Design of Sprue Bush for a Plastic Injection Mould: A Machine Perspective

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***Abstract*—Design methodology and criteria to configure sprue bush for enhancing functionality is systematically compiled from plastic injection moulding machine perspective. Sprue conduit's sensitivity to moulding objectives are quantitatively ghettoised as expansion ratio on the basis of ubiquitous empirical relationships. This generic, simple, inexpensive preventive criterion enables sprue bush conduit geometry design to exemplifying the melt injection specifically for a particular machine. Continuous Sensitivity Equation Method (CSEM) was adopted to sensitise sprue conduit expansion over infinite dimensional range exclusively for injection rate, maximum injection pressure and barrel size. Inferred results were exponential in nature with injection rate having direct proportionality, while maximum injection pressure and barrel size had inverse proportionality to conduit expansion off parting plane. Off them injection rate was found to be relatively more influential than injection pressure and barrel size.**

Keywords—Sprue bush conduit, Injection rate, Maximum injection pressure, Barrel size

I. Introduction

Sprue bush design perfection is crucial as its configured features significantly influence impression contrivability [1]. Exterior head, shank and base sections integrate to form internal conduit geometry as schematised in Figure 1 have to be very specifically configured to accomplish synchronised melt injection, distribution and ejection [2], relative to the specifications of a particular available machine. (1) **Head:** Sprue head is a positive feature possessing negative inlet orifice region to receive melt as well as accommodate abutting nozzle tip. (2) **Shank:** Sprue shank is a transition feature with tubular cross-section forming internal conical conduit between head and base. (3) **Base:** Sprue base with exit orifice region delivers melt into sprue well harmonising feed system continuance along the parting plane.

Obviously sprue conduit topology design criteria should ensure continuity, balance mechanics and equilibrate energy transactions to sustain almost perfect melt state for ideal contrivance [3]. Rarely sprue bushes are also designed to cyclonically deflate unwanted dross and precipitates proceeding into moulding impression gap by adopting micro porous powder metallurgy materials along sprue melt interface boundary.

Functionally sprue bush has to mechanically and thermally engage cold mould to hot barrel with minimum energy outlay [4]. Machine's cooling system influence is relative to sprue bush capillary ratio, which in turn depends on component features below parting plane and interface area consequent to assembly configuration. Hence an exclusive sprue design depending on maximum injection pressure, barrel shot volume *(in turn depending on injection force, screw design, speed, chosen nozzle tip, etc.),* machine's highest shearable rate for a chosen material state *(operating pressure and temperature)* as well as desired component is essential [5]. So accomplishing almost uniform melt injection pattern despite discrete periodic fluctuation warrants a conduit design criteria, that concedes with injection dynamics, which has never been given due consideration [6] and is the prime focus of this research effort.

