Plastics Pocket Power

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2nd Edition

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1 Introduction

Initial processing data given to the engineer or technician before setting up an injection molding machine for a new product can save time and money. To arrive at high-quality products as quickly as possible, the machine settings at the beginning of the injection molding process optimization procedure should be as close as possible to optimal processing conditions. However, one needs to be aware that even with a good educated guess of the processing conditions for a given material, the final conditions are dependent on specific material grades, injection molding machine size, screw wear, part and mold design, and other material-independent variables. For most materials a good starting point is always known and can be found in resin supplier data sheets as well as material data banks such as CAMPUS™. This book compiles important processing data information, such as viscosity, thermal properties, mold temperatures, and suggested heater temperatures for the plasticating unit. Through a set of easy to follow examples, this book shows how the given data can be used to generate important information about a specific material, process, and product.

2 Injection Technology

A modern injection molding machine with its most important elements is shown in Figure 2.1. The components of the injection molding machine are the plasticating unit, clamping unit, control unit, and the mold.

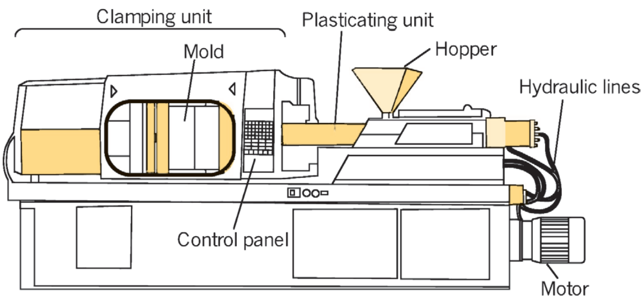

Figure 2.1 Schematic of an injection molding machine. See Figure 2.7 for a more detailed representation of the machine

Today, injection molding machines are classified by the following international convention

Manufacturer type *T*/*P*

where *T* is the clamping force in metric tons and *P* is defined as

$$P = \frac{v_{max}\ p_{max}}{1000}$$

where v_{max} is the maximum shot size in cm^3 and p_{max} is the maximum injection pressure in bar. The clamping force *T* can be as low as 1 metric ton for small machines, and as high as 11,000 tons.

There is another classification regarding specific energy consumption (kWh/kg), the Euromap 60.1. There are 10 efficiency classes: Class 1 ($>$ 1.5 kWh/kg) to Class 10 ($\leq$ 0.25 kWh/kg). For small machines (screw $\leq$ 25 mm) the class definition is different.

2.1 The Injection Molding Cycle

The sequence of events during the injection molding of a plastic part, as shown in Figure 2.2, is called the injection molding cycle. The cycle begins when the mold closes, followed by the injection of the polymer into the mold cavity. Once the cavity is filled, a holding pressure is maintained to compensate for material shrinkage. In the next step, the screw turns, feeding the next shot to the front of the screw. This causes the screw to retract as the next shot is prepared. Once the part is sufficiently cool, the mold opens and the part is ejected. Figure 2.3 presents the sequence of events during the injection molding cycle. The figure shows that the cycle time is dominated by the cooling of the part inside the mold cavity. However, in some cases the plasticating time can be longer than the cooling time, e.g., when the mold cavity number is high for the plasticating unit capacity; the plasticating time is also longer than the cooling time when the parts have thin walls. The total cycle time can be calculated using

$$t_{\text{cycle}} = t_{\text{closing}} + t_{\text{injectionunitforward}} + t_{\text{injection}} + t_{\text{cooling}} + t_{\text{ejection}}$$

where the closing and ejection times, $t_{closing}$ and $t_{ejection}$, can last from a fraction of a second to a few seconds, depending on the size of the mold and the machine.

