molding facilities?

Material Storage and Handling

6

OVERVIEW

Proper storing and movement of raw materials are important to the success of any molding operation. If materials are stored too long, or improperly, additional costs are incurred through the need for excessive storage space and potential contamination to the resins. Transferring materials from storage to process equipment is more costly if performed manually rather than with automated equipment and methods. In addition, excessive waste can occur through spillage if proper methods are not practiced during the transfer process.

Another area of concern is the proper mixing of raw materials. Most molders utilize some type of compounding, either to mix color materials (and/or other fillers) into natural resin, or for blending regrind with virgin materials. This, too, is considered part of the storage and handling process.

This chapter will present some of the more popular storage and handling methods, techniques, and equipment used in the industry today.

HOW MUCH STORAGE IS REQUIRED?

The amount of storage space required is determined by what is being stored. There must be enough space for raw virgin plastic, accumulated regrind, coloring materials (if the molder is doing its own coloring), other fillers, and auxiliary materials, such as hydraulic oil, packaging, and finished goods. There also may be requirements for work-in-process (WIP), molds, fixtures, inspection gages, and any incoming goods used for producing a finished product. While some of these items may be planned for storage in specific areas (such as inspection equipment being stored in the Quality Control department), much of it will be located in a central storage area or warehouse.

It is a good idea to hold as little consumable material in storage as possible. This reduces the amount of space required, increases the amount of available cash, and minimizes all costs (such as taxes, insurance, etc.) associated with maintaining inventory. A common practice is to maintain storage equal to the needs of a 30-day production schedule. This keeps inventory moving and allows greater flexibility in providing for customers. Also, the cost of material is in constant flux. A molder should be in a position to purchase when the cost is low, if possible. Minimal storage provides that position. Of course, molds, tooling, fixtures, and the like are not considered consumables and will probably be stored longer than 30 days.

Height Considerations

When evaluating storage space, height should not be overlooked. For a warehouse that is 60 × 100 ft (18.3 × 30.5 m) (6,000 ft^2 [557.4 m^2]), a 16-ft ceiling will provide the potential of a full 96,000 ft^3 (2,718.7 m^3) of storage. Of course, aisles are needed for fork lift or pallet-truck access (usually a minimum of 4 ft [1.2 m], but could be as much as 12 ft [3.7 m]), and the area should be laid out for maximum use.

It is common to use steel racks for storage. The racks are available in many sizes and weights, but a common size provides a "storage cell" that is approximately 4–6-ft (1.2–1.8-m) wide, 4-ft (1.2-m) tall, and 4-ft (1.2-m) deep. This accommodates the popular "gaylord" style cardboard container used by most material suppliers. A gaylord holds from 1,200–2,000 lb (544–907 kg) of material, depending on the specific gravity of the resin. Each of the cells can be stacked upon one another. The maximum safe level is usually considered four cells high (16 ft [4.9 m]). Besides resin, all of the basic consumables can be stored in these cells, regardless of the individual container sizes, because they can be attached to skids that fit nicely into the cells.

When using storage cells (of any style), it is wise to assign identification numbers to each cell. Then, the material stored in each cell can be tracked and traced for inventory control requirements. The most common tracking method is the use of alpha and numeric locator combinations, for example, A-1, A-2, A-3, etc., and continuing through the alphabet. After using Z, the next alpha designator would be AA. This provides for an unlimited number of identification combinations.

Molds should be designed so that there is never more than 15% of the entire shot available as runners and gates. If there is more than that, regrind will accumulate, because only a maximum of 15% by weight can be used when mixed with virgin material (this may vary depending on what the customer dictates). Some industries, such as medical, don't allow any regrind to be used. If products are made that result in the accumulation of regrind, find proper storage for it as needed. It should be treated like virgin material and kept properly contained, sealed, and identified. It is a good practice to keep regrind stored separately from virgin material so it will not inadvertently be used. Regrind can be sold for about 20–50% of its original cost, depending on quality and demand.

Silos

If molding a large volume of a specific resin, a silo should be considered. Silos are available in sizes ranging from around 40,000–100,000 lb (18,144–45,360 kg). The advantages of using a silo are that the cost of the material is much cheaper when buying in large volumes, and the storage is outside the building, taking up less valuable space in the molding facility. A disadvantage is that a large volume of material must somehow be transferred to the molding press. Usually, this is accomplished using a vacuum system that pulls a predetermined amount of material from the silo and transfers it to a drying operation, central handling system, and/or directly to the press.

The major disadvantage of a silo is that it is impossible to know exactly how much material is left in storage. The silo supplier will provide a table showing the approximate volume of material at predetermined and marked levels. Because the silos are not transparent, it is difficult to tell exactly at what level the stored material is standing. Usually this is accomplished by tapping the side of the silo to determine the approximate level. Then, the volume can be determined for that level by checking the supplier's chart. But the total weight of material can be estimated only if the specific gravity of the plastic is known. However, this is still problematic because the material toward the top of the silo is less dense than material at the bottom. Therefore, a "false" reading may take place.

Contamination

Next to moisture, contamination is the primary cause of defects in molded parts. This contamination comes from many sources, such as dust and dirt falling from ceilings or trash dumped into an open container of raw material that was improperly marked. The most common cause of contamination is the mixing of an improper material with a proper material. If regrind is not properly stored, identified, and covered, there is a good possibility that it could be incorrectly selected for mixing with virgin material.

For every one of the 20,000 (+) materials to choose from today, there are many grades to select from. For example, nylon has over 400 grades available. If the wrong grade is used for filling the hopper of a machine already in production, that machine may begin to produce defects if this "wrong" nylon cannot run at the same parameters as the "right" resin. Contamination of this sort can be minimized by making sure all material containers (regrind and virgin) are properly identified and kept tightly covered.

MATERIAL DRYING

This section will discuss moisture levels in plastic materials, methods of dehumidification, and how to measure the amount of moisture present.

Moisture Levels

Moisture is the number one cause of molded product defects. The moisture level of resins must be approximately 1/10th of 1 percent, by weight. If the moisture level is higher, then the moisture turns to steam as it travels through the heating cylinder of the molding machine (which is usually hotter than 300° F [149° C]). The steam prevents plastic molecules from bonding together properly and weak parts are produced. In addition, the visual evidence of this steam (splay) is usually not aesthetically acceptable.

There are basically two types of plastic materials: hygroscopic and nonhygroscopic. The term *hygroscopic* refers to the tendency for the material to absorb moisture directly from the atmosphere, like a sponge. The most common of these materials are nylon and polycarbonate (although there are many others). Hygroscopic material suppliers tell their customers that it is vitally important to predry the resin before molding and they provide detailed information for drying the resin, what temperature to use it at, and the length of time required for processing. Although the suppliers of nonhygroscopic materials (such as polypropylene and polyethylene) claim their materials do not need drying, they too can provide drying information to those who ask for it. All materials should be dried before processing to control as many conditions as possible. Even though the primary resin may not be hygroscopic, fillers used for making the final compound may be hygroscopic. Predrying the material provides a "jump-start" to processing and makes plasticizing easier. The more control a molder has of various processing parameters, the lower the cost to manufacture a product and the fewer the number of rejects produced. Therefore, an efficient injection molding operation will make the investment in equipment and time to predry all materials, regardless of whether or not they are hygroscopic.

How to Dry Materials

The two primary types of drying units are the hot-air dryer and the dehumidifying dryer. Either unit can be used for nonhygroscopic materials. However, the dehumidifying dryer must be used for hygroscopic materials.

Because nonhygroscopic materials do not absorb moisture, but merely allow moisture to stand on the surface of the pellets, hot-air dryers are sufficient for removing surface moisture. They work on the principle of evaporating moisture by applying heated ambient air to the plastic resin. When this heated air is circulated through the resin in a hopper, it absorbs the surface moisture and transfers it to a disposal area (usually a floor drain).

Since hygroscopic materials tend to absorb moisture throughout the material, they must be dried by a dehumidifying system.This is similar to the hot-air dryer but includes a dehumidifying bed that the heated, moisture-laden air circulates over before it is returned to the hopper. The dehumidifying bed contains an absorbent material (usually silica) that removes the moisture and traps it in the bed. After the bed is saturated (normally after 8 hours of drying), it is regenerated by exposing it to high-temperature air to drive off the moisture. The absorbent material is electronically charged with ions that have an opposite polarity to those in the moisture. The moisture is attracted to the absorbent material as the air circulates over the bed. This action is what pulls the moisture out of the plastic molecules and traps it within the bed.

Drying systems are available as central units designed to dry a large volume of plastic. From this unit, plastic is fed to many individual area units that dry smaller volumes and feed three or four molding machines. Drying systems also can be individual units mounted next to each machine and dedicated to that single machine. There are many advantages and disadvantages to each system and these must be explored before making a final decision on which system to use. Most larger molding facilities incorporate some of each system. One thing to consider is that the farther a plastic must travel before it is in the machine hopper, the greater the chance of inducing moisture back into the plastic before processing it.

Regardless of what system is used for drying the material, a hopper dryer should be mounted directly on the molding machine to maintain the dryness of the material being immediately processed. Do not accept claims that hopper dryers can actually dry the material while processing it. In some cases, this may be possible, but it is risky. Hopper dryer units should not be depended upon for primary drying, only maintaining dry material.

A note of awareness: plastic materials will only stay dry for 2-3 hours before they begin absorbing moisture again. For this reason, materials should be dried just before they are to be used. This applies to regrind too.

Measuring Moisture Levels

How can you tell if the material is properly dried? In general, plastic resins must have a dew point value of between –20 and –40° F (–29 and –40° C). As the material becomes dryer, the dew point reading decreases. This reading can be taken at the resin discharge tube of the dryer by using a dew point meter. The material supplier will provide data on what the acceptable dew point range is for a specific grade of material.

If a dew point meter is not available, the moisture level can be estimated using the Thomasetti volatile indicator or TVI. This test consists of making a sandwich of two glass microscope slides with three pellets of resin between them. This sandwich is then placed on a 525° F (274° C) hot plate and allowed to heat up. When the plastic pellets melt, they will form three puddles. If more than a single bubble appears in any of the puddles, it indicates moisture is present and the material should therefore be dried.

Other indicators of moisture include a frothing of the resin as it exits the nozzle during purging, splay (silver streaking) on the surface of the molded part, and brittleness of a molded product.

SUMMARY

Proper storing and movement of raw materials are important to the success of any molding operation. If materials are stored too long, or improperly, additional costs are incurred through the need for excessive storage space and potential contamination of the resins.

Most molders utilize some type of compounding, either to mix color materials (and/or other fillers) into natural resin, or for blending regrind with virgin materials. This, too, is considered part of the storage and handling process.

When considering storage space, height should not be overlooked.

When using storage cells (of any style), it is wise to assign identification numbers to each cell. Then, the material stored in each cell can be tracked and traced for inventory control requirements. The most common method is the use of alpha and numeric locator combinations, for example, A-1, A-2, A-3, etc., and continuing through the alphabet. After using Z, the next alpha designator would be AA. This provides for an unlimited number of identification combinations.

Next to moisture, contamination is the primary cause of defects in molded parts.

The moisture level of resins must be approximately 1/10th of 1 per cent, by weight. If the moisture level is higher, then the moisture turns to steam as it travels through the heating cylinder of the molding machine (which is usually hotter than 300° F [149° C]). The steam prevents plastic molecules from bonding together properly and weak parts are produced.

QUESTIONS

1. If materials are stored too long or improperly, why are additional costs incurred?
2. What determines how much storage space is required?
3. What device is commonly used for storage?
4. When is it considered advisable to use a silo for storage?
5. What is the major disadvantage of using a silo for storage?
6. What is the desired moisture level in raw plastic material, by weight?
7. Which materials should be dried prior to processing?
8. What does control of process parameters offer the molder?

Tool Room Requirements 7

Every injection molding operation should incorporate a tool room. This can range from a department capable of performing only minor repairs, such as replacing broken ejector pins, to performing major repairs, such as welding and refitting parting lines. In addition, for many reasons, a molding facility may wish to consider building its own molds rather than buying them from a vendor. Each of these situations requires a specific list of equipment to perform the associated activities. As the activity becomes more complicated, more resources are required for funding, space, and personnel. The decision for choosing the type of tool room should be based on factors, such as the availability of local talent and expertise, the amount of funding available, the degree of control desired, and the number and sizes of molds involved.

While molders need to provide "full-service" to their customers as much as possible, it is usually more cost effective to utilize outside sources for moldmaking and inside sources for maintenance and repair of those molds. The molder can still be considered a full-service vendor if full responsibility is taken for the mold, regardless of where it is made.

Large molds require large tool room equipment. Conversely, small molds require small tool room equipment. Large equipment requires greater sums of money and more space while the opposite is true for small equipment.

Today, the availability of personnel determines what level of tool room can be planned. It is quite common for a molding facility to build a big tool room only to find it cannot staff it with proper personnel. The old timers are leaving the business and there are few newcomers interested in earning a living as a toolmaker or moldmaker. The result is poorly staffed, or empty, tool rooms throughout the industry. Before investing large amounts of capital, space, and time in a tool room, it is wise to investigate the availability of talent. Because of the sensitivity of repair equipment to temperature and humidity, consider air-conditioning the tool repair department.

MINOR REPAIR FACILITY

Unless it is lucky enough to have a tool shop right next door, a molding shop should have a minor mold repair department in its facility. This department would be responsible for cleaning, inspecting, and storing molds when a production run is completed. In addition, if the inspection process uncovers any damage, this department will analyze it and determine whether or not it can be repaired in-house and make the appropriate arrangements.

The list of repairs that can be itemized as "minor" could be short or lengthy, depending on the equipment and personnel available to perform the work. The normal definition includes items such as replacement of damaged or broken ejector pins, cleaning and minor polishing of the mold and cavity surfaces, removing vent stains, replacing damaged sprue bushings, replacing O-ring seals, adding vents, and changing cavity inserts for interchangeable or family molds. To perform this work, the department should have several pieces of equipment available, such as a small lathe, small horizontal milling machine, small surface grinder, drill press, and hand tools—both manual and powered. In addition, a surface plate and measuring tools are required. A work table and chain hoist capable of holding the weight of the maximum-sized mold is required. A tool crib containing disposal items such as drills, taps, ejector pins, polishing media, etc., is also needed. In addition, there is a need for miscellaneous equipment, such as a bench grinder and shop vacuum. Even a small repair department can take up a minimum of 1,000 ft^2 (93 m^2) of space.

MAJOR REPAIR FACILITY

A major repair facility must be capable of performing all work listed for the minor repair facility and more. The additional work would include repairing damaged cavity surfaces, adding waterlines, refurbishing parting lines, welding and finishing cracks and dents in the mold proper as well as cavity surfaces, and performing work required as the result of minor engineering changes. This work requires additional equipment, such as larger lathes and milling machines, larger surface grinders and drill presses, a horizontal, metalcutting band saw, arc and TiG welding equipment, and hand tools including hand grinders and high-speed rotary equipment, and an electrical discharge machine (EDM), if possible.

Because of the increased number and size of the required equipment and the increased number of personnel, the major repair department will need a minimum of 2,500 ft^2 (232 m^2), or more. That requirement can double if a tryout press is included in the department.

MOLDMAKING FACILITY

Few shops can afford the luxury of maintaining their own moldmaking department. To have the ability to design and build molds requires different levels of expertise, with true moldmakers topping the list. Unfortunately, as mentioned earlier, moldmakers are becoming very rare. For every moldmaker working in the shop, two to four toolmakers and/or machinists are needed to build a finished mold. This is because even the simplest mold can require 1,000 or more hours to build. It becomes quickly apparent that a team of three or four people cannot build many molds over a year's time. Therefore, as the need for molds increases, more people are needed.

A typical in-house moldmaking facility works a single shift and has 6-10 people, with two or three moldmakers and the rest as support (for comparison, typical job-shop moldmaking facilities work three shifts). They typically work 50 to 60 hour weeks and require a large amount of equipment to produce molds. This equipment includes everything for the repair facilities mentioned earlier and adds the typical two or three plunge-style EDMs, a wire EDM, a heat-treating furnace for small items (large items are sent out for heat treating), a large air compressor for air-operated equipment, a multi-axis machining center, one or two centerless grinders, a large lathe, and additional surface grinders and horizontal mills. In most shops, the company does not supply basic hand tools and the machinist, toolmaker, and moldmaker are expected to provide these tools themselves. The moldmaking facility also must have mold handling equipment such as chain falls, overhead cranes, fork lifts and die carts available for its own use. They need to be located for easy access to shipping and receiving docks. A large tool crib is mandatory.

Because of the additional equipment and requirements, the moldmaking facility demands much more space than a repair facility. This space requirement can reach 5,000 ft^2 (465 m^2) or more depending on the number and size of molds it is expected to provide.

MOLD STORAGE AND HANDLING

Regardless of the type of mold repair or mold building performed, molds must be stored and handled in effective and prudent ways. Molds are expensive and this investment is usually borne by the customer, but the molder takes on the responsibility to maintain that mold while it is in the molder's possession. Maintenance costs for molds average around 5% of the initial cost of the mold, per year. The moldmaker is responsible for the quality of mold construction, and the mold designer takes responsibility for the performance of the mold design.

Any given mold will require a certain amount of repair for damage occurring during its use or storage. The more it is used, or the longer it is stored, the more damage will occur. Damage that occurs during use includes items such as broken core or ejector pins, peened parting lines, and worn gate areas. The most common damage during storage is rust.

It is a good idea to save the "last shot" from any production run kept with the mold in storage. This provides a visual example of the last parts produced by the mold. A repair person can inspect the parts to determine the fitness of the parting line, cavity surface condition, ejector pin position, and other pertinent information. A written statement of problems as seen by the molding room personnel should accompany this last shot.

Causes of Damage

Improper care is a major cause of damage to molds. The use of metal screwdrivers to remove stuck parts will result in scratching the cavity surfaces. This scratching will cause appearance defects on the molded part, but may also affect a specific dimension and cause it to be out of tolerance. It may also act as an undercut and cause subsequent parts to stick and not eject, or crack.

Failure to lubricate moving components such as slides and cams, or leader pin bushings, will result in a galling of the sliding components, and will eventually cause the components to seize. Even wiping the cavity surface with an improper rag can cause slight to major damage to the highly polished surface.

Improper processing can cause major damage. For example, a process technician, during startup, may use too much injection pressure and flash the mold. That flash could force its way between leader pins and bushings, or down ejector pin holes, or into vertical separations that force side walls out, or around slide mechanisms and cams. This results in locking the mechanism as the mold tries to open.

Allowing the nozzle to drool can result in material oozing onto the A side of the cavity set. This is thin material that solidifies quickly and becomes a hardened sheet of plastic. If it is allowed to stay there, it can cause heavy damage to the cavity set when the mold closes on it.

If mold temperatures are not properly controlled, sections of the mold will vary in temperature. If the difference is greater than 10° F (6° C), there is potential for thermal expansion variations that can cause swelling and galling of the steel.

Cleaning and Protecting Molds

After a mold has completed a specific number of production cycles (varying with type of product and molding material), it must be cleaned to remove residue formed during the molding process. The cavity surfaces and vent areas will show the greatest amount of residue, but the ejector housing, ejector pins, and runner blocks will also collect residue. Because of the tight tolerances maintained by the mold, this residue buildup may become enough to keep the mold from closing properly and/or force specific dimensions out of tolerance.

Vent areas require special attention. If the vents are occluded because of residue, they become ineffective and higher injection pressures are required to fill the mold. This may cause flashing, which may result in mold damage.

When the mold is pulled from the molding machine, it should be thoroughly cleaned, inspected, and coated (primarily inside, but lightly outside) with a rust preventive material to minimize the possibility of rust damage. The coating should be especially heavy for long-term (over 30 days) storage. It is also important to clean out the waterlines and coat them. An acid rinse of waterlines is recommended to remove deposits and protect against their return. If possible, molds should be stored in a cool, dry area to minimize rust-producing conditions.

Repairing damage to a mold can vary depending on the degree and type of damage. In some cases, a repair may require only the replacement of a broken ejector pin, while in other cases, the entire cavity set may need to be replaced. The method of repair, then, depends on what caused the damage. Removing rust from the outside surface of a mold is fairly simple and usually requires no more than a wire brushing for even the most extreme cases. However, removing rust from a cavity surface is a totally different situation and may even require welding and refinishing damaged areas. The rust may have caused so much damage that the cavity sets and other components may have to be completely replaced.

Molds are expensive tools. They require many hundreds (and possibly thousands) of hours of machining and crafting before they are ready for production purposes. Damaged molds result in losses to the molder and customer, not only in repair costs, but also in lost production and machine downtime. Although molds are usually made of high-grade steel, they are easily damaged, especially the cavity image areas and parting lines. For this reason, molds should be treated with the utmost care and protected during the production process as well as during storage between runs.

New Molds

New molds demand just as much protection as older molds. The first step for protecting a new mold is to open it at the parting line. Pry bar slots should be machined into two opposing corners on one half of the mold at the parting line to allow insertion of a set of pry bars for ease of opening. This eliminates damage caused by forcing the mold halves apart with large hammers and screwdrivers. Figure 7-1 shows the typical locations of pry bar slots.

After the mold has been opened, an inspection should be made of all exposed surfaces to ensure no obvious damage has occurred during shipment. Cavity image surfaces should be explored in fine detail looking for peened parting lines, scratched surfaces, chipped core pins, missing ejectors, etc. After this inspection is completed, the sprue bushing and locating ring should be examined to make sure they fit the intended machine and are of the proper size for the plastic that will be molded. Sprue bushings must have a smooth and polished internal tapered opening. Any blemishes will cause problems (such as black streaks) when molding.

Actions, such as slides, cams, lifters, and ejector systems, should be activated by hand to make sure they are operating smoothly and properly. Cutting oils and lubricants must be cleaned away and an inspection should be made for metal chips, filings, and dust. These will cause scratches and/or galling of metal surfaces and must be removed. Check for the presence of vents and any obstructions to them.

The entire mold, including external surfaces, waterlines, actions, vent areas, and cavity surfaces must be carefully cleaned and coated with a protective finish. The specific protective finish used will depend on the length of time that will pass

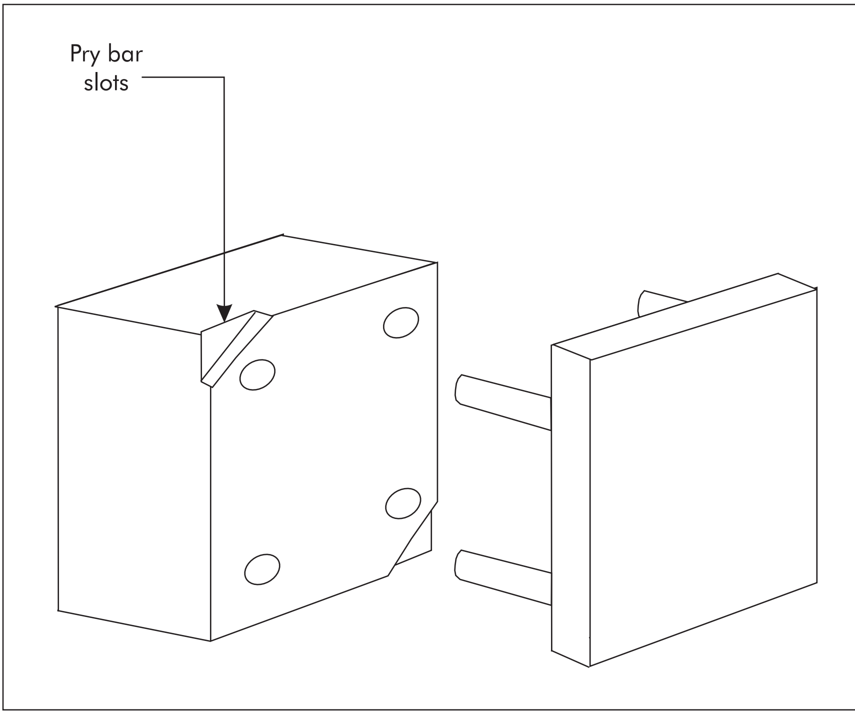


Figure 7-1. Pry bar slots.

before the mold is sampled or run. For short-term storage (up to 3 days), a light spray of vegetable oil or mild rust preventive (for example, petroleum jelly) can be used. Longer-term storage (7 to 30 days) will require a heavier coating, and very long-term storage (30 days or longer) will require a special coating heavily applied. The outside surfaces also should have a rust preventive applied. Waterlines should be sprayed with a rust preventive for short-term storage, and filled with a soluble foam for long-term storage.

Molds in Production

While molds are being run in production, they are exposed to many situations in which the potential for damage is high. To begin with, when a mold is placed and located in the molding machine, it may come apart prematurely and fall from the machine if connecting straps are not used to keep the two mold halves together during handling. Also, during this initial installation, items such as waterline connections, special electrical connectors, slide actuators, and other external components are subject to damage from accidental impact with other items, such as the press frame and platens. The locating ring can be nicked or peened if not correctly aligned and may not properly fit the mating platen hole of the machine. Burrs and nicks should be removed and the surface polished for a smooth finish.

When the clamping mechanism is brought forward for adjusting to the newly installed mold, it should be done slowly and with enough pressure to slightly close the mold. Over-clamping is a common cause of mold damage, especially to fragile items such as small ejector pins and cores.

When the mold is ready for clamps, they should be installed "toed-in." This means the toe clamp should have its heel adjusted to point the toe slightly (.125 in. [3.2 mm] is fine) toward the platen as shown in Figure 7-2. This must be done because it is impossible to maintain exact parallelism of the clamp to the platen as is desired for maximum clamping force. When clamps are adjusted to be perfectly parallel, expansion and contraction of the mold and machine result in the clamps slipping loose. If the clamps are adjusted so the toe is pointing away from the platen, the clamping force is also pointing away from the platen and the mold may fall out due to insufficient clamp force. Therefore, the toe should be adjusted to point in toward the platen to ensure that the clamping forces are directed toward the platen. Then, they should be tightened to the torque recommended for the specific bolt size being used.

