Injection Moulding of Thin Wall Articles

Keywords: thin wall moulding, flow path to thickness ratio, increased pump size, regeneration, variable injection cylinder size, accumulator

In moulding thin wall articles, a high injection speed ensures the melt does not freeze before the cavity is completely filled. Injection moulding machines below 150-ton clamping force have injection speed of above 100 mm/s, which is higher than that of bigger machines. Injection speed of more than 800 mm/s has been claimed by some Japanese injection moulding machine manufacturers. Three methods to increase injection moulding speed are described. They are

1. increased pump size,
2. regeneration/variable injection cylinder size,
3. accumulator.

Injection speed and injection rate

Injection speed and injection rate are measures of an injection moulding machine's ability to mould thin wall articles. Either or both are sometimes stated in a manufacturer's machine specifications.

Injection speed is the maximum linear velocity of the screw during injection. It is related to the maximum pump flow rate by Equation (1). Refer to Figure 1. Note that two injection cylinders are assumed. Refer to Figure 6. Injection speed is independent of screw diameter.

$$s = 100000*Q/(3*3.1416*(D_1^2 - D_2^2)) \qquad (1)$$

where
s = maximum injection speed in mm/s,
Q = maximum flow rate of pump in litres/min,
D_1 = diameter of the injection cylinder in mm,
D_2 = diameter of the injection cylinder piston rod in mm.

Maximum injection rate is the maximum volume of melt injected into the cavity per unit time. It is dependent of screw diameter and is related to maximum injection speed by the following equation.

$$r = 3.1416*d^2*s/4000 \qquad (2)$$

where
r = maximum injection rate in cc/s,
d = screw diameter in mm,
s = maximum injection rate in mm/s.

It is better to use injection speed in comparing injection moulding machines from different manufacturers as it is independent of screw size.

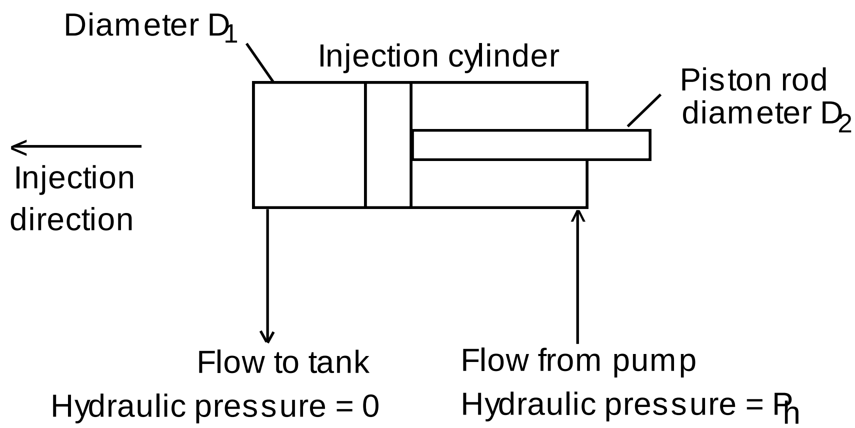

Figure 1 How injection speed is determined

Ultimately, it is injection rate that determines how fast the cavity is filled. The minimum filling time is related to maximum injection rate by the following equation.

$$t = v/r \qquad (3)$$

where
t = minimum cavity filling time in s,
v = cavity volume including that of runners and sprue gate, in cc,
r = maximum injection rate in cc/s.

From equations (2) and (3), for a given injection speed, we conclude that a bigger diameter screw reduces the cavity filling time.

The following table shows the injection speed and injection rates of an ME75 III injection moulding machine from Tat Ming Technology Co. Ltd.

Screw diameter, mm	35	39	43
Injection speed, mm/s	141		
Injection rate, cc/s	135	168	204

Table 1 Standard ME75 III injection speed and rates

How thin is thin wall?

In absolute term, a wall thickness of less than 0.5 mm could be considered thin wall. Since the amount of cooling is proportional to the cavity area and the heat in the melt is proportional to the cavity volume, cooling is very fast in thin wall moulding. When this happens, the freezing at the mould wall reduces the cross section of the flow path which must be overcome by a high injection pressure. Injection pressure is the pressure of the melt at the screw tip. Refer to Figure 2. Increasing the mould temperature does help to reduce the injection speed and injection pressure requirement but has the side effect of lengthening the cooling period.