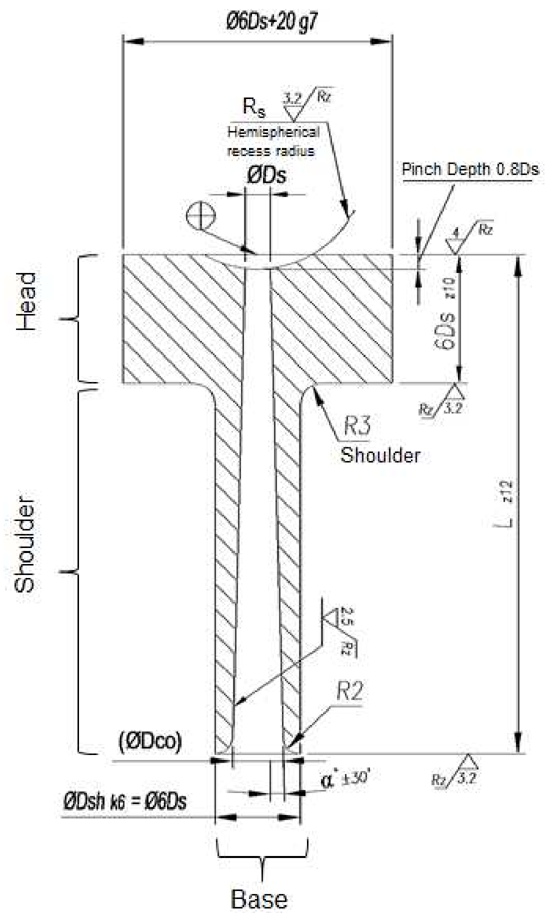

Figure 1 Schematic representation of typical sprue bush

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Off the entire feed system diverging sprue conduit inlet orifice witnesses' swiftest volumetric shear rate *i.e, maximum shear rate* with major heat and mass transformations occurring at the shock plane [7]. Accordingly, smaller nozzle orifice compel processors to inject melt at higher undesirable temperature. So sprue-bush conduit should be designed just wide enough to accomplish highest melt injection rates from maximum injection pressure available in the machine *i.e, pressure gradience*. Mitigating dynamic challenges like melt / gas entrapment, abrupt streaming and pressure / temperature variance, vortexing, undue turbulence, discontinuous splashing of streams, self-tumbling, etc, to fully contrive the impression. Sprue conduit should eventually enable contriving parts that are (1) wholly filled (2) superior surface finish (3) undistorted (4) denser (minimum voids, pores and bubbles) (5) flexible (6) superior weldmesh (7) dimensionally precise (8) uniformly shrunk [8].

Sprue bush length (L) has to flush with (cavity + bottom) plate thickness, so at component level an excess metal stock (zIT12) is provided to compensate finish grinding after final assembly. Long sprue bush lengths thermally expand causing far enough "growth" past the parting plane, eventually leading to flashing. Further the nozzle contact forces exert this projection over the moving side of the mould, acting to burst open clamping. So for non-sprue-gated parts, moulders should ensure sprue bush length is within or just off parting plane, even at highest operating temperature [9].

Consequent to conduit convergence and divergence on either side of interface shock plane, greatest restriction to inject melt occurs at the interface between nozzle exit and sprue inlet orifice. So to accomplish ideal throttle action shock section must achieve highest shearable rate *(sonic injection)* of chosen polymer *(perhaps* $M \approx 10^{-1}$ *i.e, injection velocity* $\overline{U}_{Max}$*)*. Injection shock plane Mach number specifically depends on injectant's rheological and shear degradation characteristics. Convergent nozzle and divergent sprue conduit combination, during filling phase acts as nozzle-diffuser increasing melt downstream pressure at the expense of upstream velocity *i.e increase discharge rate to expand plastic melt from higher subsonic (*$M < 10^{-3}$*) nozzle velocity to lower subsonic (*$M < 10^{-5}$*) sprue filling velocity*. Again the same combination acts as diffuser-nozzle to increase melt velocity at the expense of pressure during packing phase, *i,e compressed plastic melt from lower subsonic (*$M < 10^{-3}$*) nozzle velocity to higher subsonic (*$M < 10^{-2}$*) sprue compensation velocity*.

Sprue conduit inner surface is designed $(R_z = 2.5)$ smooth, furrow-less and polished to facilitate frictionless laminar melt impulse streaming, permit clean sprue stem stripping out with minimum drag, sticking and friction [8] and nozzle tip break off. However co-efficient of friction loss $(C_{\text{Friction Loss}})$ can be computed as,

$$C_{\text{Friction Loss}} = \left(1 - \frac{U_{\text{Sprue exit}}}{U_{\text{Nozzle}}}\right)$$

where $U_{\text{Sprue exit}}$ is velocity of injectant at spure exit and U_{Nozzle} is velocity of injectant at spure entry

Influx polymer melt state, viscosity characteristics, rheological behaviour, etc., prior to entering sprue conduit from the machine are key processing parameters directly influencing component quality and its thermal characteristics yield. Relative to heat developed and/or absorbed at shear injection shock geometry zone inherent distribution range approximately exceeds 10^0C [10]. Nevertheless temperature variation is proportional to Barrel-to-Shot ratio (BSR) *i.e, ratio of mould shot capacity to machine barrel shot capacity* [11]. Intrusive probes in sprue conduit have revealed that melt temperature sharply increase during injection followed by gradual decay during packing and significantly decrease during cooling. Probably during filling temperature intensifies due to adiabatic compression and shear friction, perhaps major thermal variation occurs consequent to hot melt volumetric injection dynamics inside sprue conduit [12].