Mold Inspection and Installation

The actual steps used for properly mounting a mold and starting it up for production are critical. The following is a typical procedure to ensure proper mold installation and protection.

A machine must be selected that is properly sized for the specific mold being installed. After the machine is selected, it must be inspected to determine its status. This inspection includes items such as:

- Proper hydraulic oil level.
- Heater bands are in place and operating.
- Mold temperature controllers are operable.
- Injection cylinder is empty and screw is forward.
- Hopper shutoff is closed and hopper is wiped clean.
- Proper material is available and dried.
- Granulator is clean and available.
- Safety gates and mechanisms are operating and in good condition.
- Vent hood(s) are clean and operating.
- Heat exchanger is clean and operating.
- Machine is lubricated, or auto-lubrication is working and filled.
- Alarms and lights are operable.

After the machine inspection is completed, the mold can be installed. The following steps should be taken, but they are generic in nature and do not preclude

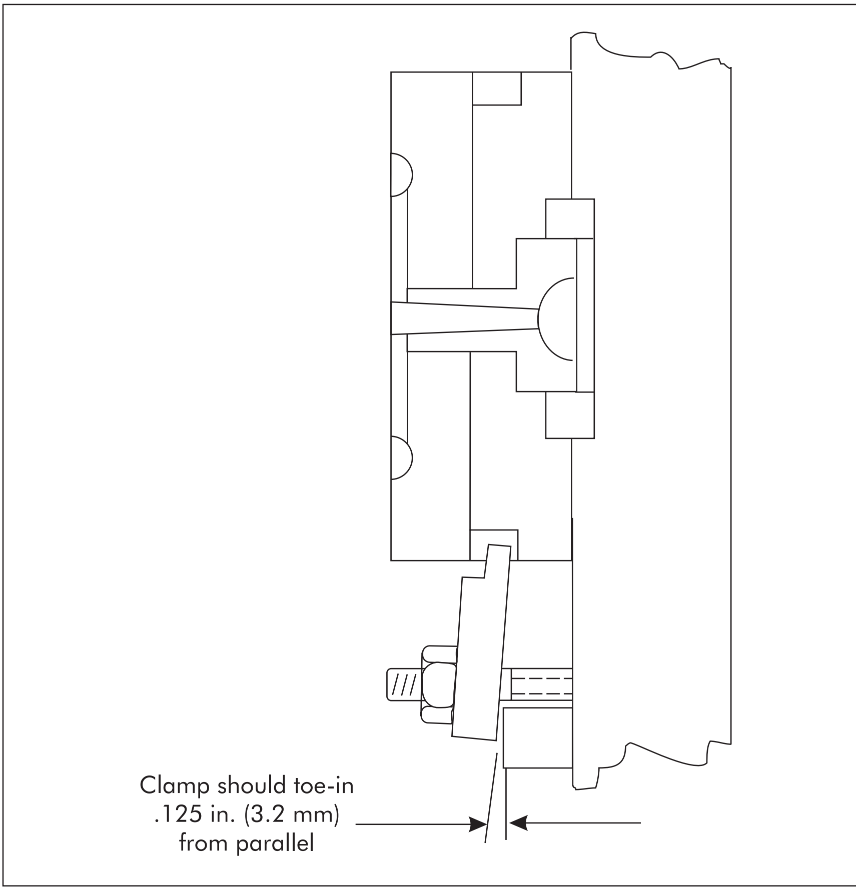


Figure 7-2. Toe-in of clamps.

the machine manufacturer's instructions. Always follow the manufacturer's instructions first and foremost.

1. Make sure that the mold has a connecting strap installed. This strap should connect the two halves of the mold and keep them from coming apart during transportation. Normally, this is a metal strap mounted across the A and B plate parting line. It is not a safe or proper practice to install the mold as two separated halves.
2. Start the machine, make sure the injection sled is in the full back position, and set the barrel heaters to the proper temperatures. The profile should run from a cool rear setting to a progressively hotter front zone and nozzle as outlined on the setup sheet. Turn on the feed throat cooling water.

3. Open the clamp wide enough to accept the mold. This is normally a dimension that equals a minimum of twice the height of the mold. This may require resetting the mold-open limit switches or control settings. Refer to the machine manual for instructions.
4. Lower the mold from the top of the machine (or slide it in from the side) using a chain fall (possibly combined with a fork lift), and manually bring the mold up against the stationary platen. The mold should rest against the platen without assistance. This is accomplished by adjusting the location of the chain fall toward the platen. For all but the largest molds, it is a good idea to have a thick metal plate placed across the lower tie bars at this point. The plate will act as a safety catch in case the chain fall breaks or the connecting hook opens.
5. At this point, the mold must be raised and lowered slightly in an attempt to position it so that the locating ring on the mold will slip into the locating hole on the platen. The chain fall should be connected such that the mold tilts slightly at the top.
6. The tilted mold should be placed slightly above the locating hole of the stationary platen, and held against it as the mold is slowly lowered. The locating ring of the mold will automatically slip into the locating hole of the platen as the mold is gently lowered. A level can be placed across the top of the mold to assist in aligning the mold so it fits squarely on the platen. After leveling, the A half of the mold is ready to clamp in place.
7. Position clamps, adjust, and bolt the A half of the mold to the stationary platen. The mold should be mounted with at least one clamp in each of the four corners. If the mold is very wide or large, additional clamps should be placed along the long dimension. If the mold is very small, it may be possible to use only two clamps per mold half, although this is not recommended. Smaller, specially built clamps may have to be utilized to use four clamps per mold half.

   The best procedure is to adjust the heel of the clamp away from the platen. This results in the clamping force being directed toward the platen through the toe of the clamp. The angle of direction should be minimal and can be such that the clamp heel is only .125–.25 in. (3.2–6.4 mm) away from parallel. The clamp is slotted for linear adjustment. This allows the clamping bolt to be located as close as possible to the mold and aids it in creating maximum clamping pressure on the mold itself.
8. If ejector rods are required, place them in the mold now. Then, slowly bring the clamp unit forward, under low pressure, to prepare for clamping the B half of the mold. This may require adjusting limit switches or settings. Check the machine manual for this information. Bring the moving platen up to within .25–.50 in. (6.4–12.7 mm) of the mold base and set limits for the “high pressure close” to activate at that point. Now, continue moving the clamp unit forward until it touches the mold base.

Allow the press to build up clamp pressure to the desired setting. This ensures that the mold is fully closed.

9. Shut off the machine. Locate clamps, adjust, and bolt the B half of the mold to the moving platen, making sure to follow the procedure mentioned earlier.
10. Remove the chain fall hook, eyebolt, and connecting strap from the mold. To avoid losing the connecting strap, it may be desirable to keep it mounted, but swung out of the way and tightened down so it will not come loose and cause mold damage.
11. Recheck all clamps on both halves to make sure they are all tight. Start the machine and *slowly* jog the clamp unit open under low pressure, watching for any indication of the mold halves seizing or binding together. Open the mold approximately .5 in. (12.7 mm) and stop. Shut off the machine and fully check the mold to make sure it is properly mounted and all clamps are still tight.
12. Start the machine and continue to open the mold slowly until the B half disengages fully from the A half. Then, stop the mold at the point described for fully open. Normally, this is a minimum of approximately two times the part depth, to ensure that the part will freely fall after ejection. It is acceptable to open the mold farther than this general reference, but it should not open farther than necessary because of the additional time required to do so. If there are slides or other actions in the mold, make sure they are still properly engaged upon full opening if at all possible. This will minimize the potential for breakage. Check for broken springs or other obvious damage.
13. After making sure all actions are in their proper location, adjust settings for proper ejection. Ejection should *not* be made to pulsate. One stroke should be adequate for part removal. If this is not enough, there is something wrong and it should be corrected before continuing production. The amount of ejection stroke should not exceed two and a half times the depth of the part in the B half of the mold (assuming ejection is located on the B half). The ejection stroke should be kept to a minimum—only what is required to get the part of the plastic that is molded in the B half freely out of the mold. More than that only adds to the overall cycle time.
14. Lubricate all moving components such as ejector guides, leader pins, and slides. Wipe off all excess. Gently clean the cavity surfaces. Close the mold under low pressure and turn off the machine.
15. Attach the hose lines from the mold temperature control unit. Blow air through the cooling lines of the mold to make sure they are not obstructed and to observe the proper path for connecting hoses. Do not loop the A half and B half together on a single line, but attach separate "in" and "out" lines for each half, and use separate control units for each half. Make sure there are no kinks in the hoses and that they will not be crushed or stretched when the mold closes or opens. After inspecting for proper attachment,

activate the temperature control units and adjust for the proper temperature setting. Check for leaks and tighten or repair as necessary.

16. Recheck all clamps.
17. Check to determine if the barrel is up to heat. It normally takes from 45 minutes to 1 hour for the barrel to properly come to evenly distributed preset temperatures. Make sure all heater bands are operable and properly connected.
18. Ensure that the hopper feed gate is closed and the hopper magnet is in position. Place fresh, dry material in the hopper. A purging compound may be required first, depending on what material was in the barrel last.
19. After the barrel attains the preset temperature that is maintained for 10 to 15 minutes, open the feed gate on the hopper and allow material to drop through the feed throat and into the cylinder Note that the screw should be in the forward position at this point.
20. Purge the machine as follows.

    A. The injection screw should have been left in the forward position of the barrel when the last job was shut down. It should stay in that position while preparing material for air shots. Activate the screw rotation until fresh material is brought to the front of the barrel. This will be obvious because the screw will spin freely to begin with but slow down considerably as the fresh material is brought forward.
    B. Set the screw return limits to the desired point and allow the screw to return to that point. The screw rotation will stop after the screw returns to the set point. Allow the material that was brought forward enough time to absorb heat from the cylinder. A minute or two is normal.
    C. With the sled still in the back position, take three air shots. An *air shot* consists of injecting a full shot of material into the air, under molding pressure, and allowing it to accumulate on a special plate designed to catch purgings. Make sure that proper time is allowed between these air shots to allow the upcoming material to come to proper heat. This time usually amounts to the total cycle time of the job that will be running in production. Using a fast-acting pyrometer with a probe, measure the melt temperature of the material injected during the air shots. This temperature must be controlled for proper molding. Adjust settings as necessary. If a different material or color is being used, 15 or 20 air shots may be required to clear the old material.

21. Set all the injection and cycle limits. These include injection forward speed and pressure, holding pressure, cushion distance, cooling time, mold open and close settings, and others as required.
22. Prepare a full charge of material for the first shot. Bring the injection sled forward until the nozzle seats against the sprue bushing of the closed mold The mold must be closed to absorb the force of the injection sled against

the sprue bushing. If the mold is open at this point, the A half may be pushed off the platen. Lock the sled control in place.

23. Open the mold and bring the clamp unit to a full open position.
24. Set the cycle indicator to "Manual," "Semi-automatic," or "Automatic" depending on requirements.
25. Close the safety gate to initiate the first cycle.
26. Observe the injection process. First, the pressures and feeds should be set for a short shot. Then, pressure and feed settings can be adjusted until a properly molded part is produced. This should be done over a long period of time (15–20 shots) and not hurried.

During production, a mold must be monitored (even if it is running on automatic cycle) to make sure ejected parts do not stick to the mold, and that all actions are operating properly. Periodic cleaning and lubrication should be performed as often as two or three times a shift depending on the type of molding material and the complexity of the mold design. Cleaning should be performed gently, with a cleaner designed specifically for molds. If agitation is required, such as in vent areas, a light-colored, nylon scrubbing pad should be utilized. The light color designates a mild abrasive action and an aggressive abrasive action is indicated by the darker colors. Scouring powders and steel scouring pads should never be used because they will damage the mold surface.

Mold releases should be discouraged, but if they are absolutely necessary, use them sparingly. It is common to think that if a little is good, more is better, but that is definitely not the case concerning mold release. If mold releases must be used, an investigation should be performed to determine why, and the cause should be corrected when possible. Mold release acts to "gum up" the works, especially the slides, cams, and lifters. This can result in a great deal of damage occurring to the mold.

If the mold must run for a long period of time (such as 30 days or so), it should be stopped periodically and cleaned, lubricated, and inspected. Waterlines should be disconnected, acid-flushed, and tested to make sure they are clean and operating properly. Parting lines should be inspected for peening. The sprue bushing should be checked for nicks and burrs, as should the entire mold.

After the production run is completed, the mold should be shut down. This includes saving at least the last shot to come off the mold. This is done for inspection purposes later and helps the mold repair personnel to determine what, if anything, must be done to prepare the mold for the next run. This last shot should consist of the entire tree, including the runner and sprue, with parts still attached, if possible.

Next, the mold should be thoroughly cleaned and sprayed with a rust preventive, including the waterlines. It is a good idea to send the mold to the tool room for inspection, final cleaning, and final rust spray before placing it in storage.

Storing Molds

Between production runs, molds are usually taken from the molding machine and placed in some type of storage. The storage area normally consists of a series of heavy-duty metal racks that the molds are placed on and tagged for identification. Usually, the mold has specific identification stamped on at least two adjacent sides for easy visibility, and the rack has an identification tag mounted on each station that corresponds to the mold identification. This helps keep everything in order and ready for subsequent use.

The type of protection that is required for these molds while being stored depends on the length of time in storage. A lighter coating can be applied for short-term storage. Long-term storage requires a heavy-duty procedure that results in a heavy coat of protective material on the mold. This latter coating is difficult to remove.

Short-term Storage

Short-term storage can be considered storage for only a day or up to 30 days. For this type of storage, the mold must be cleaned thoroughly and then sprayed with a neutralizer to remove any acids present from fingerprints or other acid-producing items. Then, a coating of rust preventive should be applied, with a light coat being adequate for a few days in storage and a medium coat for up to 30 days. Waterlines should be acid-flushed, blown dry with compressed air, and then sprayed with a rust preventive. The outside of the mold should be wiped clean and sprayed lightly with a rust preventive or light oil. The inside of the sprue bushing should be sprayed with a light oil too.

It may be necessary to disassemble the mold and clean all the ejector pins, return pins, cavity surfaces, runner blocks, etc., especially if corrosive plastics are used in the mold. The mold components should be inspected for damage, cleaned, and lubricated for storage.

Long-term Storage

Long-term storage can be defined as being over 30 days in time. If it is unsure how long a mold will be in storage, assume it will be for longer than 30 days. This method will ensure that the mold will be protected, regardless of the time span.

For long-term storage, the mold definitely should be disassembled and inspected. Damage should be repaired. The mold components and base should be thoroughly cleaned, then neutralized, reassembled, and coated inside and out with a heavy coating of rust preventive. It should be assumed that all the steps mentioned in short-term storage also apply here. However, the waterlines should be filled with a protective foam that is available from mold base supply houses. The foam rust preventive material is longer lasting than general rust preventive material and prevents the mold from rusting from the inside.

Some companies insist that all long-term molds be sealed in plastic wrap before being placed on the storage rack. However, this may result in trapped condensation, and wrapping should be used only if it is not possible for condensation to form inside it. Normally, it is better to have dry air circulating around the molds to help prevent rust from moisture.

MACHINE MAINTENANCE

Machine maintenance can be performed either by utilizing internal personnel or by contracting outside firms. If the molding facility is located in or near a large city, it can be more cost effective to use outside services. Smaller cities tend not to have such services available. Do not make the assumption that tool rooms have the equipment and expertise available to handle machine maintenance as well as tooling maintenance. They are two distinctly different arenas and must be separated as much as possible.

The requirements for machine maintenance are based on the needs for maintaining electrical, hydraulic, and mechanical mechanisms. Newer equipment requires knowledge of computer operation and/or programming. A good source of information concerning what type of maintenance is required for each machine is the manufacturer. In addition to stating what must be done to install and maintain equipment, a manufacturer can provide a useful list of spare parts available for each machine.

An in-house machine maintenance department will need to employ an industrial electrician, an industrial machinist (or two), and enough support personnel to assist them (usually two or three). The department will be responsible for maintaining and repairing all equipment and machinery associated with the molding facility, including primary and secondary equipment, as well as auxiliary and material handling equipment. This responsibility includes preventive maintenance programs and activities.

The type of equipment required to support this department includes chain hoists and overhead cranes, large lift trucks (can be shared with mold maintenance), electrical testing equipment, horizontal milling machines, surface grinders, gas welder with cutting tips, arc welder, lathe, band saw, straightening press, and drill press. Woodworking equipment and supplies are also needed for those instances when parts or equipment must be crated to be shipped to an outside source. Storage is required for hydraulic oil drums, spare machine parts, and disposable tools and cutters. In addition, large (and small) tapping sets and equipment are required, as well as magnetic drill presses (for platens), sand blasting equipment, crow bars, heavy hammers, and large torque wrenches. Personnel are usually expected to supply their own hand tools.

Due to the large amount of space required to work on machine parts, screws and barrels, and auxiliary equipment, the machine maintenance department may need as much as 5,000–7,000 ft^2 (465–650 m^2), depending on the size of the molding machines in the molding facility.

SUMMARY

Every injection molding operation should incorporate a tool room. This can range from a department capable of performing only minor repairs, such as replacing broken ejector pins, to performing major repairs, such as welding and refitting parting lines.

The selection of a tool room type should be based on many factors, including the availability of local talent and expertise, the amount of funding available, the degree of control desired, and the number and size of molds involved.

Few shops can afford the luxury of maintaining their own moldmaking department. To have the ability to design and build molds requires different levels of expertise, with true moldmakers topping the list.

Any given mold will require a certain amount of repair for damage occurring during its use or storage. The more it is used, or the longer it is stored, the more damage will occur. Improper care is the major cause of damage to a mold. Mold damage repair can vary, depending on the degree and type of damage.

Molds are expensive tools and should be treated with the utmost care and protected during the production process as well as during storage between runs.

Even the process of installing a mold in the molding machine for production can result in damage if it is not performed properly.

Short-term storage requires the use of a light-duty rust preventive, but long-term storage (over 30 days) requires the use of heavy-duty rust preventive not only on the mold, but also in the waterlines.

Machine maintenance can be performed either by utilizing internal personnel or by contracting with outside firms. If the molding facility is located in or near a large city, it can be more cost effective to use outside services. Smaller cities tend not to have such services available.

Do not make the assumption that tool rooms have the equipment and expertise available to handle machine maintenance as well as tooling maintenance. They have two distinctly different functions and must be separated as much as possible.

QUESTIONS

1. Which type of molding facility should incorporate a tool room?
2. What factors should be considered when choosing which type of tool room to incorporate?
3. Why should the last shot be saved from each run?
4. What is the result of failing to lubricate the moving components of a mold?
5. Why should the clamp toe be adjusted to point toward the platen?
6. Why is a connecting strap used on a mold?
7. How many mold clamps should be used for mounting each mold half?
8. In what position should the injection screw be left when a job is shut down?
9. How can one tell when a screw begins bringing fresh material into an empty barrel?

10. Define *short-term storage*.
11. Define *long-term storage*.

Plant Layout 8

An efficient plant layout ensures the most effective use of available plant space, and allows expansion for future growth. Many common layouts may meet these criteria. However, custom designs may be more practical. A prospective molder should visit as many molding facilities as possible and meet directly with the owners to gather information concerning the advantages and disadvantages of various layouts. Usually, they are willing to give advice if they do not perceive a threat of direct competition. In fact, they may be a source of income if they can redirect work that is outside their niche. The following section will look at some of the more common plans and develop an understanding of what is needed for an effective layout.

LAYOUT OBJECTIVES

When determining a plant layout, a prospective molder should decide what must be accomplished. To begin with, automation should be considered as much as possible. However, the use of automated equipment and robot stations usually requires more floor space than if human labor is used. Nevertheless, if automation is considered early in the process, although the plan starts with a labor-intensive situation, the facility will be prepared to accept most levels of automation without extensive rework of the existing layout.

In addition, future expansion must be considered. Normally a 5-year plan should be incorporated in the initial layout. Expansion beyond that period is too difficult to estimate because of the technical advances in equipment, materials, and processes that are to be expected over that length of time. If the layout is properly prepared, it will be flexible enough to accommodate necessary changes as they occur.

There are four objectives to keep in mind when preparing a plant layout.

1. Effective use of floor space.
2. Optimization of material flow.
3. Improvement of labor efficiency.
4. Readiness for expansion.

Effective Use of Floor Space

To use floor space effectively, a building plan must address the machinery layout and whether or not manufacturing cells will be used.

Building Plan

A molding facility consists of different departments and areas, as shown in Figure 8-1. Some are directly involved with the manufacturing of product and others are utilized as support groups. The manufacturing areas should be kept clear of congestion and nonmanufacturing activities because they can cause slowdowns

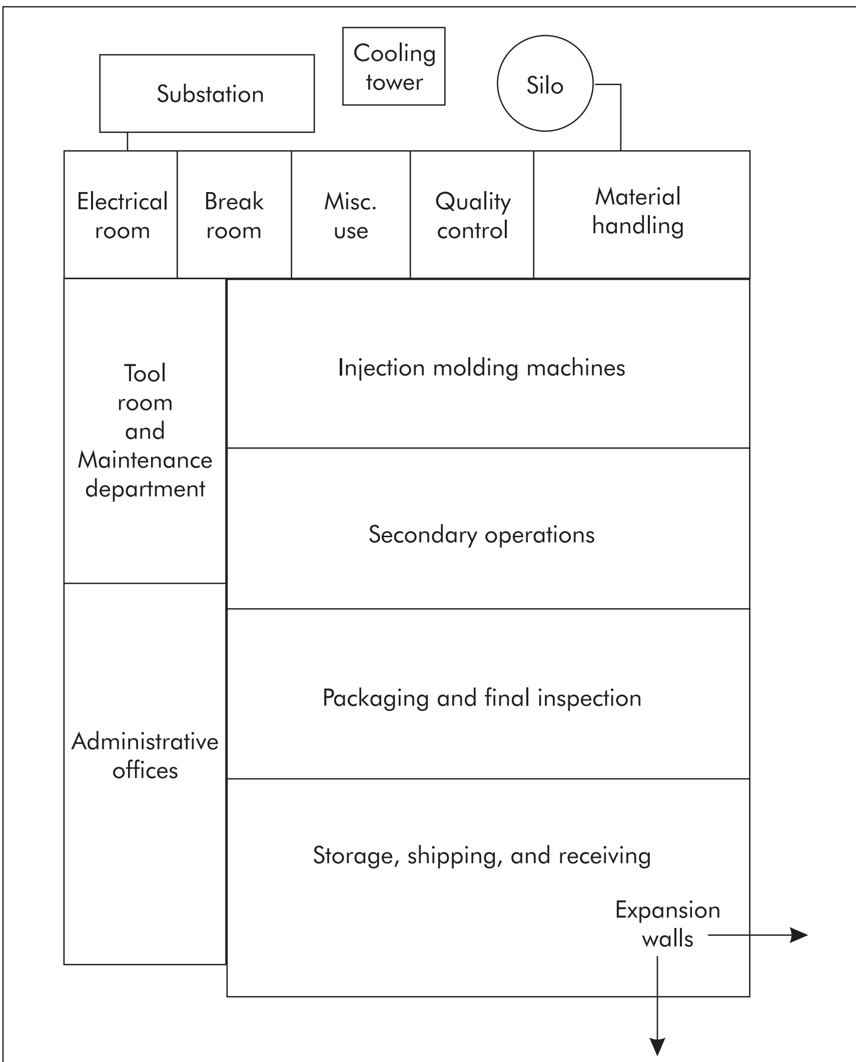


Figure 8-1. Basic plant layout.

and interfere with productivity. The lower the productivity, the less cost-effective the manufacturing operation.

In Figure 8-1, the building is designed such that the support departments are outlining the manufacturing area. The design allows for expansion in two directions and the flow of material and operations follow a one-direction path.

Machinery Layout

The foundation of any molding company is the primary equipment: the molding machines. After the decision has been made as to the sizes of molding machines required, the "footprint" of each machine (exact length and width dimensions) can be obtained from the manufacturer or seller. Then, the machine footprint patterns can be laid out to create a basic floor plan. There are three such floor plan concepts: angled, parallel, and side-by-side.

Angled machinery layout. This concept is considered the least effective layout because it encourages congestion and a confusing flow of materials. However, it should be considered when the width of the facility is limited, for example, when expanding an existing operation, or adding a molding facility to an existing plant. Figure 8-2 shows an example of angled machinery layout. The disadvantages of an angled layout far outweigh the advantages, but it may be required under certain circumstances and should be considered when necessary. Be aware that, for a given number of machines, the angled layout takes up 20% more floor space than any other layout design.

Parallel machinery layout. Figure 8-3 shows the common problems with parallel machinery layouts. The aisles tend to be congested and they must allow for two-way travel of raw materials and finished goods. This layout tends to set

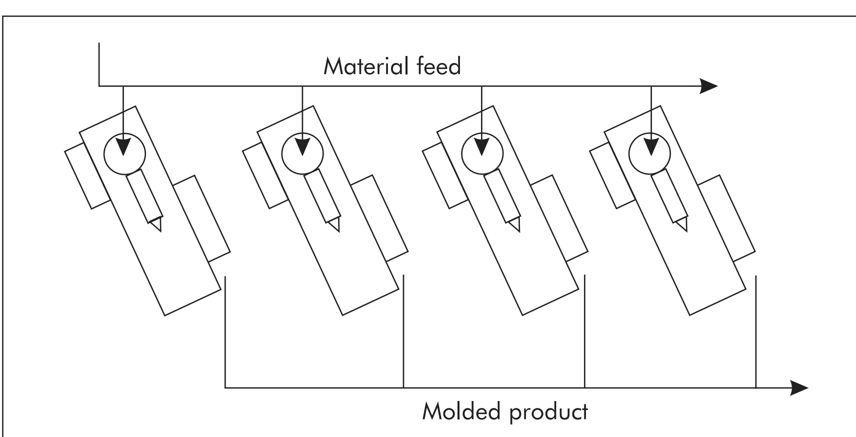


Figure 8-2. Angled machinery layout.