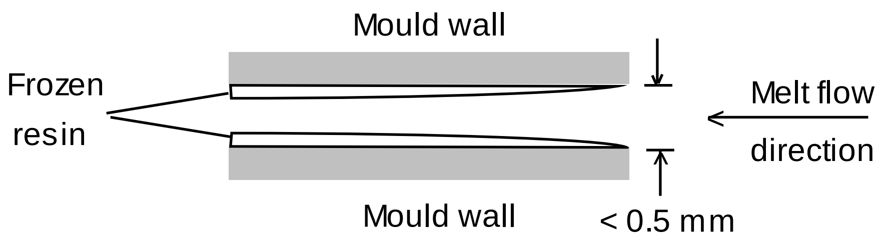

Figure 2 Thin wall moulding

For the technically inclined, maximum injection pressure is related to maximum hydraulic pressure by the following equation.

$P = 2*P_h*(D_1^2 - D_2^2)/d^2$ (4)

where

P = maximum injection pressure,

P_h = maximum hydraulic pressure,

D_1 = diameter of the injection cylinder in mm,

D_2 = diameter of the injection cylinder piston rod in mm,

d = screw diameter in mm.

From Equation (4), one sees that an increased screw diameter, which increases maximum injection rate according to Equation (2), decreases maximum injection pressure by the same proportion. Hence, one could use screw diameter to trade off injection pressure for injection rate.

The cavity pressure diagram in Figure 3 is used to estimate the clamping force needed to keep the mould halves closed, taking into account wall thickness and flow path to wall thickness ratio of the article. Cavity pressure is reduced from injection pressure by the pressure drop at the sprue gate and runners. Clamping force is cavity pressure times the area of the cavity projected onto the mould halves parting plane. Flow path is measured from the sprue gate to the extremity of the moulded part.

In relativistic term, a flow path to wall thickness ratio of more than 250 could also be considered thin wall. Above 250, the curve rises very steeply as wall thickness is reduced. We conclude that thin wall moulding also requires a high clamping force.

Increased pump size

Some machine manufacturers provide the alternative of an increased pump size (and hence pump maximum flow rate) as a means to increase injection speed. So as not to overload the electric motor driving it, a more powerful motor accompanies the larger pump.

From Equation (1), increased pump flow rate increases injection speed by the same proportion. Pumps come in discrete sizes with about 25% increase in maximum flow rate for each size in the series. However, the alternative pump is usually the next size up due

