Introduction:
A few days ago I had an opportunity to attend a technical meeting with a number of my friends from injection molding facilities to discuss a project. One of the participants arrived late at the meeting late and at the time of his arrival he offered an excuse, “Sorry, we had a problem with a mold since early morning. The mold produced short shuts. I had to take care of the problem before I left”. One of the attendees said “I hope it has been taken care of” and the reply was, “I asked my technician to increase the gate opening. It will allow the ease of flow and will take care of the problem”.

The discussion stopped at that point but I was thinking perhaps there is a lack of understanding of the importance of gate and gate size in injection mold among a number of practitioners. This problem may be coming from two sources:

a) Those that have a background in metal casting, are not realizing that the flow of plastic is a non-Newtonian flow and actually for most plastics is shear thinning. This means the viscosity or resistance to flow reduces as the flow rate or the flow speed increases.

b) Those who misunderstood the gate and the flow mechanism at the gate. There is a lack of understanding of the heating mechanism in injection molding. It is perhaps a common mistake among many who assumed the thermal energy which is offered to the plastic merely comes from the heating bands and the screw action. This is nowhere near the truth.

Figure 1: Newtonian vs. Non-Newtonian flow in an injection molding

Flow Rate
One must realize the non-Newtonian flow characteristics are mainly due to the high aspect ration of polymeric materials. The Newtonian flow follows the general trend of the thought of Isaac Newton when he stated, “for every action, there is an equal and opposite reaction”.

Figure 2:
Shear stress as a function of shear rate for Newtonian flow

This statement is completely true for metallic materials with spherical structure and to some degree the ceramic materials with a small aspect ratio. It does not hold true for plastic material.
The non-Newtonian flow and the molecular length:

This principle is related to the aspect ratio of materials. Aspect ratio is defined as the ratio of one physical dimension divided by another, for example, length divided by diameter. Molten metals with spherical shaped atoms pose an aspect ratio of 1 to 1. Hence each point of fluid moves by the applied force in the direction of flow. The movement of each atom is not restricted by the surrounding atoms.

The Importance of Gate:

For many polymers with an aspect ratio reaching millions, the Newton principle of flow is not applicable at all. Hence, the condition of short shot, as applicable in metal casting, does not work for polymers. Enlarging the gate does not facilitate the flow of molten plastic into the cavity. For plastic material, an increase in gate size will potentially compound the problem to a level much worse than before.

Gate, in plastic injection molding plays an important role which has always been overlooked. The gate in a mold is designed to reheat the molten polymer at perhaps the most crucial cycle time, mainly filling. This is the place at the molten paths where other possibilities such as heating elements, screw actions, and others are non-existent.

Source of heat in injection molding:

For many, the assumption is that the polymer is heated only by the heating band and the screw action. This is not the complete picture. In an injection molding, the source for melting the polymer to processing conditions is mainly divided into three areas:

- Heating bands and screw action
- The plasticizers and other melt facilitation additives
- The gate

Although, the heating bands are extremely important during the start of the process, they are becoming secondary and used preferably as a means for controlling the melt temperature during the course of operation. The thermal energy input of the heating bands is considered one of the undesirable types of thermal energy. In this method, the heat diffuses from the barrel into the plastic through the process of thermal conduction.

Plastic as a good thermal insulator does not have good thermal conductivity. Hence, plastic in direct contact with the barrel wall becomes too hot, while the polymer at the center of the barrel potentially stays too cold, perhaps around room temperature. The heating bands, as is the case in plunger type injection molding, often cause degradation and reduction of the polymer properties.
The screw action and other source of heating produce a sufficient friction and are considered a desirable means for plasticizing the polymer. In a typical reciprocating screw injection molding press, around 80% of the heat presumably and preferably, is offered by the screw action. The plasticizing within the screw is taking place at the transition zone, which is approximately one fourth of the length of a general purpose screw. In a so called heterogenous condition, most of the heat for melting the plastic is offered by the screw action alone. The heating band can be at “off” condition or operating at the minimal heat input.

The plasticizer, although known by every processor, is not utilized to the maximum of its potential. The plasticizers and additives added to polymers do not offer the thermal energy, but rather reduce the melt temperature. Therefore they decrease a need for the thermal energy. The plasticizer can reduce the processing temperature by as much as 50 degrees or more and can offer a substantial reduction in the energy cost. The drawback to the common use of the plasticizer is the uncertainty of the effect of additive, the conflicting opinion, and the lack of reliable data.

The most important source of heating or to be more precise, the reheating polymer, is taking place at the gate. The reheating takes place during the filling of the flow of polymer in the cavity. During this time the polymer must possess, the most desirable condition of heat, pressure and flow. Hence, the gate becomes an important location to achieve the optimum processing condition for molten polymer. Additionally, the gate is the last frontier for altering the processing conditions, especially thermal and flow characteristics.

**Figure 4:**

Cavity pressure and flow rate versus time

The reheating of the polymer at the gate is due to the transition of kinetic energy into thermal energy as well as the polymer internal friction due to turbulence flow. It can be compared to shooting a gun at the hard rock of a concrete wall. The bullet which has a substantial speed is stopped by the wall. Due to the fact the energy is not created nor destroyed, the bullet’s kinetic energy is converted into thermal energy to such a level which melts the bullet.

The same mechanism is applied to the polymer at the gate. The gate is actually a triggering mechanism for accelerating the polymer. Understandably, the smaller the gate is, the faster the flow velocity. The faster velocity is required to accommodate the volume displacement. In the case of flow for the shear thing polymer, the higher is the velocity the easier for the molten polymer to flow. Hence, the gate is selected with an opening just few thousand square inches. The gate is placed in immediate proximity of a hard wall.
The high velocity polymer flow can potentially reach over one hundred miles per hour. Upon impact the polymer will be reheated sometimes up to 25-100 degrees Fahrenheit and flow in a laminar manner to fill the cavity. Too small of a gate will generate sufficient friction and internal stress, which can potentially breakdown and degrade the molecules.

If the gate is enlarged, the flow will be negatively affected by two mechanisms. First, the flow rate will decrease exponentially. The slower the flow is, the higher the viscosity. In addition, due to the reduction in flow rate the shear stress will decrease the flow rate even further. Secondly, the reduction in flow reduces the kinetic energy. This results in a change in thermal energy at the gate to reduce it to zero. In such a condition, the cold flow front slows down and freezes before filling the cavity.

**Conclusion:**

In conclusion, one must realize the source of heat for a polymer in an injection molding, mainly, heating band and screw action, plasticizer, and the gate system. Elimination of each of these three main categories can reduce the heat input and reduce the flow ability of the polymer. This understanding can affect the ease of processing and offer a great savings in the cost of energy and materials as well.