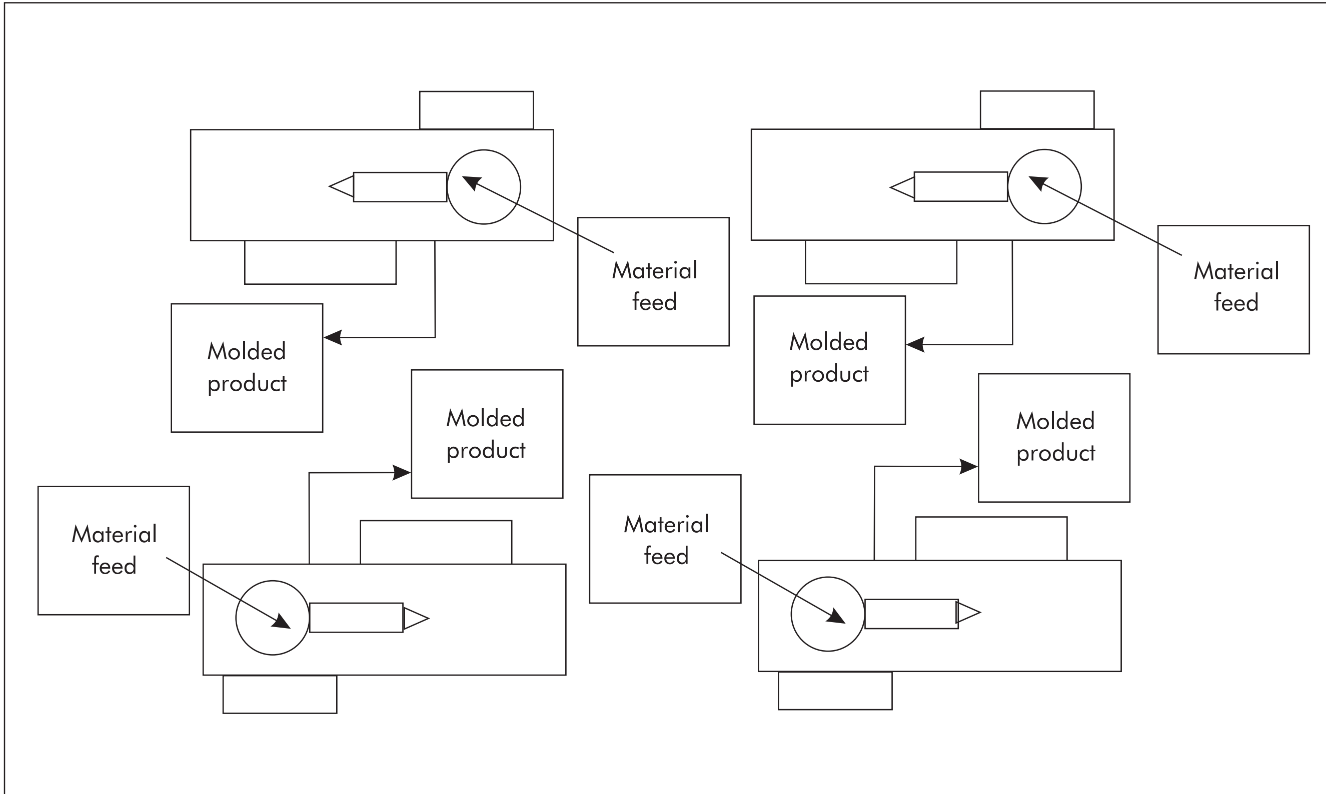


Figure 8-3. Parallel machinery layout.

machines far apart, which makes it almost impossible for one operator (or packer) to tend two machines. However, if large machines and large molds are being used, the greater distance between machines does provide for ease of mold setup. Normally, the larger molded parts require longer molding cycles, which may allow enough time for a single operator (or packer) to tend two machines. With this layout, the use of pallets directly at the machine is possible. However, for most molding applications, the parallel layout concept is not an efficient use of floor space and will create more confusion and congestion than is desirable.

Side-by-side machinery layout. By far, the most common and efficient layout for high volume, high quality, and lack of congestion, is the side-by-side concept shown in Figure 8-4. Using this method takes advantage of the capabilities of the molding and material handling equipment for both raw and finished goods. If a central feed system were utilized, the raw material storage areas would be free for additional space. The side-by-side layout has the most efficient floor space use of any of the three common layouts, and allows single purpose aisles, practically eliminating congestion. In addition, one operator (packer) can service more than one machine when required.

In Figure 8-4, the finished parts are directed toward the center aisle and the raw material is at the screw end of the machine. This is the most practical setup, but the machines could be reversed. In that case, the raw material would be located in the center aisle and the finished products would be directed into end aisles as shown in Figure 8-5. While this does take up approximately 5-10% more floor space, it is useful when many machines are dedicated to a single product line. If central feed systems were utilized, the raw material storage in the center aisle would not be needed.

Manufacturing Cells

For high-volume production requiring special operations (such as decorating or assembly), or very specialized product lines, it may be advisable to utilize the machine cell concept. In this system, everything needed for the total production of a finished product is located around the molding machine, as shown in Figure 8-6. The manufacturing cell contains the molding machine, secondary operation equipment, packaging materials, an inspection area, and a final packaging section. The entire area can be considered an individual cost center to ensure that all manufacturing costs (and subsequent profits and expenses) can be easily traced and recorded. Even raw materials can be stored in the cell if desired.

The major disadvantage to the use of manufacturing cells is the amount of floor space they require. Typically, there is an additional 25–40% space requirement for a cell format compared to performing identical activities in a standard layout format. However, special programs and/or customers may demand such requirements.

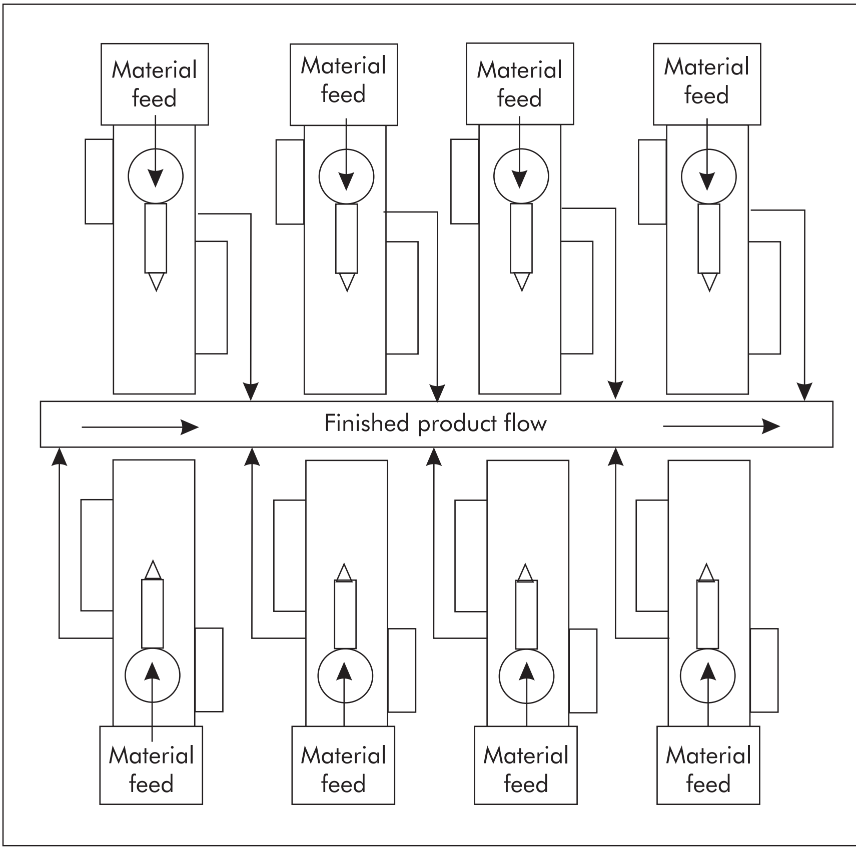


Figure 8-4. Side-by-side machinery layout.

Clean Rooms

Clean rooms are areas that are specially constructed to minimize molded product contamination from environmental particles. Medical products are the most common items molded in such areas, but other product applications may require clean room environments for many reasons.

In a clean room, the molding machine area is kept clean by a sophisticated combination of filters and maintenance procedures. Oil leaks and lubrication residues are eliminated (or at least kept to an acceptable minimum) and dust and dirt are not allowed to accumulate. Attendant personnel must wear specially designed, disposable clothing, and even the ambient air is kept at a predescribed level of cleanliness, temperature, and humidity.

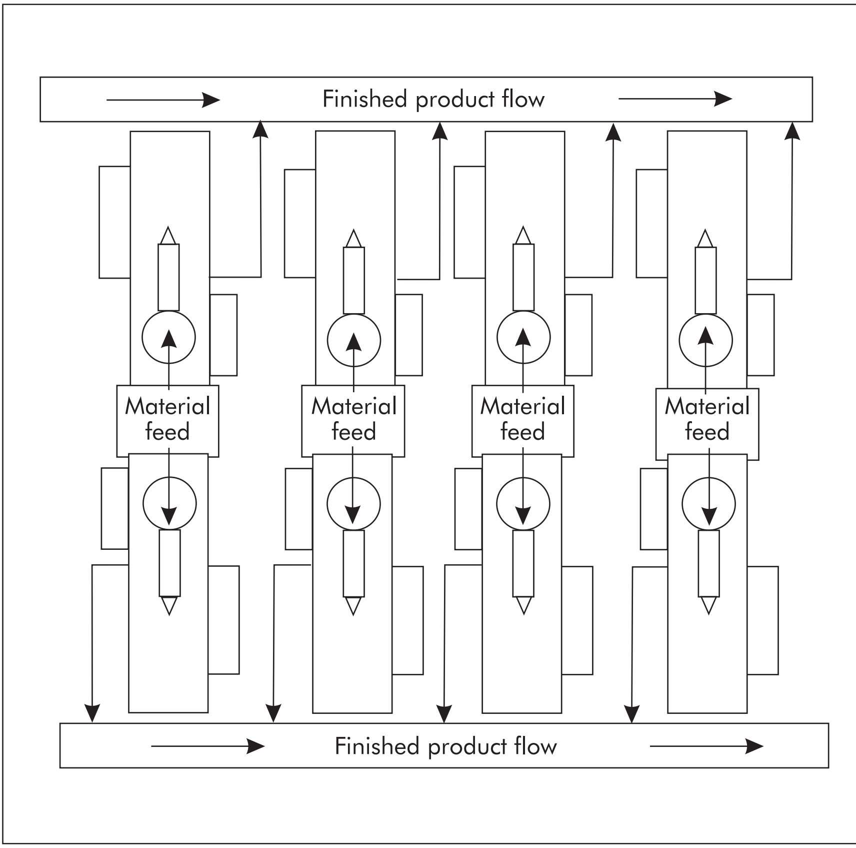


Figure 8-5. Reversed side-by-side machinery layout.

Clean rooms are rated by a class numbering system and include Class 100 (the most stringent), Class 1,000, Class 10,000, and Class 100,000 (the least stringent). The most common clean room environment is a Class 10,000, which is suitable for most medical and electronic component molding. A Class 10,000 room requires the molding machine to be enclosed and the material handling and auxiliary equipment to be located outside the molding area. A molder can achieve a Class 100,000 room by draping the molding machine in a plastic cover and ensuring no dust, dirt, or other contaminants get to the molded product or raw materials while in the room. There are other requirements, such as painted and sealed floors and walls. Most molders can easily achieve a Class 100,000 clean room condition.

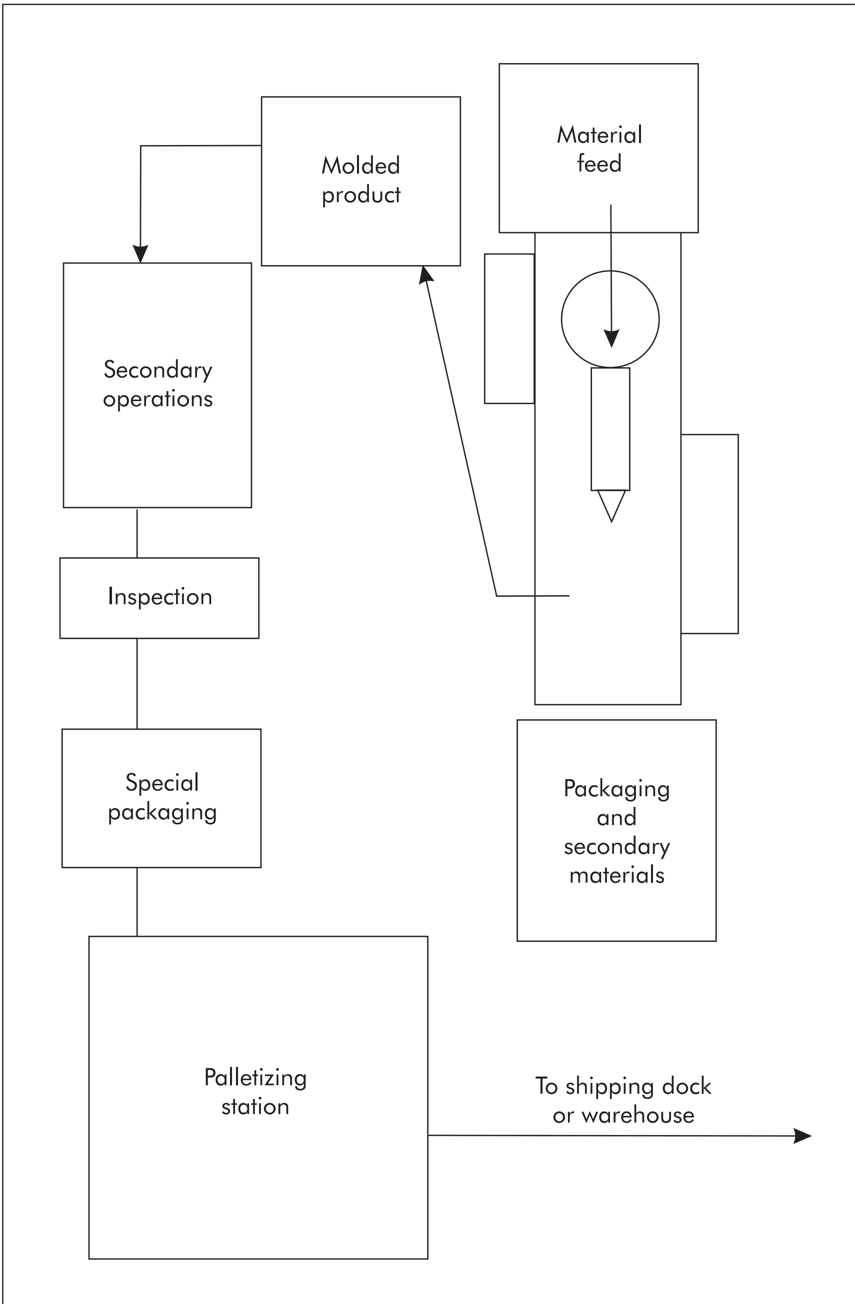


Figure 8-6. Manufacturing cell.

As with other special layout formats, the clean room will occupy much more space than the standard layout format. An additional 40–50% floor space must be allocated when considering clean room environments.

Optimization of Material Flow

For the greatest degree of efficiency and the highest level of productivity, the flow of materials through a molding facility should be as close to straight-line as possible. This is easily accomplished with a side-by-side machine layout, but is more difficult with any other format. The raw materials should enter one end of the building and travel through the required processes and exit as a finished product at the other end of the building. This is shown in Figure 8-7.

The raw material is fed from an external silo to the material handling area where it is blended, colored, and dried, as necessary. From there, it is fed to the hopper of the injection molding machine where it is converted to a melt and formed into a molded product. It is then removed from the mold, placed in a suitable container, and transferred to secondary operations. There it is processed, final inspected, and packaged. Then, it is moved into the final storage area where it is prepared for shipping.

To aid in optimizing material flow, injection machines of similar size should be located together, and all machines should be placed such that the maintenance and service aisle is at the injection end of the machine. This will minimize interference with material and product handling equipment and activities.

There should be approximately 4–6 ft (1–2 m) of clearance between each machine, as measured to the machine's extreme projections. This will provide a minimum degree of access for maintenance and setup activities, and allow for placement of product handling equipment. In the interest of conserving floor space, this dimension should be kept to a minimum, but it should not go below 4 ft (1 m).

Pallets and palletizing equipment should be kept out of the production area to minimize congestion, however, packaging materials should be kept near the product flow aisles to minimize the amount of movement necessary for packaging and inspection personnel.

Improving Labor Efficiency

It is best to automate as many operations as possible, especially the injection machine operation. Consistent cycles are critical to producing consistent products, and human beings are not capable of maintaining the same level of consistency as an automated machine. The technology exists for a molding facility to be considered a "lights out" operation starting with raw material handling and going all the way through secondary operations and final packaging for shipment. Such automation should be considered when molding high volumes of parts requiring the same operations, and that run for long periods (months) of time. The investment made in the beginning for equipment and implementation will quickly be paid back.

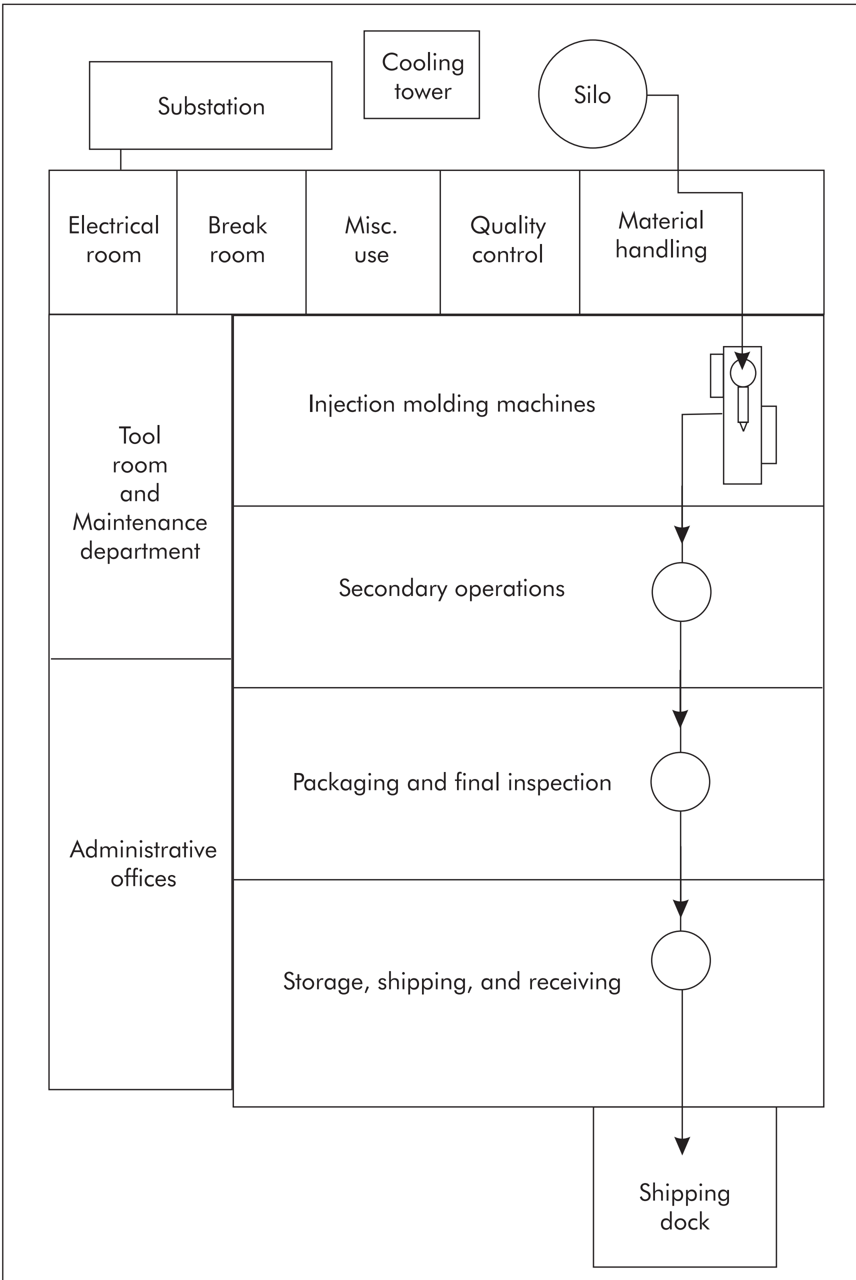


Figure 8-7. Ideal material flow.

For shorter runs, or for facilities requiring more flexibility in operations, manual labor may be required. However, even in these cases, the molds can be designed to run in an automatic mode, eliminating the need for an operator to stand by waiting for a cycle to complete. Even if an operator is needed to perform inspection and/or packaging activities, the consistency of an automated molding cycle can greatly improve the quality and profit potential of a molded part.

If secondary operations are required, it may be possible to have the machine operator (on semi-automatic machines) perform such secondary work at the molding machine while waiting between cycles of the molding operation. While this seems practical, it should only be attempted when there is plenty of time available and when the activity does not require the addition of cumbersome, space-robbing equipment or materials.

When molding in automatic modes, it is possible to have a single person perform inspection and packaging activities for an entire group of machines (two to six). The number of machines depends on the amount of work required for each and this can be easily calculated. In addition, this person may be used to relieve machine operators on manual jobs.

The molding operation should be operated continuously, 24 hours a day, 7 days a week, if possible. This is needed to obtain consistency, and to allow enough time to stabilize a molding machine and process after startup (up to 8 hours). It requires either automated molding cycles to eliminate the need for an operator, or many operators to relieve the primary operators for breaks and lunch periods, or a combination of both. In addition, due to training requirements, vacations, and other time-off activities, a bank of operators should be created to choose from in a nonautomated facility. This point should be considered in the development stage of a molding plant.

When utilizing labor, movement should be minimized as much as possible. Most movement should be considered a waste of time. For example, the farther a machine operator must walk to place a molded part in a box, the more time and cost is involved in producing it. Also, fatigue becomes a factor and (because of inefficiencies), the person becomes less productive.

Planning for Expansion

No company can continue to exist without some form of expansion. A stagnant company will soon find itself abandoned because customers want to deal with companies that are always trying to reduce costs, increase productivity, and improve technology. While some types of expansion can be accomplished through accumulating other existing businesses, the most common form of expansion is to "push out the walls" of the primary facility. For that reason, (as shown in Figure 8-1 earlier), any startup molding operation should have two adjacent walls that are considered permanent and the other two adjacent walls designed for easy removal and expansion. When administrative and other offices and rooms are built only around the permanent walls, there will be little disruption of production during the expansion phases, especially if utilities are initially installed in consideration of such expansion.

One valuable area for expansion sometimes overlooked is the building height. Because most molding facilities have high ceilings (for fast removal of fumes, use of mold installation equipment, placement of overhead lines, etc.), the sidewalls (and areas over offices) provide ideal space for many uses. This area is commonly called the mezzanine, which contains such items as material drying units, mold temperature controllers, small chillers, vacuum-loading systems, and other equipment and materials commonly used for molding. There is a danger of the mezzanine becoming nothing but a collection area for junk, but this should be greatly discouraged because of its prime space value. A mezzanine should be included in the design of the original plant layout, but can be added at any time if the cost needs to be deferred.

Expansion should be a part of the initial layout design. A 5-year plan should include an estimate of what types and sizes of additional equipment will be needed, and the layout should accommodate these. A typical example would be a molder starting up with two 100-ton (890-kN) machines, two 200-ton (1,779-kN) machines, and three 300-ton (2.7-MN) machines. If it were anticipated that four more 200-ton (1,779-kN) machines will be needed over the next 5 years, it would be advantageous to locate the *present* 200-ton (1,779-kN) machines near the area planned for expansion. This approach will allow, after expansion, all of the 200-ton (1,779-kN) machines to be located together. This is just part of the planning that must go into the original plant layout. If it is properly planned, the expansion will occur with minimal disruption of service and production and little hassle.

BUILDING SITE CRITERIA

After the decision has been made about how much floor space is needed, an estimate of loading dock space, additional warehousing space, employee parking area, and any other external real estate needs can be made. Expansion requirements should be included in this calculation. A rough estimate of the building size itself can be made by calculating an average requirement of 1,200 ft^2 (111.5 m^2) for every molding machine in place This average includes office space, break rooms, etc., and yields an approximation of the total building size required. Thus, a 12-machine shop would require a total of 14,400 ft^2 (1,338 m^2). If future requirements mean the addition of four machines, the total ft^2 (m^2) requirement would increase to 19,200 ft^2 (1,784 m^2). These are only estimates and are dependent upon machine sizes and types, as well as the amount of automation being planned (which will increase space requirements).

The type of building needed might vary with personal taste, but there are certain mandatory requirements. First, local restrictions and codes must be met. For those, local regulators and representatives should be contacted. Otherwise, the building should be constructed of quality materials that will withstand the weather and environmental conditions of the geographic area. Concrete block construction is the normal choice, but any material meeting specifications is acceptable. The floor must be reinforced to hold the weight of the molding machines. The machine manufacturer will supply you with weights and reinforcement recommendations, but concrete floors should be planned to be up to 3 ft (0.9 m) thick or more in some cases. For the production floor, it is necessary only to reinforce in the areas where machines will be located If, in the future, the machines are moved, additional reinforcement will need to be put in place in the new location.