Despite maturity in mould as well as machine exclusively from global interaction resoluteness perspective their design criteria are still deficient, while obscuring relative analysis inhibit collective decisiveness; primarily because of the high complexity. So exhaustive simulation, deliberate modifications and multifarious trails interactively and iteratively are inevitable, owing to which uncertainty befalls obviously [13]. Injection pressure delivered from moulding machine must progressively suffice nozzle, sprue, runner, gate and moulding impression gap energy transformations. Off sprue bush system significant fraction of in-mould pressure head recovery occurs within conduit geometry. So from mould function dimensional analysis perspective, recovering in-mould pressure head from influx kinetic injection velocity would be prominent performance metric, hence sprue conduit efficiency significantly influences overall mould performance quotient and so is conspicuous element for design perfection [14]. Conscientiously sprue bush conduit *(a feed system constituent)* would be where performance hearth is for critical insight [15]. Obviously, for efficient mouldability in-situ conduit pressure recovery criteria meticulousness is essential, so a rational approach seems to embrace fundamental injection mechanics methodology. Therefore present research effort appreciates melt injection dynamics [16] and then relates machine specifications analogous to extrusion profile design as a function of sprue conduit expansion, while anchoring material and moulding, believing that the criteria might enhance overall confidence.

II. SPRUE BUSH DESIGN CRITERIA

Considering sprue conduit analogous to generic capillary tube, spure conduit capillary ratio $\left(L/R\right)$ could be obtained from the ratio of injection pressure gradience (ΔP) across it to twice the injectant's critical shear stress (τ) extent through it. i.e. $\frac{L}{R} = \frac{\Delta P}{2\tau}$, where injection pressure gradience ΔP is difference between machine's nozzle tip or sprue bush conduit entrance orifice diameter to sprue well or sprue bush conduit exit orifice. Since sprue conduit expands linearly its nominal diameter could be considered an arithmetic average, i.e. $R = \frac{\bar{D}}{2}$. Hence shear stress is

$$\tau = \frac{\Delta P\ \bar{D}}{4L} = \frac{\Delta P}{4L}\bar{D} \quad (1)$$

For a linear conduit expansion as in Figure 1, from trigonometry nominal diameter $(\bar{D})$ in Eqn. (1) can be expressed as follows,

$$\bar{D} = \frac{(D_s + D_s + 2LTan\alpha)}{2}$$

$$= \frac{2(D_s + LTan\alpha)}{2} = D_s + L\ \tan\alpha \quad (2)$$

where D_s being sprue conduit inlet orifice diameter, L being sprue conduit length and α as half or taper angle of sprue conduit expansion as schematised in Figure 1. So by substituting Eqn (2) in (1) we get,

$$\tau = \frac{\Delta P}{4L}(D_s + L\ \tan\alpha) \quad (3)$$

Shear stress being maximum at the peripheral wall, declines towards central core synchronous to its velocity profile slope. Similarly to inject melt through a capillary conduit its apparent shear rate is defined as,

$$\gamma = \frac{4Q}{\pi R^3} = \frac{32Q}{\pi \bar{D}^3} = \frac{32Q}{\pi(D_s + L\ \tan\alpha)^3} \quad (4)$$

where Q is discharge rate of the melt and will be defined later. For designing a specific sprue conduit, its operational characteristic features need to be represented by functional metrics. So melt's resistance to diffuse through sprue conduit is quantitatively described as apparent local viscosity, more specifically resulting melt strain rate for an applied *(injection)* shear stress. Thermoplastic melt viscosity being a true thermodynamic property that varies with spatiotemporal melt state, also in accordance with Sir Isaac Newton's resistance postulate of 1687, the capillary rheologic formulation for polymer melt injection by neglecting strain angle $\theta(t)$ would be [17],

$$\text{Apparent Viscosity } (\mu) \neq \frac{\text{Shear Stress } (\tau)}{\text{Shear Rate } (\gamma)} \quad (5)$$

Now substituting Eqn (3) and (4) in (5) we get,

$$\text{Apparent Viscosity } (\mu) \neq \frac{\left(\frac{\Delta P}{4L}(D_s + L\ \tan\alpha)\right)}{\left(\frac{32Q}{\pi(D_s + L\ \tan\alpha)^3}\right)} \quad (6)$$

$$\neq \frac{\Delta P\pi}{128QL}(D_s + L\ \tan\alpha)^4$$

Eqn. (6) inequality represents non-newtonian melt injection across nonlinear viscosity distribution could be equated adopting Rabinowitsch correction as follows,

$$\mu = \frac{\Delta P\pi}{128QL}(D_s + L\ \tan\alpha)^4\left(\frac{4n}{3n+1}\right)$$

$$= \frac{\Delta P\pi}{32QL}(D_s + L\ \tan\alpha)^4\left(\frac{n}{3n+1}\right) \quad (7)$$

where n is injectant's shear-thinning behavioural index, that could be obtained in accordance with power law as slope of log viscosity vs log shear stress curve for a particular injection moulding case [18].