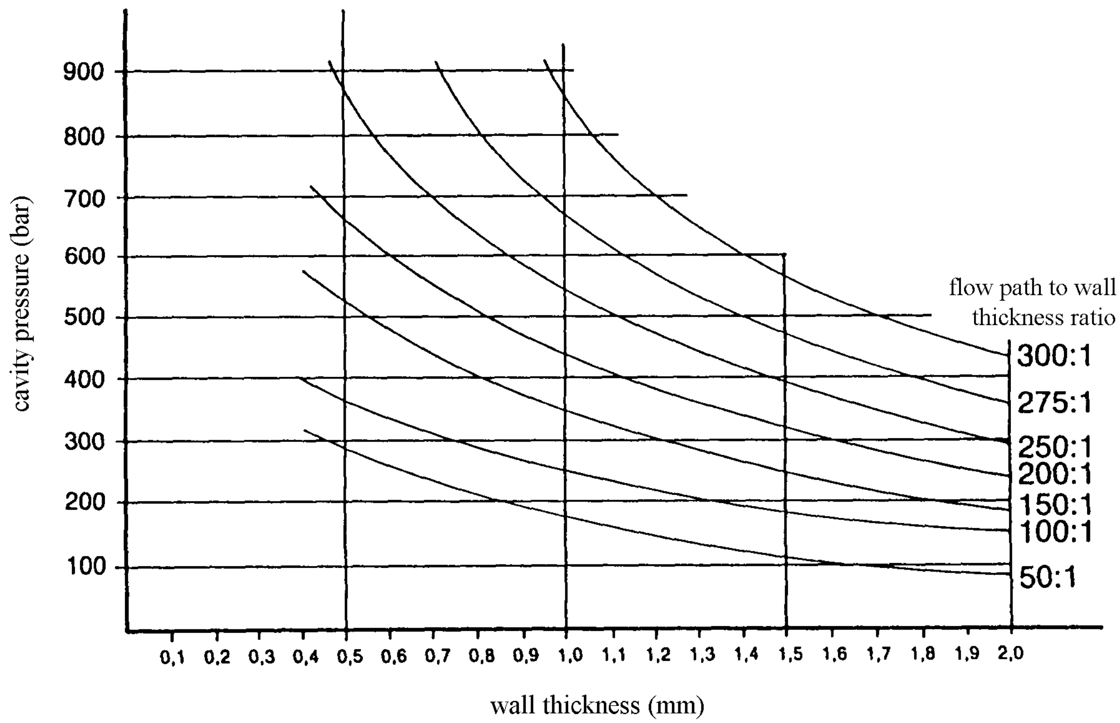

Figure 3 Cavity pressure is a function of wall thickness and flow path

to the limited excess capacity built into the standard machine (with the standard pump size).

Hydraulic valve, pipe and hose limit the flow rate through them to their rated maximum. They also come in discrete sizes, e.g. 3/8 inch, 4/8 inch, etc. Unless the hydraulic elements in the injection unit are also sized up, they may become the bottleneck in increasing injection speed by a larger pump.

Moulders who change the pump by themselves without consulting the machine manufacturer for the injection hydraulics' excess capacity may see only an insignificant increase in injection speed. Not all injection moulding machines are designed with increased pump size as an alternative.

The following table shows the injection speed and injection rates of ME75 III with increased pump size. Compare it to Table 1.

Screw diameter, mm	35	39	43
Injection speed, mm/s		176	
Injection rate, cc/s	170	211	256

Table 2 Injection speed and rates of ME75 III with increased pump size

Regeneration

Regeneration is a hydraulic circuit technique to redirect the flow out of the back of a cylinder to the front to speed up the movement. Refer to Figure 4. In an injection moulding machine, regeneration is often used to speed up mould closing. Some manufacturers use it to optionally increase injection speed. In such a machine, the injection regeneration feature could be turned on or off. Usually a speed increase of 60% is designed.

Regeneration works only when the flow out of the cylinder back is less than the combined flow into the cylinder front. In fact, by conservation of flow,
combined flow = regenerated flow + pump flow.
Rearranged, this becomes,
regenerated flow = combined flow - pump flow.
This is made possible by the use of regeneration rod at the back of the piston and $D_3 > D_2$.
Refer to Figure 4.

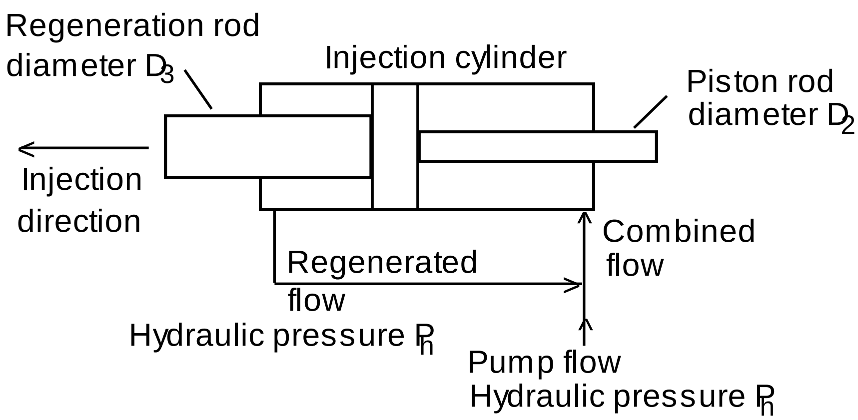

Figure 4 Regeneration increases injection speed

Notice that the regenerated flow has the same hydraulic pressure as the pump. This is to be contrasted with the zero hydraulic pressure at the back of the cylinder in the non-regeneration case in Figure 1.