For utilities, underfloor trenches, pits, and tunnels can be incorporated during the building stage. This keeps plumbing and wiring out of the way of production, but it does require deep pits that can be 4 ft (1 m) deep or more. If underfloor systems are not employed, then overhead systems will require higher ceiling heights to accommodate them.

In most cases, a ceiling height of 16 ft (4.9 m) is adequate, but large machines may cause this to increase to 20 ft (6 m) or more. High ceilings help to dissipate the fumes (and excess heat) found in any molding operation. While these fumes are not toxic (unless from thermally degraded materials), the odor can be obnoxious or offensive to some people and even somewhat alarming to those not knowledgeable of the molding process. High ceilings are a requirement for the use of overhead crane systems used for changing molds. High ceilings also allow the buildup of hopper blenders, loaders, and dryers on the injection end of the molding machine.

The main production area should be the focal point of the building. As mentioned earlier, two adjacent walls should be permanent and the other two adjacent walls should be designed for ease of expansion. Offices and other rooms can be built on the outside of the permanent walls, which allows for their alteration and improvement without interfering with production operations.

The building site should be graded to allow water runoff to be directed away from the building. Local and federal restrictions should be investigated concerning this runoff and the responsibility if contamination of any kind is involved in the future. Materials such as scrapped resin, used hydraulic oil, and cleaning fluids should never be allowed to leave the premises in any form unsuited to the environment. Usually, this requires an outside holding area where these items can be picked up by a reputable disposal company. This holding area should be fenced and kept under lock and key to prevent vandalism and potential lawsuits.

If the molding facility is large (or intended to grow large), it may be advisable to locate the facility in close proximity to a railroad spur. However, regardless of facility size, it should be placed as close as possible to main highways and intersections for ease of location by truck lines and delivery services. Too often, packages and deliveries are delayed due to poor directions, unusual addresses, or obscure locations. In addition, shipping and receiving docks should be designed for minimal congestion and easy access.

While few (if any) molding shops depend on walk-in business, the facility appearance should be of prime concern because most customers will wish to visit the plant for an assessment before placing business there. First appearances are important, so the outside of the building should be appealing, with a clearly identified entrance and parking for visitors. The reception area should be well lit, comfortable, and contain a showcase of sample parts to display the types of products and materials molded in the facility.

GEOGRAPHIC LOCATION CONSIDERATIONS

It is wise to consider various geographic locations for the facility, if the luxury of choice exists. With today's technology, it is not as important to locate near customers as it was in the past. If the facility is labor-intensive, the main item to consider is the cost of that labor, which varies dramatically across the country. A recent survey by *Injection Molding* magazine (August 1998) shows the average hourly rate for molding companies in the U.S. to be $9.90. The range is from a little over $6.00 per hour to more than $15.00 per hour, depending on where in the country the facility is located. Obviously, in a labor-intensive operation this becomes a major cost factor.

From an hourly wage standpoint, the Northeast and West (New Jersey and California) are the most expensive areas to do business, while the South Central and Southeastern states (Texas and South Carolina) are the least expensive. Of course, if the molding facility is highly automated, the hourly wage factor may not be a concern. This will improve the choices of location.

However, even with highly automated operations, there is a need for plastic expertise in the form of tooling engineers, moldmakers, process technicians, and materials personnel. This expertise tends to be located in pockets throughout the country, with the upper Midwest (Michigan, Indiana, Illinois, Ohio) and Northeast (New Jersey, Pennsylvania, Massachusetts) having the greatest numbers. The southern and central states have the fewest numbers. Many molders have located in inexpensive areas for manufacturing only to find that there are few, if any, qualified people. A thorough study of available talent should be made of any area before locating a plant.

Another factor to consider concerning geographic location is the cost of electricity. This is the most costly resource a molder uses and it can range from $.02 or $.03 per kilowatt hour (kWh) to $.15 or more, depending on the state and city in which the plant is located. State-averaged fees should not be used, because some cities within low-cost states have very high electrical fees. For example, in Texas, some cities offer $.03 per kWh and others offer $.12 per kWh, but the state average is $.04 per kWh.

Transportation costs make up another category to consider when looking at geographic location. Plastic materials usually have a freight charge that averages around $.05/lb ($.02/kg). If this average is used in determining the material costs, it will not matter much where the plant is located. However, molded plastic products demand a hefty freight charge for shipping because the finished package is mostly air. Freight companies charge dearly for this, and their fees tend to vary greatly from company to company. Therefore, a transporter of finished products should be chosen carefully and its charges should be monitored often. The transportation cost may justify the facility owning its own fleet of trucks. In that case, savings can be realized not only for product delivery, but also for the pick up of raw materials.

Open competition among many states entices plastic injection molders to locate in certain areas. This results in some very attractive financial incentives in the form of tax abatements, hiring and training services, and even land and building donations and partial payment of wages in trade for that decision. These offers should be investigated wisely, and be aware that they usually apply to economically depressed areas, which may not contain the level of expertise needed for a specific operation.

SUMMARY

A proper plant layout is needed to ensure the most effective use of space available, and allow ease of expansion to accommodate future growth. Many common layouts may meet these criteria. However, custom designs may be more practical.

When determining a plant layout, it should be decided what must be accomplished. To begin with, automation should be considered as much as possible.

The building should be designed such that the support departments are basically outlining the manufacturing area, and expansion is allowed in two adjacent directions. The flow of material and operations follow a one-direction path.

The machine footprint patterns can be laid out to create a basic floor plan. There are three such floor plan concepts: angled, parallel, and side-by-side.

For high-volume production requiring special operations (such as decorating or assembly), or very specialized product lines, it may be advisable to utilize the machine cell concept. In this system, everything needed for the total production of a finished product is located around the molding machine.

If secondary operations are required, it may be possible to have the machine operator (on semi-automatic machines) perform such secondary work at the molding machine while waiting between cycles of the molding operation.

A molding operation should be operated continuously, 24 hours a day, 7 days a week, if possible. This is needed to obtain consistency, and to allow enough time to stabilize a molding machine and process after startup (up to 8 hours).

A rough estimate of the building size can be made by calculating an average requirement of 1,200 ft^2 (111.5 m^2) for every molding machine in place. This average includes office space, break rooms, etc., and yields an approximation of the total building size required.

For utilities, underfloor trenches, pits, and tunnels can be incorporated during the building stage. This keeps plumbing and wiring out of the way of production, however, it requires deep pits, which can be 4 ft (1 m) deep or more. If underfloor systems are not employed, then overhead systems will require higher ceiling heights to accommodate utilities. In most cases, a ceiling height of 16 ft (4.9 m) is adequate, but large machines may cause this to increase to 20 ft (6 m) or more.

The main production area should be the focal point of the building. Two adjacent walls should be permanent and the other two adjacent walls should be designed for ease of expansion. Offices and other rooms can be built outside of the permanent walls, allowing for their alteration and improvement without interfering with production operations.

QUESTIONS

1. Why is proper plant layout so important?
2. What are the three most common machinery layouts?
3. What is included in a manufacturing cell?
4. What are the four primary class ratings of clean rooms and which are the least and most stringent?
5. What is the most common clean room rating and for which application is it commonly used?
6. What is the ideal flow pattern of materials in a molding facility and why?
7. Why is an automated process preferred over a manual process?
8. What is the most common form of expansion?
9. How can a rough estimate of building size be calculated?
10. What ceiling height should exist in a molding facility?
11. What is the average freight charge for raw plastic materials?

9 Determining Costs

There are many costs involved in the startup and operation of a molding facility, including initial capital requirements, processing costs, raw materials, and many others, some obvious and some hidden. This chapter will investigate these costs and demonstrate methods of calculating and estimating their values.

CAPITAL REQUIREMENTS

The single most common cause of failure of any startup company or venture is insufficient capitalization. While the most prevalent reason is lack of operating capital for a specific period of time, often the reason is a lack of knowledge of what equipment or resources are essential for the successful operation of a facility.

Capital is required for many reasons, but its primary purpose is for the purchase of land, equipment, and supplies in sufficient quantities to start and maintain the facility until incoming revenue meets or exceeds the requirements. So how much capital is required? Because of the large investment needs for equipment, even a "small" molding company today can easily require investing $1 million or more for startup. Few people have the financial freedom to place a molding machine in a backyard garage and grow that facility into a money-making venture.

Most molding companies today are formed by a group of individuals who have pooled their resources with grants and/or loans from a government agency (the Small Business Administration [SBA]) or other lending programs through the private sector, such as venture capital organizations or banking institutions. Of course, any lending group will require a portion of the business even if only until the loan is paid back. The percentage of the business that must be relinquished depends upon the amount of money involved and usually ranges from around 30% to as much as 80%. While a small molder may be worth at least $1 million, the average molding company today requires an investment of $3–10 million, depending on what services are offered.

The so-called "full service" (or, single source) molding vendor will need greater amounts of capital investment than a simple molding facility. A *full service vendor* is one that takes complete responsibility for tool design, moldmaking, molding production, secondary operations, quality, and shipping of a finished product. Whether these activities are performed directly by the molder, or contracted to other companies is transparent to the customer—the molder still takes full responsibility.

There is a definite trend today for the customer to place orders only with molders willing to take full service responsibility. As a general reference, a brand new, full-service, startup company can figure on investing approximately $500,000 for each molding machine it has on site This will cover all primary, auxiliary, and secondary equipment costs, as well as a tool room repair facility and material handling equipment, building site, and building erection. For example, a new, eight-machine, full-service molder will probably require an investment (on average) of $4 million at startup.

Building and Land

For expansion of an existing company, the land is usually a smaller portion of the capital requirements than for a brand new startup company. An existing company needs to consider the cost of expansion only, while the startup company must consider the cost of purchasing a site, erecting a building, installing a substation area, performing environmental studies, etc. In most areas of the country it will take 6 to 12 months to satisfy regulatory requirements and obtain all necessary permits, licenses, and building plan approvals to begin a startup operation. After this has transpired, the building can start. Depending on the local weather conditions and the size of the building, it can take as little as a few months to 2 years or longer to complete. While the latter can seem an excessive amount of time, it can be put to good use for the ordering, delivery, and setup of primary, secondary, and auxiliary equipment. In today's economic environment, the machine manufacturers of these types of equipment are quoting lead times of from a few months to 1.5 years.

An alternative to expansion or startup is to purchase an existing molding facility in the general geographic area desired. This provides a ready source of equipment, already installed and operating, and a possible source of personnel. However, there are some pitfalls to buying an existing facility. An examination of the financial records may reveal "on-the-surface" information, but it is difficult to determine the real condition of equipment, morale and expertise level of employees, state of customer relationships, and underlying environmental risks. Purchasing an existing molder does offer the advantage of immediate production and obtaining equipment at a price that is often much below market value. Average sale prices of existing molding vendors are in the range of $2–12 million.

When determining land needs, room for future, long-term expansion should be included. With expansion comes a requirement for additional parking spaces, employee break and recreation areas, additional storage accommodations, training facilities, and improved visitor reception areas.

It is practical to consider an industrial park when looking at various real estate locations. Industrial parks often offer utility hookups, parking facilities, central business locations, and even rail spurs at attractive rental rates. Environmental studies have already been performed, wastewater and sewage arrangements are in place, and taxes are usually lower. Lease arrangements can be very attractive for new startups. In some cases, government assistance is more readily available to companies centralized in certain industrial park areas.

Primary and Auxiliary Equipment

When determining capital for equipment, it is important to consider cost, not just price. *Price* is what the equipment costs to purchase, but *cost* is that figure plus what it takes to maintain, operate, and service the equipment during its useful life span.

Because of federal legislation, industrial machinery manufacturers must provide energy-efficient equipment. This includes items such as air conditioning (AC), variable speed motors, and pumps. Some communities offer electrical service rebates to companies purchasing such equipment. The legislation helps reduce the operating costs of new equipment and older equipment can be retrof it with such devices. The investment to retrofit older equipment is worth the cost.

Purchasing new equipment is the most expensive route to take. Molding machines cost from $30,000 for a small, benchtop press, to $1 million for a large, 1,500-ton (13,344-kN) press. Larger machines are available (up to 9,000 tons [80,064 kN]) and their purchase price goes up accordingly. For budgetary purposes, a general reference is to calculate $1,000 for each ton of clamp force the machine delivers. For instance, a 300-ton (2,669-kN) machine would assume an investment requirement of $300,000. This figure includes the cost of the machine, plus the cost of auxiliary equipment.The auxiliary equipment consists of a hopper dryer, a two-zone mold temperature controller, a granulator, drums of hydraulic oil, and a set of clamps for mounting the mold. Shipping the equipment, installation and setup, and installing conduit, cable, water lines, etc., for operation of the equipment would be additional costs.

Purchasing used equipment can reduce investment capital while decreasing the amount of lead time. Generally, well-maintained secondhand equipment will cost approximately 30–60% of the cost of new equipment. Remanufactured equipment can be purchased for approximately 50–80% of the cost of new equipment. In the case of remanufactured equipment, lead times can be reduced to 12–20 weeks, while used equipment (without being remanufactured) can be delivered within a few days of purchase.

Of course, there are trade-offs when considering used equipment. The first concern is from a legal standpoint: is clear title available? The equipment may have a lien on it and the seller may not make that apparent. Ownership is not possible unless the lien is paid The second concern is the condition of the equipment. Maintenance records should be available. There may be hidden problems that do not show up during the initial assessment.A third concern is the availability of replacement and maintenance parts. The manufacturer does not keep a large supply of parts on hand for machines that are older than a specific date, usually only a few years after manufacture. These concerns tend to disappear when purchasing remanufactured equipment from a reliable source. The remanufacturer takes responsibility to obtain and transfer clear title. When reconditioning the equipment, new technology is used, replacing outdated controllers, pumps, etc., with commonly available components that are easy to find when replacement is required. However, because of the costs involved, most remanufacturers will not provide molding machines that are less than 300 tons (2,669 kN) of clamp force. If smaller machines are required, it is better to buy new, or find a reliable source for used equipment.

Secondary Equipment

The purchase of secondary equipment will be determined by what operations will be performed. A definition of *secondary operations* could be stated as . . . "any operation that must be performed, after molding, to produce a finished product." This would include, but not be limited to, assembly (including sonic welding), painting, machining, decorating (hot stamp, silk screening, or pad printing), metallizing, plating, and laser etching. In fact, even inspection, packaging, and shipping can be considered secondary operations. Each of these operations requires a specific piece of equipment and accompanying sets of tooling. While some secondary operations can be automated, most are performed with manual labor assistance. Automated equipment requires higher capital investment.

Secondary equipment prices can range from the inexpensive (such as a drill press or glue gun) to the very expensive (such as sonic welding machines or paint booths and sprayers). It is beyond the scope of this book to provide individual costs for all the various equipment and tooling, and the unlimited combinations of secondary operations available. The equipment suppliers would be happy to help determine these costs on a customer-specific basis. Generally, an average cost for secondary equipment is approximately $25,000 per station, including tooling.

If floor space permits, and there is enough spare time between cycles, many secondary operations can be performed by the molding machine operator during the molding process. This minimizes labor costs and eliminates the need for establishing staging areas to accommodate the molded parts prior to and after the secondary operation activity. However, it does not make economic sense to add an operator to a molding machine that normally runs automatically, simply to perform the secondary operation at the press.

Most companies find that it is more effective to perform secondary operations in a dedicated area, with separate supervision and labor. In many cases, that area will have a controlled environment to minimize defects caused by high humidity or heat conditions. Operations such as sonic welding, decorating, and adhesive or solvent bonding are negatively affected by high humidity. The use of separate facilities allows common packaging, inspection, and setup operations to be performed economically without interfering with the molding activities.

Depreciation

Depreciation must be considered in capital requirements because the numeric value of depreciation is added to manufacturing costs to determine eventual processing costs. And, the processing costs will be used to determine selling prices.

Tooling costs can only be depreciated by the owner of the tooling, so this is not a concern for most custom molders. If tooling is to be depreciated (as in the case of a proprietary molder), it should be amortized over a relatively short period, normally 2 to 3 years. For accounting purposes, it is believed that the tooling will be obsolete in that period for most cases either due to product design refinements or end-of-life of the product. Although the depreciation period is considered, the tooling should be paid off at the beginning of production, and not amortized in the product cost. Volumes can change drastically from year to year, which affects piece price. If tooling is amortized over these changing volumes, the piece price becomes unstable.

Although land cannot be depreciated (because it is assumed it will continue to maintain its value), the building can be depreciated over a normal period of around 20 years. All primary and material handling equipment can be depreciated over a normal period of 7 years, and all other equipment and auxiliaries can be depreciated over a 10 year period. These time periods are subject to constant change, so it is a good idea to consult with an accountant for final determinations.

Table IX-1 gives a rough idea of the total capital investment and annual depreciation values that will be incorporated in the final processing costs for an eight-machine facility.

If equipment is designed specifically for a particular product, and is intended only for that product, the equipment should be depreciated over the expected life period of the product, normally 3 to 5 years.

Depreciation periods are general life expectancies for each specific piece of equipment or tooling. Some equipment can have greatly extended life spans if properly maintained. There are molding machines in existence that are over 30 years old, still melting plastic and making parts economically. However, because of accounting and budgeting needs, and to keep up with the latest technology, it is advisable to replace equipment at the end of its depreciation period. Old equipment often can be used for trade-in value, or sold outright for whatever the market will bear.

TOOL ROOM AND MAINTENANCE DEPARTMENT

Enclosures

Because of the nature of the work being performed and the potential access to expensive equipment and tools, it is advisable to set up the tool room and maintenance department(s) in areas separate from the production facilities. Moreover,

Table IX-1. Capital and Annual Depreciation Costs

Item	Capital Cost	Years to Depreciate	Annual Depreciation Value
Molding machines (eight) total cost	2,500,000	7	357,143
Secondary equipment	250,000	7	35,714
Material handling equipment	200,000	7	28,571
Auxiliary equipment	150,000	10	15,000
Cooling towers, chillers, etc.	200,000	10	20,000
HVAC	300,000	10	30,000
Utilities distribution	125,000	10	12,500
Tool room and maintenance equipment	350,000	10	35,000
Engineering equipment	100,000	10	10,000
Training program equipment	75,000	10	7,500
Building	500,000	20	25,000
Totals	4,750,000		576,428

Note: If the building and/or equipment is leased, the annual lease payment should be used instead of the annual depreciation value.

with computer controls and sensitive equipment, such as electrical discharge machines (EDMs) and internal grinders, there is a need for a controlled environment. Usually, this demands different conditions than the controlled environment (if it exists) of the production floor area.

Within the tool room, grinding equipment should be further separated and contained to minimize grinding dust that can get into sensitive electronic controllers and the machined ways and spindles of standard tool room equipment. To help accomplish this, the grinding room should have a separate dust control system.

The maintenance room, or area, will require a tool crib to store disposable tools, spare parts inventory, and dangerous and/or flammable fluids and chemicals. This area must be locked and accessible only to authorized personnel. There should be an entry and exit log to help monitor access activities. Special cabinets are available for holding flammable chemicals, and these should be used at all times.

If welding is to be performed, it should be done behind specially constructed walls (or curtains) to minimize the potential of fire. This also helps to minimize eye injury from unprotected observance of the welding arc.

Equipment

Tool room and maintenance equipment does not normally require a specific ROI (return on investment) value. It could be argued that one specific brand or style of equipment might be able to perform a specific function faster than another, but these issues are usually resolved during the initial design of the molding facility. Tool room equipment is generally used for maintenance and repair functions and there is no ROI applied in many instances. However, if the same equipment can be used for building molds, ROI can definitely be considered because a firm value can be assigned to the cost of the manufacture and subsequent sale of the molds.

The type, number, and size of equipment to be purchased depend on what is to be done with it. If simple repair and maintenance is desired, only a few pieces of equipment (such as a drill press, lathe, mill, and surface grinder) are necessary, and these can be purchased as used equipment to minimize investment. However, if major repairs are planned, more sophisticated and larger pieces of equipment will be necessary. While some of this can be purchased used, good equipment is generally difficult to locate and is often almost as expensive as buying new.

A typical tool room, designed only for minor tool repair, might require approximately $50,000 in used equipment. This would include a drill press, vertical milling machine, surface grinder, lathe, and special hand tools and disposable tools. Buying all new equipment would increase this cost to approximately $200,000, or more.

If the tool room is intended for major repair, the equipment list must include rod and TiG welding equipment, an EDM machine, and a horizontal milling machine. The addition of these will easily double the investments noted earlier. If a tool room is intended for building molds, the additional equipment includes not only this equipment, but centerless grinders, horizontal grinders, and possibly a wire-EDM machine.

In addition to having this equipment, there are other items needed for any tool room. These include fork lifts, heavy-duty work tables, overhead cranes and A-frames, and plenty of stock materials, such as steel bars and plates, many mold components, and cleaners, solvents, lubricants, and hand tools.

For a machine maintenance area, the same type of equipment is needed It is a good idea to maintain a separate area with its own equipment. The tool room equipment must be kept in excellent condition and not overloaded or it will not be effective for repairs and mold building. The machine maintenance equipment should be used only for its intended purpose. In addition to a lathe, mill, drill press, and grinder, there should be a heavy-duty welding unit, electrical testing equipment, large hammers and wrenches, and hydraulic lifts. Also, the machine maintenance department should have its own crib to store disposable tools, cleaners and flammable chemicals, and the large number and variety of machine spare parts that are necessary. Spare parts would include items such as screws and barrels, heater bands, motors and pumps, pump repair kits, seals, and other items recommended by the machine manufacturer. The spare parts crib is essential to keeping machines running and does take up a lot of space due to the variety of parts that need to be kept on hand. Spare parts inventory can be expensive, but not when compared to the cost of extended down time caused by the unavailability of a much needed part.

OPERATING COSTS

How much does it cost to operate a molding facility? The answer depends on what is being done. A simple, small shop doing custom molding of disposable flowerpots does not need the sophisticated equipment needed by a large shop specializing in medical or electronic molding. A "full service" shop will need extra items such as tool room services and decorating equipment, which add expenses that the small shop does not have to deal with.

Regardless of the size of the shop, operating costs must be calculated to provide the basis for establishing selling prices. Some of these costs are related to the operation of the equipment, such as electrical charges and other utility fees. Other costs are related to maintaining equipment and tooling, providing engineering functions and manpower, and providing periodic training to ensure a knowledgeable and productive staff. These operating costs are associated with the daily operation of the molding facility and are categorized as labor, water, electricity, and maintenance.

Labor

There are many people involved in the daily molding operation, even when the process runs automatically. To establish a generic cost example, assume minimal automation and an average eight-machine shop running a three-shift, five day-a-week operation. Labor costs vary depending on geographic location and economic conditions. In this case, an average entry-level wage of $7.50 per hour will be used for the molding machine operator. Include fringe benefits when determining labor costs, which can add 30–40% to the base wages (35% is about average). Fringe benefits include taxes, insurance, vacation pay, training time, holidays, etc. Daily labor requirements for a typical eight-machine operation are shown in Table IX-2.

Water

Cooling towers and chillers distribute the process water used for controlling the mold and equipment temperatures through cooling lines and heat exchangers. While these systems use circulation technology and are effective in performing their intended functions, they do lose water through evaporation, leakage, and dissipation caused by periodic cleaning. This loss can amount to 5–7% of the total water flow. An average water flow rate requirement for a single machine and single mold is approximately 50 gallons per minute (GPM) (189 liters per minute [LPM]) to provide turbulent flow. The eight-machine shop then would result in a total flow requirement of 400 GPM (1,514 LPM) by multiplying 8 × 50 GPM. Based on that figure, a 6% loss would equal 24 GPM (91 MPM), or 8.64 million gallons (32.7 million liters) per year (24 GPM × 60 min. × 6,000 [3 shifts × 5 days a week × 50 wk/yr × 8 hr/shift]). Using the average cost of $1.50 per 1,000 gallons of water, the annual water cost equals $12,960 (8.64 million gallons ÷ 1,000 = 8,640 × $1.50).

Table IX-2. Manpower Costs

Job Description and Average Wages	Number Required	Average Annual Wage + 35%	Total Annual Wages
General supervisor ($45,000)	1	$60,750	$60,750
Shift supervisor ($24,700)	3	33,345	100,035
Machine operator ($7.50/hr)	24	21,060	505,440
Setup person ($11.40/hr)	2	32,011	64,022
Inspector ($9.00/hr)	3	25,272	75,816
Mold maintenance person ($18/hr)	1	50,544	50,544
Machine maintenance person ($16/hr)	1	44,928	44,928
Totals	35	$267,910	$901,535

To minimize cost, monitor the water circulation system to ensure leaks are repaired, evaporation is minimized, and bleed-off is controlled. The water costs shown are based on using a city water supply. Individual wells can reduce this cost somewhat, but they usually require a greater investment in water treatment programs and chemicals.

Electricity

Determining estimated electrical costs can be very complicated due to different fees based on peak demand and usage, and various power factors. Your local utility can provide average data, and the following generic calculations can be used for budgetary purposes. Remember that total power requirements must be based on peak operating conditions, even though normal operations use about 60% of that number at any given time.

Based on calculations performed in Chapter 5, it can be determined that there is an average peak requirement of 300 kVA for every molding machine on the floor. That includes electrical requirements for the molding machine as well as all auxiliary equipment, lighting, exhaust fans, etc. The eight-machine facility, then, would have a peak electrical requirement of 2,400 kVA. Using a 60% real-time usage factor, there is a need for 1,440 kVA, per hour. Over the period of a year (6,000 hours), electrical usage would equal 8,640,000-kilowatt hours (kWh). The average cost of electricity in the United States is $0.05 per kWh (ranging from $0.029 to $0.151), so the annual electrical costs would equal 8,640,000 × $0.05, or $432,000.