$$n = \frac{d\log_e \mu}{d\log_e \tau} \quad (8)$$

However, for non-newtonian shear thinning viscoelastic thermoplastic melts $n < 1$ [2]. Alike high viscosity at low shear rates in blow moulding or low viscosity at high shear rates in extrusion, shear rate dependency is a prominent injection-moulding process feature to rapidly occupy thinner or thicker impression gaps with acceptable quality. Injectant's shear thinning behaviour at purge shot temperature prior to entry would be almost equal to local all through the feed conduit, despite injectant experiencing heavy shear rates as well significant fluctuation through each cycle particularly during filling and packing, typically range from 10^1 to 10^4 per second.; hence viscosity gradience and variance would be bare minimum $\left(\nabla\mu, \frac{\partial\mu}{\partial t} \approx 0\right)$. Therefore as conduit size is fixed or rigid constant viscosity (μ) assumption for idealism could be substantiated. So it is crucial to specifically design sprue conduit for fastest shear rate while maintaining uniformity as much as possible throughout the conduit. Accordingly rearranging Eqn. (7),

$$(D_s + L\ \tan\alpha)^4 = \frac{32\mu QL}{\Delta P\pi}\left(\frac{3n+1}{n}\right)$$

$$D_s + L\ \tan\alpha = \sqrt[4]{\frac{32\mu QL}{\Delta P\pi}\left(\frac{3n+1}{n}\right)} \quad (9)$$

Now resolving for conduit expansion taper,

$$\tan\alpha = \frac{1}{L}\left[\sqrt[4]{\frac{32\mu QL}{\Delta P\pi}\left(\frac{3n+1}{n}\right)} - D_s\right] \quad (10)$$

Substituting $\Delta P = C_P P_{Max}$, where C_P is injectant's characteristic co-efficient representing the extent to which sprue conduit has to recover in-mould pressure that depends on velocity of sound through injectant, while P_{Max} being rated injection pressure available in the machine [19].

where Q is discharge rate, $Q = \frac{\text{Shot Volume}}{\text{Fill Time}} = \frac{V_{Shot}}{t_{fill\ time}}$

while $t_{fill\ time} = \frac{\text{Stroke Volume of M/c}}{\text{Injection rate}} = \frac{V_{Stroke}}{U_{Injection}}$

$$Q = \left(\frac{V_{Shot}}{V_{Stroke}}\right)U_{Injection}$$

Now substituting ΔP and Q into Eqn (10), sprue conduit expansion could be resolved as,

$$\tan\alpha = \frac{1}{L}\left[\sqrt[4]{\frac{32\mu L}{\pi\ C_P\ P_{max}}\left(\frac{V_{Shot}}{V_{Shot}}\right)U_{Injection}\left(\frac{3n+1}{n}\right)} - D_s\right] \quad (11)$$

Traditionally 1° ≥ α ≥ 5° taper is arbitrarily adopted to conserve surfeit feed system volume expense, perhaps fallacious. Forthwith simplified sprue conduit expansion has been proposed based on Eqn.(11) as simplified taper design criteria,

$$\tan\alpha = \frac{(E_r - D_s)}{L} \qquad (12)$$

Here expansion ratio (E_r) is an important quadruple parametric ratio to collectively represent spatial conduit geometry change across initial nozzle tip to final sprue well base, that can be obtained by comparing Eqn (11) and Eqn(12) as,

$$E_r^4 = \left(\frac{32}{\pi}\right)\underbrace{\left(\frac{3n+1}{n}\right)\left(\frac{\mu}{C_P}\right)}_{\text{Material}}\underbrace{\left(\frac{U_{\text{Injection}}}{P_{\text{Max}}V_{\text{Stroke}}}\right)}_{\text{Machine Setting}}\underbrace{\left(L_{\text{Sprue}}V_{\text{Shot}}\right)}_{\text{Moulding}}$$

$$= \left(\frac{32}{\pi}\right)\underbrace{\text{Poly}}_{\text{Material}}\;\underbrace{\text{Ms}}_{\text{Machine Setting}}\;\underbrace{\text{Comp}}_{\text{Moulding}} \qquad (13)$$