With regeneration, Equation (1) is modified as follows.

$s_r = 100000*Q/(3*3.1416*(D_3^2 - D_2^2))$ (5)

where
s_r = maximum injection speed with regeneration in mm/s,
Q = maximum flow rate of pump in litres/min,
D_3 = diameter of the injection cylinder regeneration rod in mm,
D_2 = diameter of the injection cylinder piston rod in mm.

Similarly, Equations (2), (3) and (4) are modified as follows.

$r_r = 3.1416*d^2* s_r/4000$ (6)

where
r_r = maximum injection rate with regeneration in cc/s.

$t_r = v/r_r$ (7)

where

t_r = minimum cavity filling time with regeneration in s.

$P_r = 2*P_h*(D_3^2 - D_2^2)/d^2$ (8)

where

P_r = maximum injection pressure with regeneration.

Regeneration actually trades off injection pressure for injection speed. Intuitively, the back of the cylinder is now pressurized the same as the front of the cylinder. The differential area on the two sides leaves a net force in the injection direction. This net force is smaller than the force without regeneration. Compare Figure 4 to Figure 1.

Injection pressure is reduced by the proportion injection speed is increased. Refer to Equation (9) which is derived from Equations (1), (4), (5) and (8).

$P_r = P * s/s_r$ (9)

where

P_r = maximum injection pressure using regeneration,

P = maximum injection pressure without regeneration,

s_r = maximum injection speed using regeneration,

s = maximum injection speed without regeneration.

When the reduced injection pressure does not satisfy the thin wall moulding requirement, this method is not useful.

The following table shows the injection speeds, injection rates and injection pressures of an ME55 III injection moulding machine with and without regeneration.

	Without regeneration			With regeneration		
Screw diameter, mm	30	33	36	30	33	36
Injection speed, mm/s	104			185		
Injection rate, cc/s	74	89	106	131	159	189
Injection pressure, kgf/cm^2	2133	1763	1481	1200	992	833

Table 3 Standard ME55 III with and without regeneration

Increased pump size and regeneration could be used together. The following table shows the data of ME55 III with increased pump size.

	Without regeneration			With regeneration		
Screw diameter, mm	30	33	36	30	33	36
Injection speed, mm/s	128			228		
Injection rate, cc/s	91	110	131	161	195	232
Injection pressure, kgf/cm^2	2133	1763	1481	1200	992	833

Table 4 ME55 III with increased pump size

Variable injection cylinder size

Variable injection cylinder size technology is based on the same principle as regeneration, trading off injection pressure for injection speed. Unlike regeneration, there is quite a few choices of injection speeds. Using three cylinders in their various combinations, one manufacturer has 7 (= 2^3 - 1). Refer to Figure 5.

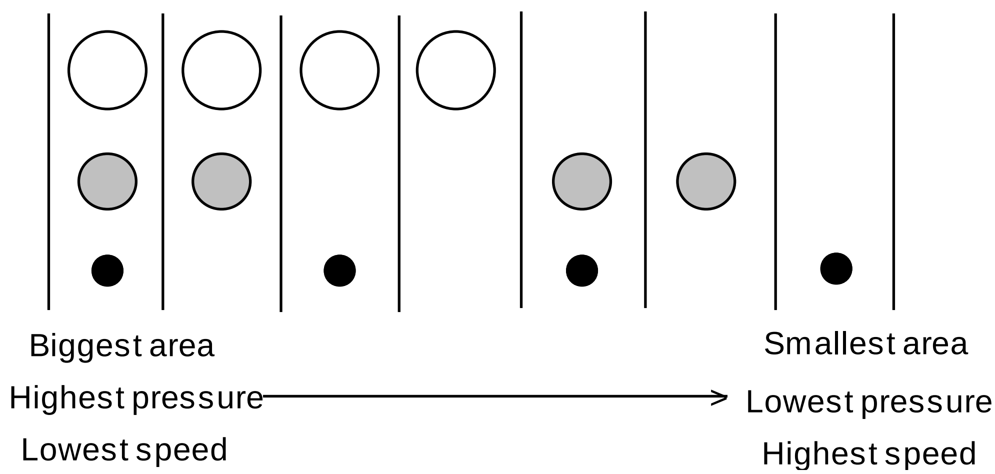

Figure 5 Seven combinations of 3 cylinders

The pressure-speed trade off is generalized from Equations (1) and (4) as follows.