Maintenance

Maintenance activities are required for the equipment, tooling, and building. Annual costs can be estimated as a cost percentage of the original equipment, tooling, or building. The annual maintenance cost for tooling is 5–10% of the original cost, with 7.5% being average. Annual equipment maintenance costs are 2–3% with 2.5% being average. Building maintenance costs are approximately 1% of the original cost per year. Table IX-3 shows the maintenance cost for the eight-machine facility.

Total Operating Costs

Table IX-4 shows the total operating costs calculated by adding labor, water, and electricity to the maintenance totals estimated earlier. These are the annual costs of staying in business and operating the facility. It does not indude raw materials, administration salaries, profit, etc., but can be used as a basis for determining selling prices.

PRODUCT COST ANALYSIS

This section will discuss how to determine machine hour rate (MHR), determine piece price, and project sales volume.

Determining Machine Hour Rate (MHR)

After the annual depreciation costs and the annual operating costs are found, the *processing cost* or *machine hour rate* can be derived. This will help determine the manufacturing cost of every item produced in the molding facility, and is used as the basis for determining selling price. The *MHR* is a value expressed as a cost per hour assigned to each molding machine. So far in this exercise, all

Table IX-3. Maintenance Cost

Description of Maintenance Item	Capital Costs	Maintenance %	Annual Cost of Maintenance
Tooling	$500,000	7.5	$37,500
Molding machines	2,500,000	3	75,000
Secondary equipment	250,000	2.5	6,250
Auxiliary equipment	150,000	2	3,000
Material handling	200,000	2	4,000
Cooling towers, chillers, etc.	200,000	3	6,000
HVAC	300,000	2	6,000
Building	500,000	1	5,000
Totals	$4,600,000		$142,750

Note: If the building and/or equipment is leased, the total lease cost should be used in place of the capital value.

Table IX-4. Total Operating Costs

Labor	$901,535
Water	12,960
Electricity	432,000
Maintenance	142,750
Total annual operating costs	$1,489,245

the molding machines were grouped together and treated the same. For more accurate costing when various machine sizes are available, each machine size (based on clamp tonnage) should have its own *MHR*, which can be calculated using machine-specific data, such as electrical fees and depreciation.

There are only two numbers needed for determining the *MHR*. They are depreciation and annual operating costs, as determined earlier. Dividing the sum of those two numbers by the annual manufacturing hours available to the facility will represent the *MHR*. This is shown in Equation 5.

$$MHR = (A_d + A_o) \div A_m \tag{5}$$

where:

A_d = annual depreciation
A_o = annual operating costs
A_m = annual manufacturing hours available

For example:

Annual depreciation	$576,428
Annual operating costs	$1,489,245
Total annual costs	$2,065,673

Now the task is to determine how many manufacturing hours are available. The facility will run 24 hours a day, 5 days a week, with a 2-week shutdown each year for vacation. This gives a total of 6,000 manufacturing hours (24 × 5 × 50) available annually. The total annual costs are then divided by the available hours to arrive at the total *MHR*.

$$\$2,065,673 \div 6,000 \text{ hours} = \$344.28 \text{ total } MHR$$

The total *MHR* is then divided by the number of machines that are available (eight). The result is an hourly rate for an individual machine of $43.04.

$$\$344.28 \div 8 \text{ molding machines} = \$43.04\ MHR$$

This figure includes the wages and benefits of a single operator. If automation is utilized and the operator is no longer needed, the *MHR* can be reduced by those wages. The individual *MHR* is the figure used for determining what it costs per hour to mold plastic products. It will be used later for determining selling price.

Determining Piece Price

Determining the piece price (or selling price) that is charged to a customer is very product specific. There are two items to calculate: machine cost (including operator), and material cost. Markups and profit margins are then added to determine the final piece price.

Machine Cost

There is a specific formula to calculate machine cost and it utilizes the machine hour rate. The formula is as follows:

$$M_c = MHR \div [(3{,}600 \div C_t) \times N_c] \qquad (6)$$

where:

M_c = machine cost
MHR = machine hour rate
C_t = cycle time in seconds
N_c = number of cavities

Cycle time is defined as the period, or elapsed time, from one point in a molding cycle to the exact same point in the next molding cycle. It is determined by the wall thickness of the product, with thick-walled parts taking longer to mold than thin-walled parts. The thickest section of the part is the basis for cycle time, which can be estimated (if it is not already known) by using Table IX-5.

For example, assume that there is a two-cavity mold with the thickest wall being .060 in. (1.52 mm). Table IX-5 shows two parts will be molded every cycle of 18 seconds. Substituting these numbers into Equation 6 results in:

$$\begin{aligned} M_c &= \$43.04 \div [(3{,}600 \div 18) \times 2] \qquad (7) \\ &= \$43.04 \div 400 \\ &= \$0.108 \text{ each piece} \end{aligned}$$

Material cost is added to this machine cost to get the total manufacturing cost for this product.

Material Cost

Material cost is determined by this formula:

$$\text{Material cost} = V \times SG \times .0361 \times P \qquad (8)$$

where:

V = volume needed for filling the part(s) and the runner system (in.^{3})
SG = specific gravity of the plastic material being molded
.0361 = weight of 1 in.^{3} of water (lb)
P = actual price/lb of the plastic

First, the total volume of plastic needed is calculated. Figure 9-1 shows the two molded parts and the accompanying runner system needed for filling the cavities with plastic as they would appear immediately after being ejected from the production mold.

Table IX-5. Estimating Cycle Times

Wall Thickness in. (mm)	Total Cycle Time seconds
.060 (1.52)	18
.075 (1.90)	22
.100 (2.54)	28
.125 (3.18)	36

First, the "projected area" should be found. This is what is shown in the top portion of Figure 9-1. It can be thought of as the shadow that would be cast if a light were shined on the molded parts and runner above a flat surface. In Figure 9-1, the projected area is equal to the length and width of each part and the runner system, and is calculated using Equation 9.

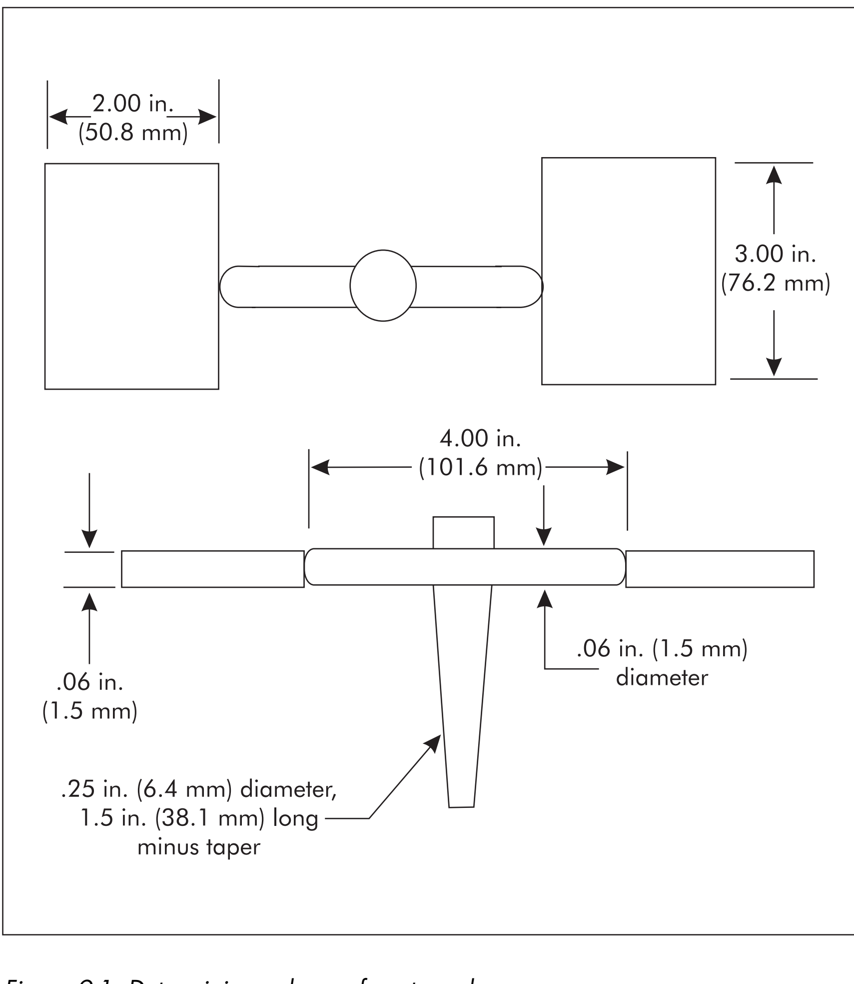


Figure 9-1. Determining volume of parts and runner.

$$P_{AT} = P_A \times P_t \tag{9}$$

where:

P_{AT} = projected area at the top of drawing
P_A = parts area (length × width), in this case, (2.00 in.) × (3.00 in.) = (6 in.^{2}) × (2 parts) = 12 in.^{2}
P_t = part thickness

The *volume* of these parts (P_V) is determined by multiplying the parts area by the thickness of .060 in.

$$P_V = 12 \text{ in.}^2 \times .060 \text{ in.} = .72 \text{ in.}^3$$

Now, the volume of the runner (R_V) system is figured.

$$\begin{aligned} R_V &= \pi r^2 \times \text{runner length} \\ &= [3.1412 \times (.0375 \text{ in.}^2)] \times 4.00 \text{ in.} \\ &= (.0044171 \text{ in.}^2) \times 4.00 \text{ in.} = .0177 \text{ in.}^3 \end{aligned}$$

$$\begin{aligned} \text{Sprue volume} &= .5\ (\pi r^2 \times \text{length}) \\ &= .5 \times (3.1412 \times [.125 \text{ in.}^2]) \times 1.500 \text{ in.} \\ &= .5 \times (.04908^2) \times 1.500 \text{ in.} = .03681 \text{ in.}^3 \end{aligned}$$

Adding these numbers (parts volume, runner volume, and sprue volume) together yields a total required plastic volume of .77451 in.^{3}, as shown in Equation 10.

$$\sum P_v = P_V + R_V + S_V \tag{10}$$

where:

$\sum P_v$ = total required plastic volume
P_V = parts volume
R_V = runner volume
S_V = sprue volume

This number is used for calculating the material cost.

Material is purchased by weight, so the amount of area that can be molded by a specific plastic material must be known. Each of the more than 20,000 materials available today has its own specific gravity (*SG*) value. This can be found by searching the information sheet from the supplier for the material or using a generic SG for a particular family of materials. This generic information can be found in many sources, such as the annual encyclopedia available from *Modern Plastics*, or the annual *Manufacturing Handbook* available from Plastics Technology.

The *SG* value for polycarbonate is, on average, 1.2. This is now substituted in the formula:

$$\text{Material cost} = SG \times .0361 \times V \times P \tag{11}$$

where:

SG	= specific gravity
.0361	= weight of 1 in.^{3} of water (lb)
V	= volume of plastic
P	= actual price/lb of the plastic

$$1.2 \times .0361 \times .77451 \text{ in.}^3 \times \$4.00 \text{ (estimated)} = \$0.1342$$

This number ($0.1342) represents the cost of all the material needed to mold one complete cycle of production. Because two parts are made at one time, this number should be divided by two to determine the cost of each piece. So, $0.1342 ÷ 2 = $0.0671 is the material cost for each part molded. This number is added to the machine cost that was determined earlier ($0.108 each). Therefore, the total cost to manufacture this part is $0.1751 each.

The calculations used here assume that the runner system cannot be reused, as is the usual case with medical and some electronic parts. If the runner can be reused, it does not have to be included when determining material costs, as long as it is no more than 15% of the entire shot volume. If it is more than 15% of the total, any portion above the 15% must be included. This is because it is usually not permissible to use more than 15% regrind in a mix of compound. If a hot runner is utilized, there will be no runner to include.

Markups and Profit Margins

Now that an estimate of how much it costs to manufacture a given product is available, markups and profit margins can be added to determine the final selling price to the customer.

Markups are those add-on values included to cover costs not accounted for in the previous calculations. These would include (for example) charges for sales commissions, increased level of difficulty for molding extremely close tolerances, penalties for special deliveries, special handling requirements, special documentation, management wages and benefits, front office support systems, advertising, etc. It is common to include a 1–2% handling charge for raw materials. In addition, all overtime wages must be considered. The idea is to make sure every cost associated with running the business and producing the product is covered somewhere during this exercise. Most companies have their accounting department determine a fixed percentage that can be applied to every product to cover these items, but it may still be necessary to include other markup items for product-specific requirements.

Profit margins are usually the last item to be calculated and added to the price. This arrives at the final cost to the customer. The typical custom molder will add approximately 10–15% to cover profit margins, but even proprietary molders have some type of profit margin to apply. Profit margins are extremely difficult to benchmark because they are determined in so many different ways. Some companies add a single percentage to their manufacturing costs and incorporate all of their markups and profits in that number. Others find it more effective to add a single digit profit percentage after incorporating all other costs, as was done in the preceding exercise. Still others simply look at the manufacturing costs, and "best-guess" a selling price based on experience in the industry and/or knowledge of what the customer is willing to spend For these reasons, various molders may claim profit margins anywhere from 1% to 40%, depending on what impression they are attempting to portray at the time.

When determining profit margins, a molder should not be conservative. No customer expects a company to run its business at a loss. A molder must decide how much profit it wishes to make. If a company has developed a special niche in the industry, it may be capable of demanding higher profits than an "ordinary" molding operation. It is reasonable to assume that the more offered to the customer, the more valuable the company is to that customer. Customers may complain about pricing, but most of them are willing to spend a little more to get consistent, high-quality product from a vendor who can make deliveries and honor pricing commitments. In today's world, more and more customers are relying on the molding vendor to supply parts from start-to-finish, and they are willing to pay for that luxury. In other words, the more responsibility the molder takes, and the more drudgery that it can handle for the customer, the more dependent the customer will become.

Projecting Sales Volume

So, how much money will be made? How many items can a custom molder sell? In the case of a proprietary molder, how can the company be competitive with the custom world? What is the company worth now? What is it's future worth? These are all questions that every molding manager asks, and the national average answers are certainly encouraging.

According to recent surveys published by *Plastics News*, the top 30 custom molding companies in the United States realized, on average, $972,444 in annual sales for each molding machine they had on the floor. All of these companies were "full-service" molders who were able to capitalize on the additional services they provided over injection molding to achieve such numbers. This points out the type of revenue that can be attained. Altogether, these top 30 molders had approximately 3,000 presses, with the average being 100. Nevertheless, even those with only seven or eight presses were able to realize the same average sales per press.

What sales numbers can be expected just from the molding machine? Using the example given earlier, a 300-ton (20.6-MN) machine (the most common in the industry) had a machine hour rate (MHR) of $43.04. With 6,000 hours available each year, it should generate a minimum of $43.04 × 6,000, or $258,240 just by its use. After adding material costs, markups, profit margins, and tooling profits, it can be seen how that figure can easily climb toward $500,000 annually. A full-service vendor would also realize sales for secondary operations and associated tooling, easily seeing the industry standard of $972,444. This survey information was compiled over a period spanning 1996–1997. This would indicate that, in 1998, the potential would be right at $1 million per machine.

Another way of estimating sales is by number of employees. Those same 30 companies averaged $116,918 annual sales per employee. All employees, not just direct labor, are included in this figure. By creative interpretation, the average number of employees per molding machine ($972,444 ÷ $116,918) would be approximately 8.5. Anything that could be done to minimize that number would directly improve the bottom line profits. The eight-machine facility then, should employ a maximum of 8 × 8.5 or 68 people. This includes all personnel, from janitors to plant managers. These numbers are based on 100% efficiency and utilization, and a 24-hour day, 5-day week, and 50-week operation. It is not practical to believe the facility can actually maintain this type of utilization and efficiency.

Efficiency can be defined as how many cycles are run in the time allotted, and how many parts are shipped versus how many were produced. In other words, if the estimates assume 60 cycles an hour, but only 50 are run, the cycle time efficiency is only 83%. Likewise, if 1,000 parts are produced but only 900 are shipped, the defect rate is 10%, resulting in a production efficiency of 90%.

Utilization is another matter and can be defined as the amount of time the molding machines are actually producing good parts, versus the amount of time available to do so. Assuming 6,000 production hours available annually, if product is only molded for 4,000 hours on a given machine, the utilization factor is 67%. The time not being used for production is considered "down" time. Downtime can be due to mold changes and setups, repair activities, operator truancy, or many other things. For top utilization, all nonproduction activities should be scheduled for nonproduction hours, such as on weekends, if at all possible. If not possible, the number of available hours for production should be reduced to accommodate these items.

Recent studies performed by Texas Plastic Technologies show that custom molders have been averaging around 85% utilization and 98% efficiency. Most proprietary molders are averaging closer to 70% utilization and 85% eficiency. This seems to indicate that custom molders are more efficient and productive than proprietary molders. While this may or may not be true, it does appear that custom molders are organized to be more flexible, allowing faster response to customer needs. This may be a function of levels of bureaucracy more than expertise or knowledge.

SUMMARY

There are many costs involved in the startup and operation of a molding facility, including initial capital requirements, processing costs, raw materials, and many others, some obvious and some hidden.

The single most common cause of failure of any startup company or venture is insufficient capitalization. While the most prevalent reason is lack of operating capital for a specific period, often the reason is a lack of knowledge of what equipment or resources are essential for the successful operation of a facility.

An alternative to expansion or startup is to purchase an existing molding facility in the general geographic area selected. This provides a ready source of equipment, already installed and operating, and a possible source of personnel.

When determining capital for equipment, it is important to consider cost, not just price. *Price* is what the equipment costs to purchase, but *cost* is that figure plus what it takes to maintain, operate, and service it during its useful life span.

Purchasing used equipment can be a viable method of reducing investment capital while reducing the amount of lead time required. On average, well-maintained used equipment will cost approximately 30–60% of the cost of new equipment. Remanufactured equipment can be purchased for around 50–80% of the cost of new equipment.

Depreciation is an item that must be considered in capital requirements because the numeric value of depreciation is added to manufacturing costs to determine eventual processing costs. The processing costs will be used to determine selling prices.

The type, number, and size of tool room and maintenance equipment to be purchased depends on what is to be done with it. If simple repair and maintenance is desired, only a few pieces of equipment (such as drill press, lathe, mill, and surface grinder) are necessary and these may be purchased used to minimize investment. However, if major repairs are planned for, more sophisticated and larger pieces of equipment will be necessary.

Based on calculations, there is an average peak requirement of 300 kVA for every molding machine on the floor. That includes electrical requirements for the molding machine as well as all auxiliary equipment, lighting, exhaust fans, etc. An eight-machine facility, then, would have a peak electrical requirement of 2,400 kVA.

The MHR is a value expressed as a cost per hour and is assigned to each molding machine.

A typical molding facility operates 24 hours a day, 5 days a week, 50 weeks a year, yielding 6,000 available hours of production for each machine on the floor.

Cycle time is defined as the period, or elapsed time, between one point in a molding cycle to the exact same point in the next molding cycle. It is determined by the wall thickness of the product, with thick-walled parts taking longer to mold than thin-walled parts.

Markups are those add-on values included to cover costs not accounted for in the standard calculations.

The typical custom molder will add approximately 10–15% to cover profit margins.

According to recent surveys published by *Plastics News*, the top 30 custom molders in the United States realized, on average, $972,444 in annual sales for each molding machine they had on the floor.

Utilization can be defined as the amount of time the molding machines are actually producing good parts, versus the amount of time available to do so.

Recent studies show that custom molders have been averaging around 85% utilization and 98% efficiency, while most proprietary molders are averaging closer to 70% utilization and 85% efficiency.

QUESTIONS

1. What is the single most common cause of failure of any startup company or venture?
2. What is another term for a "single source" vendor?
3. What is a full service vendor responsible for?
4. What are the primary advantages of buying an existing company versus starting a new one or expanding an existing one?
5. On average, what is the cost of remanufactured equipment versus new?
6. What is an average cost that can be expected for secondary operation stations?
7. What is the normal depreciation period for primary equipment and material handling equipment?
8. What is the depreciation period for product-specific equipment?
9. Why is it important to know the operating costs?
10. What is the average benefits percentage that should be added to wages to determine actual labor costs?
11. What is the required water flow (in GPM) required to produce turbulent flow for a single molding machine and a single mold?
12. What is the average electrical requirement (in kVA) for each molding machine on the floor?
13. What is the average number of hours available per year for each machine?
14. What is meant by the acronym MHR?

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Organizational Structure 10

"Plan your work, and work your plan." Everyone has heard this at one time or another in their careers and it is one of the best pieces of advice to follow. It applies to individual efforts, but also to company-wide strategies. It certainly applies to determining organizational structure. The concept of organizational structure is more than just a flow chart that shows levels of authority. It also entails:

- Getting the most productive work from employees.
- Minimizing the number of employees required.
- Defining responsibilities and reporting relationships.
- Ensuring efficient flow of information and communication.
- Promoting an atmosphere of camaraderie among all personnel, especially between management and labor.

There are four basic phases involved in developing the organizational structure.

1. Identify the needs or functions.
2. Define individual and team responsibilities.
3. Establish reporting relationships.
4. Document the structure.

IDENTIFYING NEEDS

The first order of business is to identify what is needed (beyond equipment and supplies) to make the business run properly and smoothly. Then, which parts of the business are kept and which parts are candidates for contracting to outside firms must be determined. Some of the activities needed for a typical molding facility are shown in the following list.

- Accounting.
- Financial planning.
- General management.
- Human resources.
- Industrial engineering.
- Inventory control.
- Legal.
- Machine repair and maintenance.

- Marketing.
- Material handling.
- Molding.
- Mold repair and maintenance.
- Plant Engineering.
- Plant (building) maintenance.
- Product engineering.
- Production control.
- Purchasing.
- Quality control (assurance).
- Receiving.
- Safety.
- Sales.
- Security.
- Shipping.
- Warehousing.

Each of these functions (they could be called departments) requires a definition of responsibilities and accountability, coupled with a manpower requirement to fulfill those responsibilities, and identification of an individual responsible for all activities and personnel associated with the area. Some departments could be combined to reduce employee count and crossover of responsibilities. This might also help speed communications, especially in a smaller company. If a company uses team concepts for resolving issues, the teams should consist only of in-house members, if possible, to minimize reporting activities and maximize communications. Sometimes it is advantageous to work with outside contractors, as in the case of mold design and construction. In those cases, it is wise to bring in the outside companies as early as possible. However, they should be considered only as resources for the in-house team, not as actual team members.

After the functions, or departments have been identified, they can be analyzed to determine which can be combined, which need to be expanded, and which need to be eliminated, or added. The final list becomes the basis for the organizational chart. The following exemplifies this concept for a typical shop.

The example facility is an average eight-machine shop with equipment running from 50–1,000 tons (4,448–8,896 kN) of clamp force. This could be considered a small-to-medium molding company depending on what degree of full-service is offered. For this exercise, full service is assumed. The company will provide tool design, tool build, primary molding, secondary operations, and take full responsibility for those functions, as well as anything else needed to ship the customer a final product. Full production is considered 24 hours a day, 5 days a week, 50 weeks a year.

There is a need for a large number of employees. Use of automation can reduce the employee numbers, but even a fully automated facility requires a surprising number of personnel to operate effectively. In today's world of high technology, it is advisable to eliminate the need for clerical and secretarial help through use of personal computers and network systems. All levels of management should be encouraged, and expected, to create and publish their own reports, documents, filing systems, etc., and make them available to, and compatible with, other similar documents within the company. Even travel accommodations, meetings, and appointments can be made by the individual rather than a secretary. While this may seem to be penny-wise and dollar-foolish on the surface, it will prove to be effective and productive in practice.

GENERAL MANAGEMENT

There are many legal definitions regarding the function of general management and they will vary depending on the type of company (general corporation, limited liability corporation, etc.). This exercise assumes a general corporation structure. For an injection molding facility, this will require a board of corporate officers including a CEO (chief executive officer), a president, a vice president, and a secretary. In many cases, the position of secretary can be filled by any one of the other officers. This structure is a legal requirement and considered a necessary burden, and the basic job descriptions are predetermined. This section will focus on the management level just below the CEO. Reporting directly to the CEO will be the president and the vice president. Each of these positions has a series of department managers reporting to it. In most cases, the president is responsible for the production side of the facility, while the vice president is responsible for the marketing and finance side. This structure permits these processes to occur without impeding their function and allows them to complement one another.

President

The position of president assumes complete responsibility for the day-to-day operation of the molding facility. The president usually has the production-oriented department managers reporting to him/her as shown in Figure 10-1. These include, but are not limited to, the managers of Human Resources, Quality Control, Product Engineering, Manufacturing Engineering, and the plant manager.

Human Resources

The Human Resources department is responsible for developing and implementing a company-wide personnel policy that addresses the quality-of-life issues and concerns of company employees at all levels. This activity includes the administration of benefit packages, safety and security programs, training and personal improvement programs, implementation of state and federal regulations concerning employment practices, and maintenance of all employee records. Other programs, such as child care assistance, medical and dental insurance, IRA funds and retirement packages, and employee job descriptions are usually handled by the Human Resources department.