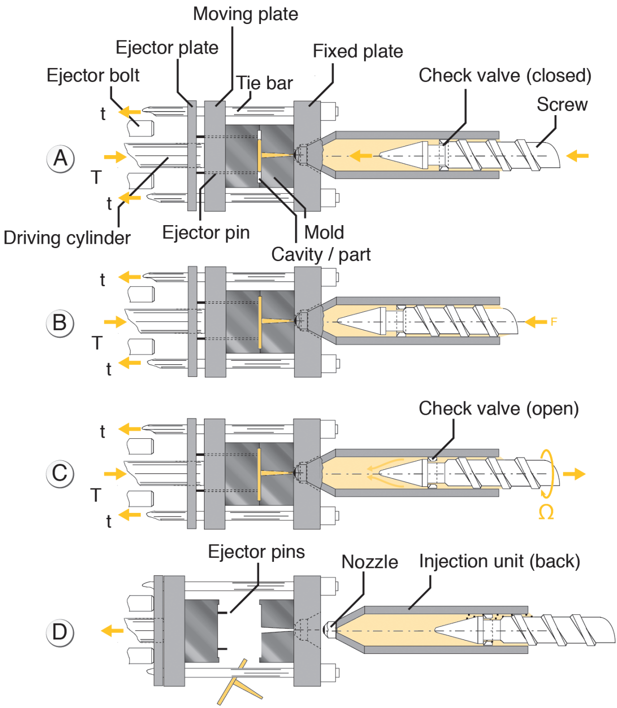

Figure 2.2 Sequence of events during an injection molding cycle

Using the average part temperature history and the cavity pressure history, the process can be followed and assessed using the PVT diagram as depicted in Figure 2.4. To follow the process on the PVT diagram, we must transfer both the temperature and the pressure at matching times. The diagram reveals four basic processes: an isothermal (constant temperature) injection (0–1) with pressure rising to the holding pressure (1–2), an isobaric (constant pressure) cooling process during the holding cycle (2–3), an isochoric (constant volume) cooling after the gate freezes with a pressure drop to atmospheric (3–4), and then isobaric cooling to room temperature (4–5).

The point on the PVT diagram where the final isobaric cooling begins (4) controls the total part shrinkage, Δv. This

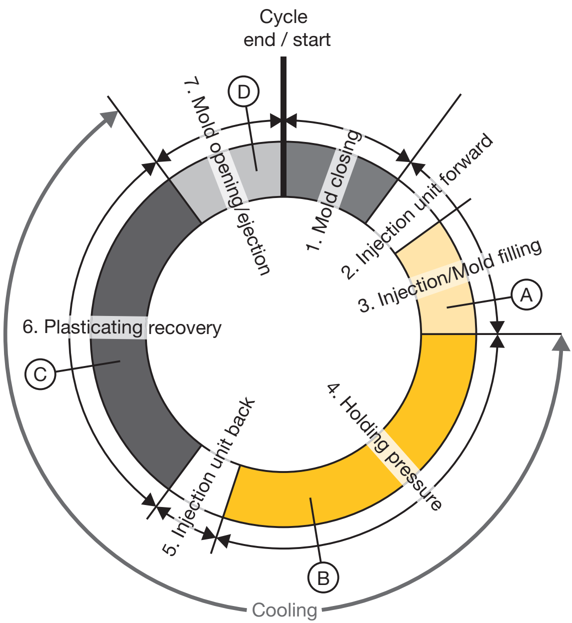

Figure 2.3 Injection molding cycle

point is influenced by the two main processing conditions—the melt temperature, T_M, and the holding pressure, p_H—as depicted in Figure 2.5. Here, the process in Figure 2.4 is compared to one with a higher holding pressure. Of course, there is an infinite combination of conditions that render acceptable parts, bound by minimum and maximum temperatures and pressures.

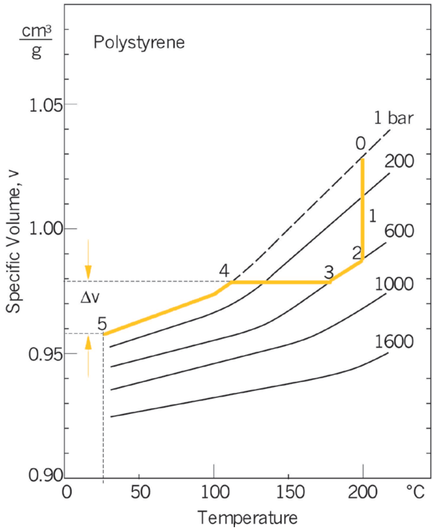

Figure 2.4 Trace of an injection molding cycle in a PVT diagram

Figure 2.6 presents the molding diagram with all limiting conditions. The melt temperature and the injection speed are bound by low values that result in a short shot or unfilled cavity and high values that lead to material degradation. The hold pressure is bound by a low pressure that leads to excessive shrinkage or low part weight, and a high pressure that

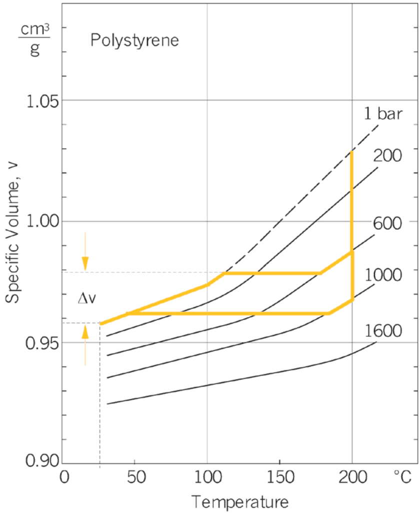

Figure 2.5 Trace of two different injection molding cycles in a PVT diagram

results in flash or jamming. Flash results when the cavity pressure force exceeds the machine clamping force, leading to melt flow across the mold parting line. The holding pressure determines the corresponding clamping force required to size the injection molding machine. An experienced polymer processing engineer can usually determine which injection molding machine is appropriate for a specific application. For the untrained polymer processing engineer, finding this appropriate holding pressure and its corresponding mold clamping force can be difficult. Nowadays there are computer programs for simulation to help them with this critical task. In the following pages some useful equations are presented, and it is explained how to use the physical properties con-