As per Eqn. (13) now sprue conduit expansion geometry is specifically sensitive to a particular set of moulding, material and machine combination. Since the influences of material, machine and moulding are specifically quantified to deduce taper angle it is highly reliable. Further individual parameter sensitivity information is highly valuable to responsibly configure conduit design so machine specifications or capacity proportional to injection velocity and inversely proportional of machine size, *i.e, machine size quantified as product of maximum shot volume per stroke and maximum injection pressure* are exclusively perturbed for hypothetical illustrations.

III. Illustrations

Conventional design criteria typically focuses on direct mathematical substitution just enough to specify some discrete or numerical value. Whereas Continuous Sensitivity Equation Method (CSEM) represented in Eqn (13) contrasts to examine relative sensitivity at infinite dimensional range. CSEMs are capable of adopting illustrative intervention to deliberate conduit design sensitivity at wisdom level much beyond pragmatic experimentation or classical analytical studies. Although the inference is still wonted, the analogous derivations compliment a unique perspective over prevalent myths. So three different situational combinations of practical scale are illustrated, by perturbing each at a time [20].

As part of a broader investigation scope to illustrate holistic sprue taper expansion design sensitivity, we choose injection grade acrylonitrile butadiene styrene (ABS) as the hypothetical thermoplastic to be moulded,

Material data listed in Table 1 is used to compute the material term range of Eqn (13) as $\text{Poly} = \{696.786,\ 117.699\} = 499.682$. Similarly a 2500 cc shot volume injection moulding component to a depth of 80 mm sprue bush length are representatively adopted to compute component term of Eqn (13) as $\text{Comp} = 80\times10^{-3}\times2500\times10^{-6} = 0.2\times10^{-3}$. Further Windsor Machines Ltd., Mumbai, Sprint series horizontal injection moulding machine with 2.5mm nozzle orifice has been representatively adopted.

Table 1: Characteristics properties of ABS were obtained from MATWeb

Injection temperature	190 – 210 oC
Capillary Rheometry	
power law index, n	0.2390 to 0.4340
Apparent viscosity	96.99 - 22.19 (N/m2) – sec
In-mould injection pressure required to contrive impression gap	4 140 – 130 000 kPa

A. Sensitivity to Injection Rate

Since most viscoelastic shear-thinning thermoplastic melts are highly sensitive to applied shear force magnitude for instance polyacetals easily decomposes under excessive shear forces action, especially at elevated temperatures. So manipulating injection rate by either or both injection pressure and temperature is currently more

Figure 2 Sprue taper expansion relative to injection rate in a machine

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of wisdom driven owing to their melt state within an acceptable cycle time. Because in general injection shear rate to sprue conduit expansion combination is a prevalent relative judgement across maximum for productivity and minimum to retain injectant quality at its best characteristics [16]. Like thin mouldings require rapid injection rates to ensure impression gaps are filled well before melt solidifies. Despite higher injection rate machine availability correct sprue conduit design is essential to rapidly inject melt into impression gaps, while melt state is still as much uniform as possible to avoid differential shrinkage. Designing sprue conduit expansion specifically to available injection effort would be pretentious, rather than scuttling probabilistically over a set of optimising iterations [16]. In pursuit of this wisdom current research effort intends to perturb injection moulding machine's injection rate in isolation over an infinite range to sensitise sprue conduit taper. By choosing 650T Sprint machine specifications, for which maximum injection pressure is $P_{Max} = \{1260,\ 2230\}$ bar and corresponding stroke volume of $V_{Stroke} = \{3180,\ 8588\}$ cc to illustrate maximum injection pressure is hypothetically anchored to an intermediate value of 1500bar along with 50% BSR as well as 5000cc barrel stroke volume. Should a mould designer intend to accomplish best feasible performance then according to Figure 2, sprue conduit expansion was exponentially sensitive to injection rate extent. Inferentially even a large injection rate requires very nominal widening change rate. So controlling injection rate has modest influence on overall sprue conduit design perfection and eventual injection moulding success. On the other hand excessive high injection rate above Figure 2 curves are also detrimental because they lead to high injectant orientations that are susceptible to stress cracking. For instance ABS mouldings are frequently exposed to acidic solutions for electroplating, so have to be injected at very slow injection speeds to minimise any particular orientation. Further with exorbitant speeds above Figure 2 curves transverse melt injection occurs as in most real mouldings superimposing subsurface orientation over primary orientation, resulting in biaxial orientation effects [21]. Conversely injection rates below Figure 2 curve could be insufficient to recover necessary in-mould pressure, extend fill time, etc., Hence to accomplish best feasible performance we propose to have a combination with sprue expansion and injection rates that lie on the Figure 2 curve.