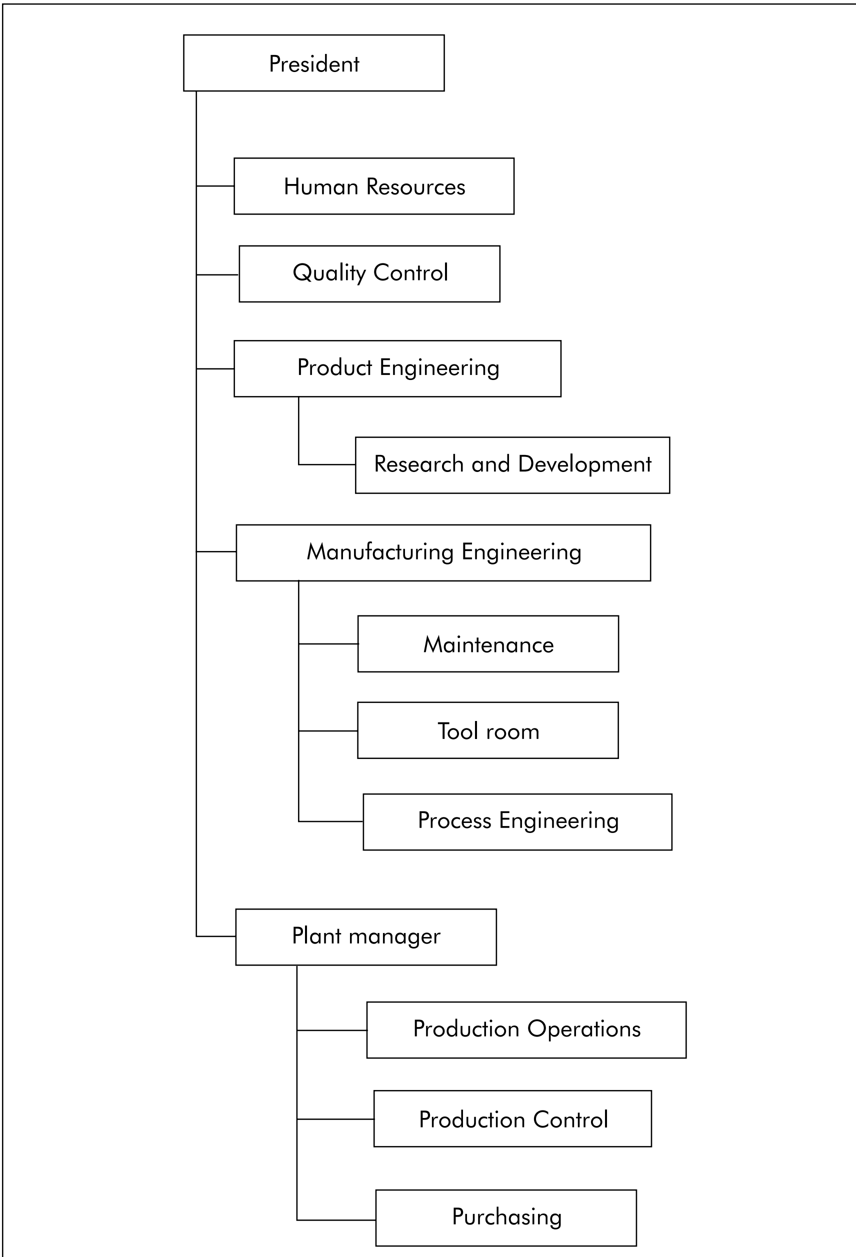

Figure 10-1. Manager positions reporting to the president.

Because of the extent of necessary daily involvement and the potential legal ramifications, the Human Resources department normally reports directly to the president of the company. In an eight-machine facility, because of the workload requirement and constantly changing employee practice laws, the Human Resources department will usually require at least two employees full-time. A large employee benefits package can add another employee just for implementation and record keeping. The number used in this exercise is two, one being the manager.

Quality Control

The Quality Control department is one of the most important and influential departments in the company. In truth, it should be given the responsibility for being able to shut down any job in the plant at any time if the job is deemed running outside predetermined quality parameters. Of course, the production floor would have the authority to continue to run production, but the parts would have to be placed in quarantine until a formal disposition is made by a company review board.

The Quality Control department's mission is to develop and implement a company-wide quality plan for use across departmental lines, which addresses the quality concerns of customers, potential customers, and the company itself. This includes the documenting and maintenance of all necessary operating procedures for all quality control equipment and methods. It also involves the establishment and monitoring of quality standards for products, processes, and raw materials. The Quality Control group is the single department that develops, monitors, audits, and controls all quality-related issues in the company.

For an eight-machine shop, the Quality Control department should have a minimum of one roving inspector (on the production floor) per shift, one technician for running some of the more sophisticated tests, and one manager, for a total of five.

Product Engineering

The Product Engineering department takes responsibility for product design, for both existing and potential products or customers. It is expected to act as an interface and work closely with the final customer and manufacturing floor personnel in recommending design changes, raw material selections, and any product improvements to facilitate ease of manufacturing and cost reductions. It is also deeply involved with the discovery of new business opportunities related to products. In some cases, the research and development section will be involved with developing distinct material compounds for specific products. For an eight-machine shop, the number of employees would be two, one being the manager.

Manufacturing Engineering

The Manufacturing Engineering department has the responsibility to develop standards and practices for establishing the actual costs of manufacturing any given product. Working with the plant manager, it implements these standards and helps to increase operational efficiencies and reduce scrap through use of proper procedures, materials, and tooling. In addition, it is expected to investigate and implement new and current equipment, materials, tooling, methods, and processes for the benefit of the company.

The maintenance portion of this department is responsible for maintaining equipment, buildings, and grounds. This group is also responsible for developing and implementing a preventive maintenance program for all equipment, both primary and secondary. It should include a hydraulics technician, an electrical technician (sometimes these can be combined into one person), and a machinist, as well as a grounds keeper. There should be an emergency maintenance person on second shift, and one should be on call for third shift. In many cases, it is better to subcontract the grounds maintenance and janitorial functions. The subcontracted labor would take direction from the Manufacturing Engineering department. The eight-machine shop will require four maintenance area employees (one being the manufacturing engineering manager). The grounds and building maintenance work will be contracted as needed.

The tool room portion of the Manufacturing Engineering department has the responsibility for building and/or repairing molds, fixtures, and jigs that are used in the production of molded products. If it is determined that the building of molds is beyond the tool room capability (due to lack of expertise or equipment investment), the Manufacturing Engineering department normally takes responsibility for procuring molds from outside sources. An eight-machine shop will need at least one tool repair technician on both first and second shift, and an additional moldmaker on first shift. Add at least one more moldmaker and four toolmakers if molds will be built as well as repaired. In addition, a tool engineer will be needed. That totals nine people.

The Manufacturing Engineering department has responsibility for developing processes and methods for molding and manufacturing any product made by the molding company. This activity includes cycle and process optimization, secondary operation methodology and standards, equipment and tooling setup and debugging, and the initial inspection approval of finished product. All procedures must be documented and approved by management before production begins. The number of employees needed for an eight-machine shop is at least one process engineer and one setup person.

Plant Manager

The plant manager is given total responsibility and authority to perform all functions necessary to maintain production operations on a day-to-day basis. He or she is responsible for ensuring that all products are produced according to the standards and schedules negotiated between the company and the customer. The plant manager must work with other departments to increase operational efficiencies and reduce scrap through the proper application of processes, methods, materials, tooling, and equipment. Usually, the plant manager is expected to be an integral liaison with the customer or potential customer in an effort to increase business opportunities and satisfy existing requirements. The plant manager, in cooperation with Human Resources, is responsible for developing and implementing training programs for the production personnel. The three areas controlled by the plant manager usually include Production Operations, Production Control, and Purchasing.

The Production Operations area is responsible for all production-oriented facets of the injection molding operation as they pertain to actual manufacturing, including secondary operations. Staffing of personnel, training, defect reduction, process optimization, cycle optimization, material movement, and effective utilization of equipment, materials, and tooling, all fall within its responsibility. It can be considered the heart of the molding facility. Production Operations is also responsible for process documentation, product inspection during specific production phases, and fostering new business growth by molding products that meet customer expectations.

The Production Operations department is a three-shift operation and must employ enough people to staff all three shifts. Assuming the eight-machine facility has two machines running on automatic (not needing operators in attendance), six operators and one relief operator are needed per shift. A supervisor and a material handler are also required for each shift. The first shift will need at least one setup person. The requirement, so far, is for 28 people. Adding the plant manager brings the total to 29.

The Production Control area is responsible for making sure that the Production Operations area has all the materials and tooling it needs to perform the daily molding and secondary manufacturing activities. This includes:

- Procurement and warehousing of raw materials and packaging.
- Packaging and shipping finished goods and arranging for transportation of finished product to the customer.
- Providing and auditing product counts.
- Developing and implementing inventory control procedures.
- Storage of molds, tools, and materials used for production purposes.

Production Control also provides scheduling information. This is to ensure that products are manufactured and shipped in a timely manner to the customer according to his or her requirements. Coordinating these efforts can appear to be a monumental task, but computer programs are available for easing the strain, and most production control areas utilize standardized methods that are universal throughout the industry. This not only helps reduce the workload, but also increases the efficiency and accuracy of the operation. The Production Control area primarily requires a first-shift execution of activities, with some limited off-shift needs. The eight-machine facility will require a warehouse person, a clerical person, and a supervisor on first shift, and a warehouse person on either second or third shift, for a total requirement of four people.

The Purchasing department has the responsibility to procure raw materials, molds, tooling, and supplies for the entire molding facility. These items must be purchased at the lowest possible price and with the highest degree of quality to meet customer and company specifications and requirements. In addition, lead times must be as short as possible to minimize production delays and warehousing needs. Purchasing is also responsible for finding and selecting vendors who are reputable and who can provide the required services or products on a regular, continuous basis. They must be willing to work with the company to provide whatever services and products are required for the customer. Purchasing is responsible for implementing vendor audits and certification programs, and for issuing the purchase orders that are considered legal procurement documents.

In most companies, Purchasing is given the task of reducing the cost of raw materials, tooling, and supplies on a continuing basis, with successful reduction being considered around 2–3% annually. However, this may be a dangerous demand to place on a Purchasing group, because cost may become the only determining factor when procuring these items. If quality and lead times are not also considered, a loss of business due to dissatisfaction of the customer can result. It is the responsibility of Purchasing to find the best products and services at the best quality, prices, and lead time combination. The eight-machine facility will require two people in Purchasing, one of them a department head.

Vice President

The position of vice president is responsible for the planning and accounting operations of the molding facility. The vice president usually has the Marketing and Finance department heads reporting to him/her as shown in Figure 10-2.

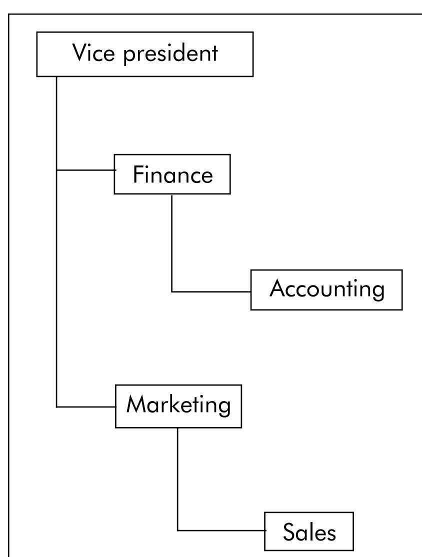

Figure 10-2. Manager positions reporting to the vice president.

Finance

The Finance department has three primary responsibilities:

1. To find, determine, and provide the funding required for the day-to-day company operations;

2. To determine and control the profit margins needed to provide funding for future programs and expansion of the business.
3. To determine and monitor actual operation costs and provide incentive to reduce costs and increase profits. This is accomplished through the development and implementation of procedures and programs that are designed to capture the actual costs of operations.

To determine the actual costs, it is necessary to:

- Accurately measure electrical and utility usage.
- Compare raw material costs versus projections.
- Evaluate cycle times versus estimates.
- Determine efficiency of operations data as provided by other departments, and compare these numbers to other companies in the same business (benchmarking). Much of this information is readily available, but some of it is an estimate based on experience and knowledge of the molding business coupled with analysis of external economic influences.

Part of the Finance department incorporates accounting activities. The accounting area is responsible for profit and loss data accumulation. This includes making proper journal entries for expenses, costs, payments received, commissions paid, payroll distribution, and an accurate determination of profits. This information is compiled and used for determining actual operating costs as well as selling prices.

The total number of finance staff (including accounting) required for an eight-machine shop is two.

Marketing

Marketing is responsible for advertising and sales. In some cases, companies elect to have external sales groups, called manufacturer's representatives (or reps), perform the selling activities. If doing so, a sales percentage (called the commission) must be added to every piece price to pay for the representative's services. Usually, this is within a sliding range of 1–5% of the total sales price (including tooling), with the smaller percentage applied to large volumes and the larger percentage applied to smaller volumes. Sometimes the company elects to have all sales coordinated through an internal sales force. In this case, there is not normally a commission paid, but the internal sales employees could be paid a basic wage, with an additional commission bonus for every sale.

Whether or not the sales efforts are internal or external, or a combination of both, they must be managed by an internal department, usually Marketing. In addition, the Marketing department normally assumes the advertising responsibilities for the company. While this usually encompasses magazine advertising, direct mail flyers to potential customers, and advertising to current customers, there also may be internet advertising and a company web site. Advertising can consume many resources, but manpower should not be one of them. Because of the requirement for specific skills in specific areas, advertising efforts should be left to the contracted professional and he or she should be used as needed. Still, advertising should be controlled by a single in-house function, usually Marketing. This results in the requirement of one employee for advertising purposes and two internal sales people, for a total of three in Marketing.

Totals

To this point, adding up the number of employees noted earlier brings the total requirement to 64 (not including the corporate board of three to four). Some or all of the members of the corporate board can be used to fill some of the 64 needed positions, and it is feasible to combine some of the responsibilities of staff to further reduce the total. However, a properly staffed, three-shift, eight-machine, full-service molding facility will definitely require a large number of people for proper operation. The 64 is not unreasonable because it agrees closely with the national average for total number of company employees (8.5) needed for each molding machine on the floor.

DEFINE INDIVIDUAL AND TEAM RESPONSIBILITIES

After the needs have been identified, it is necessary to determine specific responsibilities for the individuals assigned to each area or function. A *job description* that lists the responsibilities and measurements of performance for each job title identified must be created. There are many sources available for establishing the actual wording, including the Internet. The important item to remember about job descriptions is that they are intended to be general in nature and usually include such statements as "work with other departments to increase efficiency," or "work in a safe manner." *Job performance* is the amount of actual work done compared to requirements in the general job description. An evaluation is made on an annual or at least regular basis, so the employee always knows exactly what is expected and how he or she measures up to those expectations. Job performance plans are actually more important than job descriptions and should be written with the cooperation of the employees. The employee should be able to refer to the plan at any time to determine how they are doing. The expectations must be clear and specific, and performance must be measurable. Such terms as "…reduce scrap…" are not specific because there is no guidance as to what is acceptable and no target against which a measurement can be made. A better terminology might be "…reduce scrap to an acceptable level of .001% on electronic product line by May 1, 20XX." This identifies the exact performance requirement as well as a period by which it must be performed.

A job description should document the general expectations of the job. It is the basis for recruiting to fill a specific position. An example of a simple job description for a mold setup person is shown in Table X-1.

A job description should be written for every job title used within the company, including the president. These should be coupled with performance plans,

Table X-1. Simple Job Description—Mold Setup Person

1. Responsible for placing molds in presses and mounting them to the machine.
2. Connects and sets up all necessary auxiliary equipment such as hopper dryer, loaders, water temperature control units, granulators, etc.
3. Ensures all production material and information is available at machine.
4. Performs some preventive maintenance on equipment and molds while in production mode, such as clean and lubricate molds once a day, maintain oil level in presses, check water pressure, etc.
5. Performs all work in a safe manner.
6. Reports directly to Manufacturing Engineering manager.

the most common being for a 6-month period. New employees may be placed on probation for 90 days, which would require a performance plan of shorter duration.

At the end of the performance plan period, a meeting should be held with the employee to discuss performance compared to the requirements listed in the plan. A decision will be made as to what the next performance plan will include, assuming the employee stays in that position. A performance plan documents specific job duties and expectations so that the employee understands what responsibility (or authority) he or she has been given. It is never desirable to think about the possibility of employee termination, but if termination is necessary, the performance plan results are considered legal documentation for the decision.

After individual job descriptions and performance plans are in place, it is time to assign team responsibilities, if the company mission entails team concepts. Every team needs a leader to provide continuous direction. At the same time, every team member must be allowed to demonstrate his or her performance excellence. A team that does not allow individuals to show their attributes will not succeed because enthusiasm will be suppressed. It is fine to think of things in terms of how the team reacts, but it is very divisive to tell an individual that they are not a team player because they wish to point out their own successes. Every team ever assembled consists of, and depends on, individual actions.

Like individuals, teams need specific direction. A detailed performance plan should be created specifically for a particular team function. Teams must be told why they are being assembled, what is expected of them, and when they will be disbanded. No team should have eternal existence. Teams should only be assembled for a specific purpose and after that purpose is satisfied, or no longer matters, the team members should be released to return to their original, individual jobs.

ESTABLISH REPORTING RELATIONSHIPS

Now that departmental functions have been established and individual and team responsibilities are in place, it is time to determine reporting structure. In the past, the manufacturing floor was considered separate from the rest of the company. This should be discouraged as much as possible by placing manufacturing and engineering under the same reporting path.

One concern is that the plant manager has control of everything needed to perform production activities on a daily basis. This is necessary, but can interfere with systematic procedures, such as preventive maintenance, which usually require downtime on production equipment. If the maintenance personnel report to the plant manager (which is common), the preventive maintenance will always be subordinate to production needs. So, in the eight-machine shop scenario, the maintenance personnel report to the manufacturing engineering manager. Then it becomes the responsibility of the plant manager and the manufacturing engineering manager to develop the details and schedule for preventive maintenance activities. Often, scheduled maintenance can be performed on weekends to minimize interruption of production during the standard 5-day work week.

For example, Quality Control may be given authority to shut down any machine in production if the parts being produced are considered defective. But, the plant manager (being told that the customer needs parts no matter what) must have overriding authority to keep the job running and place the parts in quarantine until disposition can be made by a formal review board. Of course, each party must be made accountable for their decision.

While conflict and personality differences are inevitable, they should never be considered when determining reporting structure. It may be easier to place a troublesome employee under a controlling manager rather than a meek manager, but the position should be placed, not the person. The job functions and expectations must be the only considerations used to determine where to place an employee in the reporting structure.

Separate the engineering and production functions, but have them report to the same authority, such as the president. The reasoning is that they each operate by two distinct methods and thought paths; engineering tends to be long-term oriented and production tends to be short-term oriented. While both can certainly perform their respective duties effectively, it is difficult to have agreement on all subjects. This is when a mediator (in the form of the president) can assist them, or actually make the final decision.

DOCUMENT THE ORGANIZATIONAL STRUCTURE

The final phase of creating the organizational structure involves documenting and informing all employees of the facts. Use of a flow chart is usually the best way to describe the reporting structure, and this, along with job descriptions, should be posted for all employees to refer to at any time. Of course, to foster team involvement and cooperation, management should hold meetings with all employees to explain the reasoning and solicit comments before finalizing the structures. However, after that is done, the final flow charts and descriptions should be distributed. Then, all employees should be expected to know the reporting structure and the levels of authority. This will go a long way in maintaining open communications and job satisfaction. Everyone likes to know exactly what is expected of him or her and what he or she should expect from others. Of course, when changes are made to the structure or job descriptions, all employees must be made aware of those changes to minimize confusion.

TRAINING PROGRAMS

Many company officials make the statement that they cannot afford the time and money needed to train employees. What they do not understand is that training *will* occur. It may occur in a formal, structured, time-effective manner or while the employee is on-the-job, making mistake after mistake until the job is done at an "acceptable" level. The cost and time is much lower in the first scenario than the latter, but in either case, training does occur.

How much training is required? This can be answered by asking another question: how efficient and productive do the employees need to be? To start with, every company has its own requirements and methods. Even with an experienced, knowledgeable new hire, it takes a certain amount of time for that employee to match the specific needs of the company. A new hire might be able to start working immediately, but he or she will only be about 60% productive and 50% efficient while learning the process. In the best of cases, the learning curve will take a few months. Because opportunities and technology change as time evolves, additional training may be necessary to meet new requirements. Training should be ongoing and it should involve every employee at every level.

What type of training is effective? Seminars are extremely effective in providing the basic information needed for a particular industry or a specific operation. However, these should be coupled with specifically tailored programs performed in-house using the company's equipment. The combination of classroom and hands-on training creates an ideal training structure that produces the best efficiency and productivity. Employees should be given an opportunity to apply their recently acquired "book" knowledge to resolve current issues.

Training helps to stabilize the work force. When training is job-specific and tailored to the company needs, employees feel more inclined to stay with the company and utilize their newfound knowledge. Of course, the higher the level of training achieved, the greater the employee value, and wages must keep pace or the employee may find financial incentive to go elsewhere. Proper training and adequate wages go a long way to foster employee allegiance and dedication to a company.

SUMMARY

The concept of organizational structure is more than just a flow chart that shows levels of authority. It includes:

- Getting the most productive work from employees.
- Minimizing the number of employees required.
- Defining responsibilities and reporting relationships.
- Ensuring efficient flow of information and communication.
- Promoting an atmosphere of camaraderie among all personnel, especially between management and labor.

There are four basic phases involved in developing the organizational structure.

1. Identify the needs or functions.
2. Define individual and team responsibilities.
3. Establish reporting relationships.
4. Document the structure.

If a company uses team concepts for resolving issues, the teams should consist only of in-house members, if possible, to minimize reporting activities and maximize communications.

After the functions, or departments, have been identified, they can be analyzed to determine which can be combined, which need to be expanded, and which need to be eliminated, or added. The final list becomes the basis for the organizational chart.

In today's world of high technology, it is advisable to eliminate the need for clerical and secretarial help through use of personal computers and network systems. All levels of management should be encouraged, and expected, to create and publish their own reports, documents, filing systems, etc., and make them available to, and compatible with, other similar documents within the company.

Reporting directly to the chief executive officer (CEO) are the president and the vice president. Each of these positions has a series of department managers reporting to it. In most cases, the president is responsible for the production side of the facility, while the vice president is responsible for the marketing and finance side.

The position of president entails complete responsibility for the day-to-day operation of the molding facility.

The position of vice president entails responsibility for the planning and accounting operation of the molding facility.

The national average for the total number of company employees needed for each molding machine on the floor is 8.5.

Every team must have continuous direction. At the same time, every team member must be allowed to demonstrate his or her performance excellence. Every team ever assembled consisted of, and depended on, individual actions.

There has always been a tendency to consider the manufacturing floor to be separate from the rest of the company. This should be discouraged as much as possible by placing manufacturing and engineering under the same reporting path.

While conflict and personality differences are inevitable, they should never be considered when determining reporting structure.

Use of a flow chart is usually the best way to describe the reporting structure. This, along with job descriptions, should be posted for all employees to refer to at any time. Everyone likes to know exactly what is expected of him or her and what he or she should expect from others.

QUESTIONS

1. What are the four basic phases involved in developing the organizational structure?
2. Define the responsibility areas for the president and vice president of a molding company.
3. What is the primary responsibility of the Human Resources department?
4. What is the primary responsibility of the Manufacturing Engineering department?
5. What is the primary responsibility of the Process Engineering portion of the Manufacturing Engineering department?
6. What is the primary responsibility of the plant manager?
7. According to the national average, the total number of company employees needed for each molding machine on the floor is _____.
8. Which employees require a job description?
9. If a shop runs 24 hours a day, 5 days a week, when can scheduled maintenance be performed?
10. Why should the engineering and production areas be separated on the reporting structure chart?
11. Why do employees need to know the information contained in job descriptions and organizational charts?

11 Quality Control Concepts

Dictionaries list many definitions for "quality," but those that might directly apply to injection molded products include ". . . superiority of kind," and ". . . degree or level of excellence." While the actual definition may be debatable, the amount of time and money spent each year to achieve high quality standards demonstrates its importance. The goal is to provide the expertise, equipment, materials, and tooling necessary to make a product according to the customer's expectations and/or specifications. This is possible, but it can be extremely expensive, if not reasonably defined.

The actual definition of quality must be created for every molded product, and must be as detailed and quantitative as possible, without going to extremes. For example, the customer should state the length for the part and have a practical tolerance range placed on it to show the highest and lowest dimensions. For normal purposes, this might be plus or minus one specified dimension. But for extremely critical fit or function, the tolerance might be greater. This tighter tolerance reduces the processing range for the molder to a point where constant adjustment must be performed to mold parts that are within the acceptable range. During this process, many defective parts will be produced and these will have to be scrapped or reworked. Of course, every part must be paid for, so the cost of the scrapped parts must be absorbed by the cost for the accepted parts. This results in a much higher piece price than if the looser tolerance had been specified.

Any dimensional tolerance or characteristic note regarding the expected quality level of a molded part must be defined in proper detail. Saying that a part must be "blue" in color is too vague because there are thousands of shades of blue available to the molder. This vague statement allows parts to be anywhere from a light, pale blue to a dark, midnight blue. A standard color code number should be matched from one of the many industry color palettes that are available. Of course, if the shade or hue is not important, the vague statement is acceptable. Then, as long as the parts are molded in any blue, they can be determined to have an extremely high quality level, at least as far as color match goes. The cost for this low-detail quality is much less than for high-detail quality.

Quality requirements are not difficult to determine if they are well defined. In most cases, the function of the finished part (or assembly of parts) is the determining factor as to whether or not it is acceptable to the customer. If functional parts are produced with nonconforming dimensions and they are deemed acceptable, the print should be changed to reflect the acceptance. This can become a major problem with many customers, but the molder should make the request to change the print because it is considered legal documentation of the part quality. Letterheads with formal exceptions are only temporary and cannot be used as a permanent override of the print callouts. Phone calls and scraps of paper with scribbled notes will not stand up in court.The molder must be able to make parts to the legally accepted part print. But, the part print must be properly defined to allow the molder to do that. It is usually easier, less expensive, and less time consuming, to change the part print to match the parts rather than change the tooling and process to match the print.