$s_i = 25000*Q/(3*A_i)$ (10)

where

s_i = maximum injection speed using area A_i, in mm/s

A_i = total area of an injection cylinder combination, in mm^2.

$P_i = 8*P_h*A_i/(3.1416*d^2)$ (11)

where

P_i = maximum injection pressure using area A_i,

d = screw diameter, in mm.

If a particular combination of injection speed and injection pressure satisfies the needs of thin wall moulding, this technology could be used.

Accumulator
An accumulator is an energy storing device that is most often employed to increase injection speed. Unlike regeneration and variable injection cylinder size, it does not trade off injection pressure for injection speed. The injection speed can be up to three times that without accumulator. Refer to Figure 6.

During the cooling phase when there is no machine movement, the delivery from the pump is directed to charge the accumulator with pressurized oil which is released during injection. Alternatively, an additional pump could be dedicated to charging the accumulator.

During injection, the flow from the accumulator augments that from the pump in pushing the screw forward.
Combined flow = accumulator flow + pump flow.

If necessary, sized up valve and hose are called for to remove the bottlenecks into and out of the injection cylinders. A deceleration circuit is needed to brake the fast-moving screw near the end of its stroke.

The following table shows the injection speed and injection rates of an ME75 III with the accumulator option. Compare it to Tables 1 and 2.

Screw diameter, mm	35	39	43
Injection speed, mm/s	395		
Injection rate, cc/s	378	470	571

Table 5 Injection speed and rates of an ME75 III with the accumulator option

Injection compression (Coining)
While not a high speed technology, injection compression technology, also known as coining, is also effective in moulding thin wall articles. It has the advantages of reduced clamping force and reduced residual stress in the article.

With the mould not completely closed (e.g. short by 1 mm), injection is started. The mould is then closed, squeezing the melt to the corners of the cavity.

Injection compression technology does require a more sophisticated mould and an injection moulding machine with coining capability. In particular, the machine has separate hydraulic circuits for the injection and the clamping sides as the clamp is moved during injection. Accurate shot volume is needed to fill the cavity without flashing. Accurate mould movement is also needed.

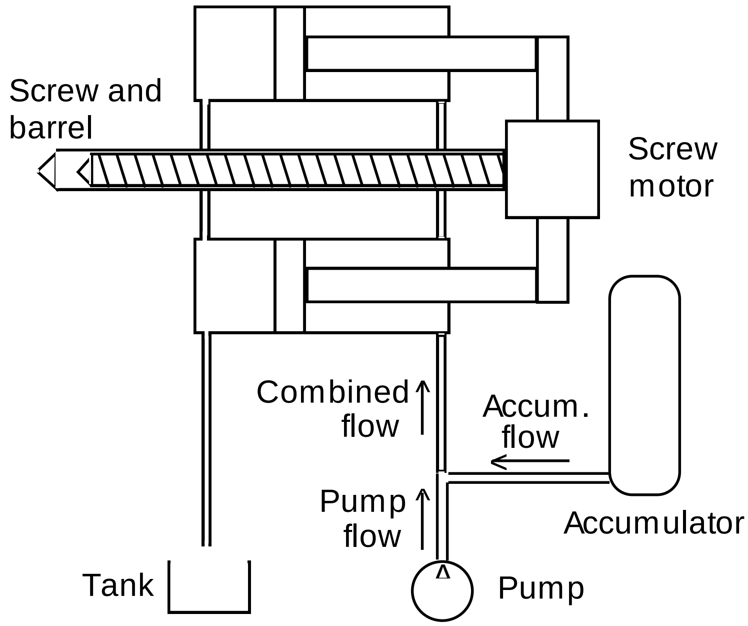

Figure 6   A charged accumulator assists the pump in delivering pressurized oil to the injection cylinders

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