QUALITY PROGRAM SELECTION

There are so many quality buzzwords and programs that it is difficult to learn and understand what they mean and how they help. When it comes to determining which to use and which to avoid, the decision must be based on what the customer wants. Almost every industry has its own guidelines and requirements; some mandated by the federal government. Not all customers are concerned about industry standards, but many will work only with those molders in compliance with their own quality program, as is sometimes found in the automotive and aircraft industries. In other cases, a customer will not deal with a vendor that has not registered in worldwide standards programs, such as ISO (International Organization for Standardization, also referred to as International Standards Organization) 9000. There are many books written about quality programs that may be worth reading before making any decisions. However, in this book, the ISO 9000 standard will provide basic quality information that will help any company create an effective quality control program. It has become the basis for most of the quality programs in existence today.

ISO 9000

ISO 9000 is the name given to a system of business reflection, documentation, and auditing activities developed by the European industrial communities and adopted by other countries to provide positive and meaningful standard quality concepts among member companies. It was expected that if a company was ISO 9000 registered, its standard practices and procedures were automatically compatible with the needs of a potential customer. Therefore, business could be conducted without expensive, time-consuming surveys and certification studies. The ISO 9000 program grew to include North America because Americans felt the program would give them an advantage in the European industrial marketplace. The assumption was that if they were ISO 9000 registered, they would be in a position to provide products and services to a worldwide market without needing to “qualify” each bid.

In the United States, Underwriters Laboratories was selected to implement, train, register, and audit the ISO 9000 program. This provided a local source of registration and made it convenient for companies within the U.S. to attain ISO 9000 registration in a relatively short period of time (12–18 months). The program was immediately successful and many companies participated while visualizing huge profits from the anticipated increase in business. However, that never materialized. Increased business came about, but nowhere near the volume that was expected.

However, the American ISO 9000 program was not a bust. The companies that did participate discovered many ways to improve their existing business and company structure, resulting in greater productivity, increased profitability, and improved efficiency. They found that the preparation process for becoming ISO 9000 registered forced them to define what they were actually doing versus what they were supposed to be doing. This awareness proved to be extremely enlightening and resulted in immediate benefits from the implementation of proper procedures, methods, and processes. As the improvements were made, existing customers began to request additional work, and potential customers were easily recruited.

ISO 9000 is not a set of quality rules by which the company must abide; it is not a tested method of applying specific quality standards; and it is not a regulatory agency that controls how a company is run. ISO 9000 is a concept that forces the company to look at itself and answer the basic question, "what does this company (or department, or area) do and how is it done?" Then, the ISO 9000 concept states, "show that the company can do it," and "properly document this activity." Finally, ISO 9000 says, now "audit the activity at random" and make sure the company continues to do what it said it could do and how the company said it would be done.

ISO 9000 is the name of the overall concept. It is classified in the categories 9001, 9002, 9003, and 9004. A company determines what type of business or service it has to offer and this defines which category it matches. Most full-service molders are classified as ISO 9002.

To grant ISO 9000 recognition (formal registration), the inspection team must be satisfied that a company has specific procedures in place for reliably controlling its operations in the following areas of concern:

- Management responsibilities.
- Quality system.
- Contract review.
- Document control.
- Purchasing.
- Customer-supplied materials.
- Product identification and traceability.
- Process control.

- Inspection and testing methods.
- Inspection, measurement, and testing equipment.
- Inspection and test status.
- Control of nonconforming materials.
- Corrective action.
- Handling, storage, packaging, and delivery.
- Quality records.
- Internal quality audits.
- Training.
- Statistical techniques.

As can be seen, these areas are the same that must be considered for a good manufacturing and quality approach. They are basic areas that need to be defined, implemented, audited, and improved throughout the life of the company. Certification is not an approval. It is a notice of recognition (through a central registration agency, ANSI—American National Standards Institute) that a company meets the requirements set forth by the ISO 9000 policy. For this, the company is awarded a plaque along with a seal to attach to the company's letterhead. Every 6 months to 1 year the company is audited to ensure continued compliance with its statements. If nothing has changed, the company continues to receive the recognition. If it fails an audit, it may lose the formal recognition.

ISO 9000 recognition will not earn more business. However, the exercise to achieve recognition will expose the internal faults and discrepancies so they can be fixed, altered, improved upon, or eliminated. This will help a company become a lean machine that is highly productive, with improved efficiency, leading to greater profits and more business because it is now in a more competitive position.

ISO 14000

The ISO 14000 program is designed to do for environmental management what ISO 9000 did for quality management. Inspectors are instructed to look for, ". . . commitment to compliance with applicable legislation and regulations, and for continued improvement."

It is wise to consider obtaining both the ISO 9000 and ISO 14000 recognition. After the mechanism is in place for attaining ISO 9000, the attainment of ISO 14000 is fairly easy. The double recognition gives a company the marketing edge over companies with only one. ISO 14000 recognition helps alleviate environmental regulatory burdens and liabilities. Implementing the procedures required to obtain ISO 14000 will also help minimize resource requirements (such as water and electricity) for the molding facility, thus reducing operating costs and increasing profit levels.

THE QUALITY MANUAL

Every injection molding company needs documentation of standard procedures to perform for specific conditions. None of these documents is more important than the quality manual. This document must be created to delineate individual and organizational responsibilities in connection with process control, product test requirements, and audit responsibilities for the manufacture of plastic parts and assemblies.

The quality manual should mandate that certain procedures and methods be followed to achieve the highest possible level of excellence (as negotiated with the customer) in the production, inspection, testing, and shipping (including special packaging) of finished products. It should direct manufacturing personnel to utilize the manufacturing equipment in a manner prescribed in an accompanying manufacturing certification manual.

The manual should also, with the cooperation of processing departments, dictate the listing and daily monitoring of critical parameter settings, times, and temperatures related to the molding operation. It should also outline the testing procedures and methods required to be performed (at specified frequencies) by quality or manufacturing personnel for critical dimensions as determined by the customer. Periodic auditing (regular and random) of finished products should be outlined and implemented through direction of the quality manual.

Other items that are typically included in a quality manual are detailed inspection procedures for specific parts, material vendor certification requirements, material handling and tracing procedures, and specifications and procedures for special testing (such as melt flow index or moisture content) to ensure molding uniformity.

SUMMARY

Dictionaries list many definitions for "quality" but those that might directly apply to injection molded products include ". . . superiority of kind," and ". . . degree or level of excellence." While the actual definition may be debatable, the amount of time and money spent each year by the industry to achieve quality standards is high. This demonstrates the importance of providing the expertise, equipment, materials, and tooling necessary to produce a product exactly to the customer's expectations and/or specifications.

The actual definition of quality must be created for each molded product, and must be as detailed and quantitative as possible, without going to extremes.

Tighter tolerances reduce the processing window for the molder because continuous adjustments must be performed to mold parts that fall within the acceptable range.

If functional parts are produced with nonconforming dimensions and they are acceptable to the customer, the print should be changed to reflect the acceptance.

There are so many quality buzzwords and programs in the world today, it is difficult to learn and understand what they mean and how they help. When it comes to determining which to use and which to avoid, the decision must be based on what the customers want.

ISO 9000 is the name given to a system of business reflection, documentation, and auditing activities developed by the European industrial communities and adopted by other countries to provide positive and meaningful standard quality guidelines among member companies.

The ISO 14000 program is designed to do for environmental management what ISO 9000 did for quality management.

The quality control manual must be created to delineate individual and organizational responsibilities in regard to process control, product test requirements, and audit responsibilities for the manufacture of plastic parts and assemblies.

QUESTIONS

1. What definitions for "quality" might directly apply to injection molded products?
2. What is the primary result of requiring tight tolerances on a molded part?
3. How can an exact color shade be called out on a part print?
4. During initial mold trials, if nonconforming dimensions are detected, but the part is functional, what step should be taken?
5. What legal documents define quality?
6. What do the initials ISO stand for?
7. What is the reason for creating a quality manual?

Effective Management Practices 12

Successful management of a molding company in the next century will not only require a total commitment to quality, but also a need to strive for long-term relationships with customers, suppliers, and vendors. In addition, the successful molding company will need to provide extensive premolding and postmolding services, such as product design assistance, mold designing and building, and secondary operations. These business requirements will mandate a set of management practices that are stable and practical, and at the same time predictive, futuristic, and far-reaching.

DEFINITION AND REQUIREMENTS

It could be stated that the concept of effective management practices is "a dedication to continuous improvement in every category related to manufacturing." Effective management practice, then, becomes a moving target that the manager (or management team) must constantly aim for while performing the routine duties assigned to his or her job.

Effective management practices, also called EMP, are those that satisfy the requirements set forth by, or expected by, the customer for the basic management of a manufacturing facility. Every customer may have his or her own opinion of what constitutes EMP and many attempts have been made to qualify and quantify the term. In most cases, EMP is considered adequate if it meets some basic criteria. First, EMP must comply with preferred industry standards. Second, EMP must be customer-driven. Third, EMP must be concerned with quality as well as environmental issues. Fourth, EMP must consider the welfare of company employees, suppliers, and stockholders, in addition to customers.

Complying with Industry Standards

Each industry has standards for companies to abide by and upon which improvement is encouraged. For example, the medical industry is partially governed by the FDA, which mandates compliance with specific regulations concerning clean rooms and basic molding practices. If a company expects to provide molded medical products, it should investigate the industry regulations and ensure compliance with them before soliciting work from potential customers. This, of course, is true regarding any industry.

A manager committed to excellence will normally establish his or her own standards based on what is needed by the customer. Because most custom molders serve a wide variety of industries, it is often necessary to adopt a specific set of standards for each customer. It is not practical to attempt to use the same standard for all industries and customers, because the highest standard (and associated costs) then must be applied to all, and this may become an economic deterrent to receiving business from customers who do not require such high standards. The customer will simply go to the shop offering the lowest price.

Therefore, many molders are looking at specific niches, such as only serving industries or customer types that demand the same level of excellence. This allows a focused investment in equipment, training, and other resources that results in a single type of standardization throughout the molding facility. The risk associated with this philosophy is that if there is an economic slump in the niche industry (such as occurs during contract talks between automotive companies and unions), the molding company suffers due to lack of customer orders.

One sure path to failure is to assume that a company can mold anything. There are over 20,000 basic material formulations available today, with more than 100,000 combinations of different fillers, blends, and possible alloys. No molder can be expected to have the equipment, expertise, and talent available to correctly process all these materials. Also, specific part designs require certain properties and functions. A set of disposable plastic tableware does not require the same processing ability as a set of medical body implants. The successful manager will direct the company toward producing only specific types of products and selected materials to ensure compliance to standards. A company should not be afraid to reject potential customers if their product lines and material choices do not correspond to its strategies. After specific industry niches are chosen, the company should stay with them for the long term and ensure compliance with the standards associated with those industries.

Customer-driven Requirements

Whatever industry(ies) is targeted, each customer within that industry will expect a cooperative working relationship with the molding company. EMP dictates that this process be as painless as possible for the customer. For example, nothing bothers a customer more than to have multiple contacts for the transfer of information. The customer does not wish to wait on the phone and be switched from person to person when attempting to increase an order, discuss a potential engineering change, or request a quotation. Effective management practices would allow the customer to contact a single source for all communications. This source would then relay the information to or from specifically concerned employees within the molding company.

Many customers and potential customers are not really aware of what the accepted injection molding standards are, nor do they know where to find them.

The Society of the Plastics Industry provides an excellent resource for this information entitled *Standards and Practices of the Injection Molding Industry*.

Much of what a customer expects from a molding company should be determined even before a customer visits the facility. Examples of what should be identified include: expected quality standards, types of materials required, annual volume requirements, type of secondary operations needed, procurement policy for tools, special packaging requirements, and a timetable for production (and prototype if needed). After these are identified, the customer tries to match his or her requirements to the capabilities, resources, and strategies of the molder. If there is a match, a visit can be arranged. If not, the molder may be willing to suggest a different vendor that can meet the customer's requirements. This helps to foster good working relationships for any future opportunities and provides some excellent word-of-mouth advertising.

One method for determining company compliance to accepted industry standards is through benchmarking (see Appendix A). While benchmarking results should never preclude previously determined marketing and management strategies, they can be used to find new opportunities. A good source of benchmarking data is the monthly *Injection Molding* magazine. Other sources are local government publications and studies, and worldwide annual data from the Society of the Plastics Industry.

Benchmarking can be used to see how one company compares with other companies in a certain specialty area. For example, if the percentage of parts scrapped internally at a company is greater than the industry standard as compared to the total number of parts produced, benchmarking results will reveal that fact. Positive bench-marking results will show that the management practices are proper and moving in the right direction.

Quality and Environmental Issues

There are many standard quality procedures and tests that the injection molding industry has adopted. These include the *melt flow index* as a material flow indicator, *moisture analysis* and/or *dew point measurement* to determine moisture content of raw materials, and *certification requirements* for both incoming and outgoing materials and products. The most commonly recognized standards are the ISO 9000 quality standard and the ISO 14000 environmental standard.

The main reason customers are so adamant about quality and environmental standards compliance is that consumers and the government are mandating adherence to rigid standards in these areas. The entire supply chain is affected; products can only be as quality and environmentally excellent as the vendors supplying those products. Therefore, a molder should demand compliance from material suppliers, moldmakers, and any other vendor used. Compliance with quality and environmental standards will help reduce liability in cases of product failure or environmental disaster, and will provide an image of good corporate citizenry for the company and the industry.

Welfare of Others

EMP can play a major role in gaining allegiance from employees, vendors, customers, and suppliers by providing tactical programs that foster cooperation, opportunity, and prosperity.

Employees

Employees are the most valuable resource any molder can have and they deserve to be treated as such. Beyond wages and the standard benefits, EMP allows for profit-sharing programs, annual bonuses, award programs, and achievement recognition for all employees at all levels.

While most companies spend some amount of money on training programs, the majority is usually spent for off-site training of higher level management and supervision rather than for more effective on-site training of floor personnel, such as operators and technicians. Yet, the floor personnel are the ones most vital to the company and can benefit the most from such training. EMP states that the majority of training resources should be expended on lower-level personnel. Certificates of completion are welcomed by employees and should be made a standard feature of all training programs. Copies of these should be placed in employee files, and can used as proof of compliance for all quality programs.

The work environment must be a prime factor when considering employee welfare. An employee should have an environment that is comfortable and inviting. Many molding shops utilize air conditioning and humidity control to maintain a constant environment for equipment and molding machinery. These also provide a comfortable work environment for the employee, resulting in improved attendance and greater productivity. To determine whether or not the work environment is acceptable, EMP asks this prime question: Would an employee enjoy coming to work here every day?

Employees are a great source of information regarding improvements that can be made to a process, procedure, tool, or machine. The closer they are to the operation, the more effective their suggestions. EMP considers solicitation of ideas from the most direct employees regarding specific operations, and will reward implemented ideas with money, gifts, or promotions. Comments and opinions should be solicited from floor personnel and they should be included in any decisions made for the implementation of additional equipment, tooling, or procedures.

Vendors

Vendors should be considered valuable resources. EMP dictates continued and demonstrated loyalty to select vendors to ensure the lowest cost, best availability and selection, and quick delivery times. One of the biggest complaints vendors have is slow or late payment of invoices. There is an appearance of no consideration for the welfare of the vendor when he or she must constantly phone the customer to collect for a product or service already delivered. This results in a lack of interest from the vendor the next time an order is placed by the customer. Vendors are in business to make a profit and explore new opportunities. Negotiations may reduce prices and lead times, but a vendor should not be expected to lose money. EMP allows the vendor to make a reasonable profit without overpricing.

EMP also dictates that it is a good idea to involve vendors when making decisions as to which products or services should be purchased. Early involvement with vendors will provide less chance for communication problems and delivery delays when it comes time to purchase.

Customers

Without customers, no business can stay a business for very long. In one way or another, the existence of every business depends on the existence of its customers. We have all heard the statement that, "the customer is always right." Well, in the molding business, it is the job of the molder to advise and assist the customer until their product and requirements actually are "right." Seldom does a customer come through the door with a part that is properly designed for manufacturing, and/or with the proper material selected. It is the responsibility of the molder, using EMP, to advise the customer on what design or material changes can be made to improve the quality, price, delivery, or manufacturability of any given product. By looking out for the customer's welfare, the molder creates a relationship that will prove to be long-lasting and profitable as the customer becomes more and more comfortable with the molder's practices.

Customers are not easy to please. With few exceptions, they normally do not have the expertise required to understand the molding process and the methods and tooling needed to make molded products. The molder can help by explaining what is needed and how it is achieved. By doing so, the molder allows the customer to understand requests for certain design changes or quotes for tooling that seem high.

Customers expect delivery of their products on a timely basis. Usually, the delivery date is negotiated ahead of time and is specified on the purchase order. The molder is expected to meet this delivery date, whatever it is. Too often, molders miss the date and do not inform the customer of the expected delay. Then the customer, assuming parts are coming in, starts up the assembly equipment, puts people to work, and/or makes other arrangements to accept the parts and get them to a waiting market. Undelivered parts usually mean tragic financial losses to the customer. EMP should not allow this to happen; sometimes deliveries cannot be met, but every effort should be made to keep this from happening. If and when it does happen, the molder has an ethical (if not legal) obligation to inform the customer, as soon as the information is known, of the delayed delivery and what steps are being taken to expedite a solution. Of course, the customer will be mad. But, at least he or she can now adjust resources to accommodate the problem and minimize any probable financial loss. The customer may even be able to help.

For example, if the company truck breaks down, the customer may be willing to send his or her own truck to pick up the delivery.

Some customers expect to be wined and dined whenever they visit a facility. This is not a good practice and should be discouraged. A catered lunch, served in the company cafeteria or in a conference room, will demonstrate the concern for the customers needs and can be made a standard practice for all customers. EMP reflects that all customers should be treated equally. This applies to holiday gifts as well. Most large companies do not allow their employees to accept gifts with a value of more than $25,and some companies do not allow acceptance of any gifts at all. EMP states that gifts should be limited to items less than $25 in value and should be the same for all customers. This helps to minimize the appearance of favoritism and demonstrates the company's efforts to reduce overhead costs.

ALLIANCES AND PARTNERSHIPS

Many companies cannot afford to invest the resources or space to provide customers with additional services or secondary operations on-site. Nor can they afford to provide a service that is only utilized on-site a few months out of the year. To penetrate new markets without having to spend the time and money to research and develop the opportunity, many companies have developed an alliance or partnership with another company.

Strategic Alliances

A strategic alliance is a formal, contracted arrangement between two or more companies, each offering a specific expertise, equipment, or process to attain a negotiated, agreed-upon goal. They all contribute and share the rewards. The primary advantage is that each company's resources are greatly increased without investing time and money in additional equipment or personnel.

The formal contract for the alliance must detail the expected contribution and benefit for each company and a precise plan must be outlined. This plan is developed with the cooperation of all the parties involved and becomes the reference guide for determining individual involvement as opportunities arise.

A strategic alliance can be formed between a molder and moldmaker, between two molders, or, between a molder and its vendors. In the latter case, the molder is able expand its capabilities while the vendor expands its business, each with little or no investment.

Effective management practices (EMP) utilize strategic alliances to increase productivity and sales volumes while minimizing resource investment. But, EMP also requires the ability to work with existing employees to develop healthy work attitudes toward any alliance, otherwise, blame will occur any time the process falters.

Partnerships

To reduce vendor bases and minimize procurement hassle, many customers are attempting to form "partnerships" with vendors. While the goals may be the same, a partnership is usually less formal than a strategic alliance and does not normally involve the use of legal contracts. However, a partnership does involve a great deal of trust. Each partner must be allowed to know the pricing and cost structures of the other's products or services to provide the basis for forming the partnership. For example, a computer manufacturer (OEM—original equipment manufacturer) may wish to enter into a partnership with a full-service molder. The main advantage to the OEM is that a single vendor can provide all the plastic parts, finished and ready for final assembly. In addition, the OEM may not have to use a quotation process because it already has access to the costing structure of the molder and can estimate costs accordingly. The advantage to the molder is its "preferred vendor" status, eliminating the need to bid low to get the business. There will be steady work available as long as the intent of the partnership is satisfied.

EMP dictates that the company must be able to accommodate the detailed "intrusion" of privacy; the molders books, procedures, costing methods, testing procedures, processing conditions, quality standards, etc., must be made available to the partner (customer) on a regular basis. It is not easy for a molder to allow customer access to such private information, but partnerships cannot exist without it. It is the duty of the managers to provide the data willingly, while protecting the interests of the company. Of course, it is expected that the customer will not make such information public, and some partnerships require signed confidentiality agreements.

Partnerships are most effective when the vendor is geographically close to the OEM. In some cases, the vendor may place a section of its company within the walls of the OEM's building. As the distance between vendor and OEM increases, the effectiveness of the partnership dwindles. Close proximity is the major reason for success of the maquiladoras (twin businesses) on the Texas-Mexico border. These vendor-OEM partnerships are located such that the vendor is literally across the street from the OEM. This allows just-in-time (JIT) delivery of product to the OEM and stability and growth opportunity to the molders.

There are many other molder-customer or molder-vendor arrangements. They include (in ascending order of effectiveness) equity investment, cross-licensing, joint ventures, mergers, acquisitions, and subsidiaries. They each have their place and level of opportunity and each should be investigated as a logical means of improving business and growth.

EFFECTIVE COMMUNICATIONS

The two sentences that follow both say the same thing:

1. The controlling federal influences regarding measurement of employee's continuance of performance activities dictate that an alteration be discharged in the manifestation of a time measurement device to be positioned in proximity of the employee's ingression portal. It is mandated that each person utilize the device to chronicle daily performance activities in a precise manner.
2. According to government regulations, a time clock will be placed at the employees' entrance. Please be sure to use the clock to record your daily activities.

Which statement is the easiest to comprehend? Which is most effective in communicating the message? Which should the EMP manager use? This exercise demonstrates what is meant by effective communications. Words can have many meanings. But two words with identical meanings may portray two entirely different messages if they are not properly utilized, or if they are placed in the wrong context.

EMP must include effective communications to ensure that all employees understand what is expected from them and what they can expect from the company. Effective communications ensure that information transfers between the company and customers are accurate and have the same meaning to both parties. EMP must dictate use of effective communications among all company personnel or that order for 10,000 parts shipped to Austria may become 1,000 parts sent to Australia.

Exact words should be used to describe exact items or conditions. As Mark Twain once said, "If you think exact words are not important, consider the difference between lightning and lightning bug." EMP states that communications are effective only when the right words and methods are used to convey information. A scribbled note on a piece of scrap paper cannot be expected to have the same effect or portray the same importance as a properly typed message. Although communications should contain as much detail as necessary, they should never be lengthy or wordy. Short, right-to-the-point statements should be used. In fact, bulleted comments are the most easily remembered.

Verbal communications should be made with steady eyes, looking directly at the person (or group) being addressed, and with an aura of interest in the subject being presented. A short course in proper presentation methods can be extremely valuable (and highly recommended) to the manager (and his employees).

UNDERSTANDING TIME RELATIONSHIPS

Time is a resource that is the very core of what the injection molding process is all about. Every product is molded during a certain cycle of time. The product is priced using a basis of how much time it took to produce. Profits are based on how many parts can be produced in a given amount of time. Therefore, time should be closely monitored and utilized to its fullest potential. An EMP program should establish goals of production based on the minimum possible cycles needed for producing acceptable parts. Because each molding machine has its own idiosyncrasies, every mold should run only in the most productive mold-to-machine combination available.

On average, every second of manufacturing time in a molding plant has a value of $0.0125, per machine ($45 per hour ÷ 3,600 seconds per hour). This value ($0.0125) is the operating cost for a 300-ton machine, which is running 6,000 hours a year and does not normally include revenue from material and tool sales, or profit, markup, and burden. If every 30-second cycle is reduced by 1 second, there is a potential savings of $8,100 a year per machine. For the average eight-machine facility, this represents annual savings of $64,800. This goes directly to the bottom-line profit. Studies have shown that a molding facility has about 30% of its molding machines operating with excessive cycles (Texas Plastic Technologies). Excessive cycles are defined as those running at least 5 seconds too long. This can add up to some hefty revenue loss over a 1-year period. Because of the great potential for profit or loss, EMP programs should be instrumental in ensuring that all manufacturing processes, especially molding, are optimized and monitored for maximum productivity and minimum downtime.

MAKING ADJUSTMENTS

No management strategy should be considered fixed. Flexibility is key to developing management strategies and effective management practices. Worldwide economic conditions, federal regulations, state-wide business enhancement programs, etc., must be considered and monitored on a regular basis to determine whether or not existing policies should be altered to accommodate changes. Any EMP program requires an understanding of existing laws and regulations, along with commitments to employees, suppliers, and customers.

It is suggested that the EMP program and its policies be administered through an EMP board consisting of representatives from Human Resources, Manufacturing, Engineering, and the company president's office. Meetings should be held regularly to discuss required policy changes, but these meetings should be short, to the point, and productive. "Productive" means that each attendee should understand the reason for calling the meeting and bring recommendations. In addition, at the end of the meeting each attendee should know what is to be done and what the individual roles will be in implementing any changes.

Each manager in the company must be able to look at his or her area of responsibility and determine what specific items should be implemented, altered, or deleted based on the impact to the area. However, all EMP policies should be created and developed to apply to all areas and departments whenever possible. If a policy is directed toward only one department, it must be scrutinized to assess its value to the company because it could most likely be deemed biased.

In all, EMP programs are intended to provide policies for guidance in overall terms. Specific situations require specific solutions, and there will always be individuals finding fault with any policy program. The EMP program must be designed to be the "umbrella" policy, with each manager then responsible for implementing the general provisions, and providing individual solutions for specific situations. Human Resources should be consulted for any situation not covered directly by the EMP.

PROVIDING MOTIVATION

Money is not the primary motivator for all employees. Many studies over the last few years have demonstrated that job satisfaction, opportunity for advancement, and company recognition are greater motivators than money. This is not to say money cannot be a part of all these motivators, but money itself is considered only a temporary encouragement.

Employees deserve to be treated fairly and with respect, regardless of their position within the company. People usually treat others as they are treated. Thus, EMP should demonstrate respect and fairness through example by the managers. This practice must prevail through all management levels, including the president and CEO.

Recognition goes a long way in developing motivation. Every employee wants to believe they are contributing something to the success of the company and a word of thanks once in a while from management reinforces that belief. Employees should be made to understand and believe that their job performance is critical to the success or failure of a particular product, project, or process. They should be made aware of how the finished product is used by the customer, and, if possible, be shown working models of the final product in action. This provides a feeling of association between the product and the employee's individual involvement in its manufacture. This, in turn, provides a positive feeling of personal pride and accomplishment, which are their own motivators.

Of course, money can motivate. To start with, fair wages should be paid for all job levels. What is fair can be determined by benchmarking similar jobs in the immediate area and adjusting wages accordingly. If good employees are desired, good pay must be offered. EMP must provide a fair process for employees to advance in rank or wages based on job performance and company requirements.

Finding the right motivational tools is a challenge. EMP should accept this challenge and routinely adapt the motivators that make sense for the company and the employee. Surveys of existing employees may provide the basis for selecting motivational tools. However, most people will place money at the top of the list when answering an impromptu survey question. Only when the question is well delivered and seriously considered will the employee answer in a more thoughtful manner. One thing is sure: a company should do whatever is feasible to hire and keep productive, efficient, and motivated personnel.

SUMMARY

Successful management of a molding company in the next century will not only require a total commitment to quality, but also a need to strive for long-term relationships with customers and vendors.

The concept of effective management practices could be defined as, "a dedication to continuous improvement in every category related to manufacturing."

In most cases, EMP is considered adequate if it meets some basic criteria. First, EMP must comply with preferred industry standards. Second, EMP must be customer-driven. Third, EMP must be concerned with quality as well as environmental issues. Fourth, EMP must consider the welfare of company employees, suppliers, and stockholders, in addition to customers.

A manager committed to excellence will normally establish his or her own standards based on what is needed by the customer. As most custom molders serve a wide variety of industries, it is necessary to adopt a specific set of standards for each customer.

One sure path to failure is to assume that a company can mold anything. There are over 20,000 basic material formulations available today, with more than 100,000 combinations of different fillers, blends, and possible alloys. No molder can be expected to have the equipment, expertise, and talent available to correctly process all these materials. Also, specific part designs require specific properties and functions.

A company should not be afraid to reject potential customers if their product lines and material choices do not correspond with its strategies. After the specific industry niches are chosen, a company should stay with them for the long term and ensure compliance with the standards associated with those industries.

One way to determine company compliance to accepted industry standards is through benchmarking. While benchmarking results should never preclude previously determined marketing and management strategies, they can be used to find new opportunities.

The main reason customers today are so adamant about quality and environmental standards from their vendors is that customers are being asked by the consumer to adhere to rigid standards in these areas.

EMP can play a major role in instilling allegiance from employees, vendors, and customers by providing tactical programs that foster cooperation, opportunity, and prosperity to all.

A strategic alliance is a formal, contracted arrangement between two or more companies, each offering a specific expertise, equipment, or process to attain a negotiated, agreed-upon goal. While the goals may be the same, a partnership is usually less formal than a strategic alliance and does not normally involve the use of legal contracts.

Words can have many meanings. But two words with identical meanings may portray two entirely different messages if they are not properly utilized or if they are placed in the wrong context.

On average, every second of manufacturing time in a molding plant has a value of $0.0125, per machine ($45 per hour ÷ 3,600 seconds per hour). This value ($0.0125) is the operating cost for a 300-ton machine, which is running 6,000 hours a year and does not normally include revenue from material and tool sales, or profit, markup, and burden.

Studies have shown that on average a molding facility has about 30% of its molding machines running excessively long cycles.

QUESTIONS

1. What will be the primary requirement for a successful molding company in the 21st century?
2. Define the concept of *effective management practices* (EMP).
3. On what does a manager committed to excellence determine his or her standards?
4. What is the primary advantage of a molding company serving a specific niche?
5. What could be a sure path of failure for a molding company?
6. According to EMP, how many employees of a molding company should a customer contact to obtain information?
7. How can benchmarking results be utilized?
8. Why are so many customers adamant about quality and environmental standards compliance from their vendors?
9. What is the most valuable resource a molder can have?
10. According to EMP, what question should be asked to determine whether or not an employee's work environment is acceptable?
11. What is one of the biggest complaints vendors have of their customers?
12. What advantages are there to involving vendors early in the EMP decision-making process?
13. What does the existence of any business depend on?
14. Define the term *strategic alliance*.
15. When are partnerships most effective?
16. On the average, what is one second of manufacturing time worth for each machine in a molding facility?

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Answers to Chapter Questions

CHAPTER 1

1. 1868.
2. 1872.
3. The presence of World War II created a demand for inexpensive, mass-produced products.
4. 1979.
5. Injection molding can be defined as a process which consists of heating a plastic material to a point at which it becomes soft enough to force into a closed mold, at which point the material cools down enough to solidify and form a specific product.
6. Over 100.
7. Four.
8. 500° F (260° C).
9. The softening (or melting) of the plastic is achieved by causing the individual molecules within the plastic material to go into motion.
10. Rear, center (middle), front.
11. 225° F (107° C).
12. The heat exchanger.
13. Injection pressure, holding pressure, clamp pressure.
14. To determine the viscosity, therefore the relative ease of flow of the molten plastic.
15. *Clamp pressure* can be defined as the amount of pressure required to hold the mold closed against injection pressure.

CHAPTER 2

1. Any complex, organic, polymerized compound capable of being shaped or formed.
2. A reaction caused by combining a monomer with a catalyst, under pressure, and with heat.

3. Crude oil and natural gas.
4. To create copolymers, it is necessary to react monomers of different groups together.
5. An *alloy* is a material formed by mixing two (or more) basic plastics to form a "new" plastic, while a *blend* is not homogenous and merely exhibits an average of the property values of the original plastics.
6. A plastic material that when heated, undergoes a *physical* change. It can be reheated and reformed, over and over again.
7. A plastic material that when heated, undergoes a *chemical* change and "cures." It cannot be reformed and reheating only degrades it.
8. Amorphous and crystalline.
9. *Amorphous* materials are those in which the molecular chain structure is random and becomes mobile over a wide temperature range.
10. In *crystalline* materials, the molecular chain structure is well ordered and becomes mobile only after the material is heated to its melting point.
11. Any three of: clear, low shrinkage, high impact, poor chemical resistance, and low lubricity.
12. Any three of: opaque, high shrinkage, low impact, good chemical resistance, and high lubricity.

CHAPTER 3

1. Adequate information about the types of products that will be manufactured.
2. Thin-walled, high-volume parts will require fast cycling equipment with state-of-the-art controls to allow competitive pricing.
3. "Full-service."
4. This means the customer wants a single vendor to be responsible for all the activities involved in the total production of a product.
5. There are over 20,000 plastic materials to choose from today. When including all of the filler combinations and various grades of plastics, this number quickly climbs to 100,000 choices.
6. 1,875 kVA.
7. Generally speaking, automation requires space.
8. A broker performs a title search and guarantees free title.
9. This will provide the flexibility to produce a wider variety of products on a limited number of machines.
10. A specific point in one cycle to that exact same point in the next cycle.
11. 60,000 pieces.
12. Multiply the projected area (in $in.^2$) by a factor from 2 to 6 tons per $in.^2$ to determine the total amount of clamp tonnage required.

CHAPTER 4

1. Under-the-press, beside-the-press, and centrally located.
2. Hygroscopic.
3. Tomasetti volatile indicator (TVI).
4. Mechanical, vacuum, positive pressure.
5. 50 ft (15.2 m).
6. To combine two or more materials.
7. To reduce the size of molded material to resemble virgin pellets.
8. Two, one to each half.
9. Water and oil.
10. Rigid and flexible.
11. Flexible.

CHAPTER 5

1. Utilities can be thought of as nonhuman resources required for the operation of primary and secondary equipment. They include electricity, water, and compressed air.
2. From 15–50% or more.
3. 480 volt, three-phase, 60 cycles.
4. 100 kVA.
5. Proper lighting levels are determined by the size of the area being lit, the reflectivity value of the wall surfaces, and the ceiling height of that area.
6. The basic need is 1 watt of lighting per ft^2 (0.09 m^2) of area.
7. 18 kVA (1 kVA per 1,000 watts).
8. For controlling mold temperature and oil temperature.
9. The biggest advantage is that it allows much more operating space above ground.
10. They are either two-stage reciprocating compressors or rotary screw compressors.

CHAPTER 6

1. If materials are stored too long, or improperly, additional costs are incurred through the need for excessive storage space and potential contamination to the resins.
2. The amount of storage space required is determined by what is being stored.
3. Steel racks.
4. When molding a large volume of a specific resin, consider using a silo.
5. The major disadvantage of a silo is that it is impossible to know exactly how much material is left in storage at any one time.

6. The moisture level of resins must be in the area of 1/10th of 1 per cent, by weight.
7. All materials should be dried prior to processing.
8. The more control a molder has of various processing parameters, the lower the cost to manufacture a product and the fewer the number of rejects produced.

CHAPTER 7

1. Every injection molding operation should incorporate a tool room.
2. The decision for choosing the type of tool room must be based on many factors, including the availability of local talent and expertise, amount of funding available, the degree of control desired, and the number and size of molds involved.
3. This provides a visual example of how the parts were being produced for the mold maintenance area.
4. Failure to lubricate moving components, such as slides and cams, or leader pin bushings, will result in a galling of the sliding components which will eventually cause the components to seize.
5. The toe should be adjusted to point in toward the platen to ensure that the clamping forces are directed toward the platen.
6. This strap is used to connect the two halves of the mold and keep them from coming apart during transportation.
7. Each mold half should be mounted with at least one clamp in each of the four corners.
8. The injection screw should be left in the forward position of the barrel when a job is shut down.
9. The screw will spin freely in the beginning, but slows down considerably as the fresh material is brought forward.
10. Short-term storage has a duration of from 1–30 days.
11. Long-term storage is considered 30 days or more.

CHAPTER 8

1. A proper plant layout is needed to ensure the most effective use of space available, and allow ease of expansion to accommodate future growth opportunities.
2. Angled, parallel, and side-by-side. In addition, there is a reversed side-by-side variation.
3. Everything that is needed for the total production of a finished product.
4. Clean rooms are rated by a class numbering system and include Class 100 (the most stringent), Class 1,000, Class 10,000, and Class 100,000 (the least stringent).
5. The most common clean room environment is a Class 10,000, which is suitable for most medical and electronic component molding.

6. For the greatest degree of efficiency and the highest level of productivity, the flow of materials through a molding facility should be as close to straight-line as possible.
7. Consistent cycles are critical to producing consistent products, and human beings are not capable of maintaining the same level of consistency as an automated machine.
8. The most common form of expansion is simply to "push out the walls" of the primary facility.
9. A rough estimate of the building size can be made by calculating an average requirement of 1,200 ft^2 (111.5 m^2) for every molding machine in place.
10. In most cases, a ceiling height of 16 ft (4.9 m) is adequate, but large machines may cause this to increase to 20 ft (6 m) or more.
11. Plastic materials usually have a freight charge that averages around $.05 per pound (0.023/kg).

CHAPTER 9

1. The single most common cause of failure of any startup company or venture is insufficient capitalization.
2. A "full-service" vendor.
3. A full-service vendor is one who takes complete responsibility for tool design, mold making, molding production, secondary operations, quality, and shipping of a finished product.
4. It provides a ready source of equipment, already installed and operating, and a source of personnel (assuming the desire to retain existing employees).
5. On average, remanufactured equipment can be purchased for around 50–80% of the cost of new equipment.
6. An average cost that can be generally applied for secondary equipment is approximately $25,000 per station, including tooling.
7. All primary equipment and material handling equipment can be depreciated over a normal period of 7 years.
8. If equipment is designed specifcally for a particular product, and is intended only for that product, the equipment should be depreciated over the expected life period of the product, normally 3 to 5 years.
9. Operating costs must be calculated to provide the basis for establishing selling prices.
10. 35%.
11. On average, the water flow rate requirement for a single machine and single mold is approximately 50 gal (189 L) per minute to provide turbulent flow.
12. There is an average peak requirement of 300 kVA for every molding machine on the floor.
13. 6,000.
14. Machine-hour rate.

CHAPTER 10

1. There are four basic phases involved with developing the organizational structure.
   a. Identify the needs or functions.
   b. Define individual and team responsibilities.
   c. Establish reporting relationships.
   d. Document the structure.
2. In most cases, the president is responsible for the production side, while the vice president is responsible for the marketing and finance sides.
3. The Human Resources department is responsible for developing and implementing a company-wide personnel policy that addresses the quality-of-life issues and concerns of company employees at all levels.
4. The Manufacturing Engineering department has the responsibility to develop standards and practices for establishing actual costs of manufacturing any given product.
5. The process engineering portion of the Manufacturing Engineering department has responsibility for developing processes and methods for molding and manufacturing any product made by the molding company.
6. The plant manager is given total responsibility and authority to perform all functions necessary for maintaining production operations on a day-to-day basis.
7. The national average for total number of company employees needed for each molding machine on the floor is 8.5.
8. A job description should be written for every employee within the company, including the president.
9. On weekends.
10. There are two distinct methods and thought paths between engineering (which tends to be long-term oriented) and production (which tends to be short-term oriented).
11. Everyone likes to know exactly what is expected of him or her and what he or she should expect from others.

CHAPTER 11

1. Definitions for *quality* that might directly apply to injection molded products include "superiority of kind," and "degree or level of excellence."
2. The tighter tolerance reduces the processing window for the molder.
3. A standard color code number should be matched from one of the many industry color palettes that are available.
4. If functional parts are produced and acceptable, the nonconforming dimensions should be changed on the print to reflect the acceptance.

5. The part print is considered the only legal document concerning part quality.
6. International Organization for Standardization or International Standards Organization.
7. This document must be created to delineate individual and organizational responsibilities in connection with process control, product test requirements, and audit responsibilities for the total manufacture of plastic parts and assemblies.

CHAPTER 12

1. Successful management of a molding company in the 21st century will not only require a total commitment to quality, but also a need to strive for long-term relationships with customers and vendors.
2. The concept of effective management practices could be defined as, "a dedication to continuous improvement in every category related to manufacturing."
3. The customer's needs.
4. It allows a focused investment for equipment, training, and other resources, which results in a single type of standardization throughout the molding facility
5. One sure path to failure is to assume that the company can mold anything.
6. One.
7. While benchmarking results should never preclude previously determined marketing and management strategies, they can be used for guidance in finding new opportunities.
8. The main reason customers today are so adamant about quality and environmental standards from their vendors is that the customer is being asked by the consumer and government to adhere to rigid standards in these areas.
9. Employees are the most valuable resource.
10. To determine whether or not the work environment is acceptable, the EMP approach is to ask this prime question:"Would an employee enjoy coming to work here every day?"
11. One of the biggest complaints vendors have is slow or late payment of invoices.
12. Early involvement of vendors will provide less chance for communication problems and delivery delays when it comes time to purchase.
13. In one way or another, the prosperity of every business depends on the existence of its customers.
14. A strategic alliance is a formal, contracted arrangement between two or more companies, each offering a specific expertise, equipment, or process to attain a negotiated, agreed-upon goal.
15. Partnerships are most effective when the vendor is geographically close to the OEM.
16. On the average, every second of manufacturing time available in a molding plant is worth approximately $0.0125, per machine.

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Appendix A

Benchmarking an Injection Molding Facility

Benchmarking is a comparison of the metrics of one company to the industry averages for other companies. Each company desires particular information. For example, a comparison can be made with others of the percentage of defects molded versus the number of acceptable parts produced. But another company may be more interested in knowing how they compare in number of sales dollars versus the number of employees on hand. Both are meaningful numbers, but each company may place varying degrees of importance on them.

First, the categories should be determined. Some category suggestions for a molding facility are listed here. The industry averages mentioned are based on facilities running 24 hours a day, 5 days a week, 50 weeks a year, and are taken from survey results of the top 50, full-service molding companies in the U. S., unless otherwise noted.

1. Machine utilization = number of hours run to produce acceptable parts ÷ number of hours available on an annual basis. Industry average is 75%.
2. Scrap (internal) = number of parts scrapped ÷ number of parts produced. Industry average is 3%.
3. Scrap (delivered to customer) = number of parts scrapped or returned by customer ÷ number of parts shipped. Industry average is less than 1%.
4. Employee to press ratio = number of employees, company-wide ÷ number of molding machines on the floor. Industry average is 8-10.
5. Sales dollars per press = total sales generated (includes tooling and secondary operations) ÷ number of molding machines on the floor. Industry average is $1,023,360 annually.
6. Sales dollars per employee = total sales generated ÷ the number of employees company-wide. Industry average is $116,918 annually.
7. Material waste = weight of raw material “lost” to handling procedures, short shipments, and waste ÷ weight purchased. Industry average is 5%.

8. Press size = range of molding machine sizes based on clamp tonnage. Average industry range is 100–1,000 tons (890–8,896 kN), but the single average machine size is 300 tons (2,669 kN).
9. Mold change time = total number of minutes needed for a mold changeover as measured from the last acceptable part molded on the removed mold to the first acceptable series of parts molded on the set mold. Industry average is 122 minutes.
10. Average machine-hour rate = total amount of annual operating costs (see Chapter 9) based on machine size ÷ number of available hours for production on that machine. Industry average is $45 for the average 300-ton (2,669 kN) machine.
11. Average operator starting wage = average hourly wage paid for a molding machine operator at entry level. This is widely variable depending on geographic location, ranging from minimum wage to $12.00 per hour. Industry average is $7.75.
12. Average operator wage (all levels) = average hourly wage paid for a molding machine operator with average experience and average length of service. Industry average is $10.60.
13. Training hours = number of training hours provided annually ÷ number of employees receiving the training. Industry average for full-time employees is 6.0.
14. Average number of machines is taken from surveys applying to all molding companies, not just the top 50. Industry average is 30.
15. Total annual revenue average is taken from surveys applying to all molding companies, not just the top 50. Industry average is $30,700,800.
16. Return on assets = the total annual profit margin of each molding machine investment. Industry average is 7.9%.

Depending on the company location and degree of automation, it could be on the small end or the large end of any of these categories. But, where should it be? It is not possible to make that determination from a single benchmark report. Benchmarking is a process that requires 3–5 years to really determine its impact. As the frequency of benchmarking increases, the more accurate and meaningful the results become.

When should benchmarking be done? There is one school of thought that believes internal benchmarking is just as meaningful as the benchmarking of other companies. Internal benchmarking can be performed without divulging operating procedures and costs to other companies, and can be a revealing experience. To perform internal benchmarking, it is a function of recording and compiling information, and then comparing the results on a regular basis. But, it also entails attempts to improve existing processes and methods to reduce scrap, improve productivity and efficiency, and maximize profits. With these goals in mind, internal benchmarking can be just as productive (if not more so) than external comparisons.

Appendix B

What Customers Look For

When customers look for a molding vendor, they are primarily interested in finding a molder that can provide a finished product at a reasonable price in a reasonable time frame. Many buyers turn to the local telephone book to quickly find a local vendor that is able to meet their needs. Others use existing vendors that have proven capable or hire consultants to find vendors to choose from.

However, before any business is placed, the potential customer usually performs a survey, audit, or a personal visit to the vendor to ensure compatibility and capability of the potential source. Following is a checklist of items that can be used for those determinations. A molder can use this as a basic guideline to prepare for a customer's visit.

QUALIFICATION FORM

Figure B1 is a specially designed form that can be used for qualifying a potential plastic molding vendor. It is being used with permission from Texas Plastic Technologies, the designer of the form. Texas Plastic Technologies gives permission to the reader to copy the form and use it for noncommercial reasons.

Vendor Qualification Form

Date: ____________________________

Vendor name: ____

Division of: ____

Street address: ____

Address two: ____

City: ___________________________ State: ____ Zip code: ______ - _____

Phone: ______________________________ Fax: ________________________

E-mail address: _______________________ URL: _______________________

Executive and Key Personnel

President: ____

Vice president: ____

Engineering manager: __________________ Phone: ___________________

Production manager: ___________________ Phone: ___________________

Quality manager: ______________________ Phone: ___________________

Total personnel: ______ Quality: ______ Engineering: ______

Production: ______ Tool Room: ______

A. Molding Process Capability

1. Thermoset (*please check all that apply*)

☐ Compression molding ☐ Transfer molding ☐ Transfer/injection
☐ Injection ☐ RIM ☐ Other
Thermoset specialty: ____

2. Thermoplastics (*please check all that apply*)

☐ Injection ☐ Blow molding ☐ Sheet manufacturing
☐ Thermoforming ☐ Structural foam ☐ Two-shot injection
☐ Insert molding ☐ Overmolding ☐ Other
Thermoset specialty: ____

3. Materials most commonly used — Approximate annual weight lb (kg)

a. _______________________ _______________________________
b. _______________________ _______________________________
c. _______________________ _______________________________
d. _______________________ _______________________________
e. _______________________ _______________________________
f. _______________________ _______________________________

☐ Check here if the company has mechanized color mix capability.

Figure B-1. Plastic molding qualification form.

4. Molding equipment

Brand	Year built	Tons	Ounces	Number
________	________	______	______	______
________	________	______	______	______
________	________	______	______	______
________	________	______	______	______
________	________	______	______	______
________	________	______	______	______
________	________	______	______	______

Comments: ____
____
____

5. Type and method of drying equipment ______________________
____
____

6. What type of process controllers are on the presses? ______________
____
____

B. Finishing/Secondary Process Operations (*please check all that apply*)

Process	*Manual*	*Automatic*
Painting	☐	☐
Silk screening	☐	☐
Hot stamping	☐	☐
Pad printing	☐	☐
Sonic welding/inserting	☐	☐
Plating	☐	☐
Vacuum metallizing	☐	☐
Drill/tap/machine	☐	☐
Assembly operations	☐	☐
Other: ______________	☐	☐

Specialty: ____

C. Manufacturing Specialty (*please check all that apply*)

☐ Miniature functional parts ☐ Large functional parts
☐ Small decorative parts ☐ Large decorative parts
☐ Electronic parts ☐ Precision molding
☐ Insert molding ☐ Two-shot molding
☐ Prototypes ☐ Engineering materials
☐ Other: ____
Preferred: ____

Figure B-1. Plastic molding qualification form (continued).

D. Production Volumes

1. Preferred annual volume range: ____________________
2. Minimum annual production volume: ____________________

E. Company Specialty

____
____
____

F. Mold Manufacture and Repair

1. How many moldmakers are employed in the shop? Repair __ Build __
2. What level of repair can be performed?

	Yes	No
a. Minor (replace pins, add vents, etc.)	☐	☐
b. Medium (alter gates, rework waterlines, etc.)	☐	☐
c. Major (alter cavities/cores, repair parting line, etc.)	☐	☐
☐ Repairs are not performed at this facility.		
3. Are molds built at this facility?	☐	☐
4. Does the company have design capabilities?	☐	☐

If "Yes," which programs? ____________________

G. Record Keeping

1. What type of molding records are kept? ____________________
____
____
2. What department is responsible for keeping these records updated?
____
3. How long are records kept before archiving or destroying? __________
4. Does the company maintain machine set-up records? ☐ Yes ☐ No
5. If yes, what department is responsible for keeping these records updated?
____
____
____
6. Can an individual part be traced back to the lot of material that it was molded from? If so, what method is used? ☐ Yes __________ ☐ No
7. How are rejected parts and defects tracked? ____________________
____
____

Figure B-1. Plastic molding qualification form (continued).

8. How is rejected material tracked? ______________________________
____
____

9. Are samples kept of each lot of material? ☐ Yes ☐ No
If yes, how much and where is it kept? ______________________
____
____

10. What method of raw material storage is employed? ____________
____

11. How is material from storage to the finished part tracked and what type of labeling system, if any, is used? ________________________
____
____

H. Inspection

1. What type of test and inspection equipment is used for molded parts?
____
____
____
____

2. What type of test equipment is utilized for raw material? ________
____
____

3. If a "zero-defect" type program is employed, define it and describe how it is applied to molded parts: ___________________________
____
____
____
____
____
____

I. Certification

1. How is a "lot" of parts certified that it meets all the material and dimen-ensional specifications? ___________________________
____
____
____

Figure B-1. Plastic molding qualification form (continued).

2. How is compliance of incoming raw material certified? ____________
____
____
____

3. What is the mold approval procedure for new molds? ______________
____
____
____

4. What is the mold approval procedure for reworked molds? __________
____
____
____

5. What is the policy and approval procedure for molds transferred from another source? ______________________________________
____
____
____

6. Has ISO 9000 registration been obtained? ☐ Yes ☐ No
7. If "no" to #6, is it, or a similar program, being pursued? ☐ Yes ☐ No
8. If "yes" to #7, when is its anticipated completion? ________________

J. General Comments

____
____
____
____
____
____
____
____
____
____
____
____

Prepared by: ________________________________ Date: ____________

Title: ____

Figure B-1. Plastic molding qualification form (continued).

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