Actually injection rate is available injection moulding machine's performance limit, contemporary machines offer multiple stages for which an injection speed *(mm/sec)* could be set. Since injection rate has modest influence on conduit expansion, the following scheme is recommended to accomplish defect free mouldability.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

Stage 1 Initial injection speed well known as boost has to be set relative to injection stroke distance until screw reaches 20% of its stroke length. During start-up, it is always better to initiate at modest injection speeds, otherwise short shots, burns, voids, weld lines, etc., may occur. As impression gaps begins filling injection speed is also increased.

Stage 2 A specific injection speed has to be set as screw reaches 40% of stroke length and so on till stage 5. Typically injection rates drops for the last 20% (cushion) of the stroke, By stage 5, transfer position should be reached to change screw action from injection to pack (or mould).

Successful injection moulding is aided by rotating screw as slowly as possible, because in addition to controlling screw RPM, tongue control is also important i.e, the amount of energy necessary to turn screw. Some low viscosity materials *(PP, PE, PS, etc,)* require least torque, in contrast to highly viscous materials *(PC, Acrylic, etc).* Hence depending on melt viscosity torque and speed have to be balanced. So shear heating occurs only when screw is actually injecting *(b/n stage 2 to 4)*. Since melt viscosity changes with injection rate, quite obviously maintaining a constant injection rate profile as in Figure 3 ensures

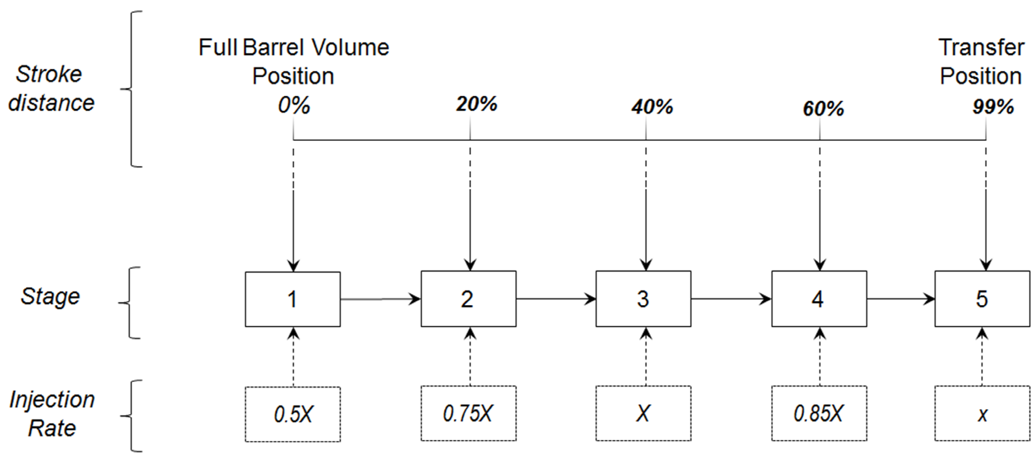

Figure 3 Typical Injection rate profile control for an injection moulding machine

process stability *i.e, to consistently fill impression gap during each shot*. For this injection ram velocity or fill time have to be continuously controlled. However velocity could also be electronically set directly for intrinsic control in few modern microprocessor based machines.

B. Sensitivity to Injection Pressure

Advancing injection unit screw exerts injection pressure to squeeze the injectant ahead through nozzle into sprue conduit, so is a most prominent performance parameter of a moulding machine [22]. As soon as melt encounters cooler sprue conduit surface it starts solidifying, consequent to chilling *i.e, temperature gradience between mould (room temperature) and injectant (molten temperature)*. However injection mechanics conservation laws attribute injection resistance to conduit geometry, therefore injection pressure has significant influence on overall sprue conduit design. Hence to perfectly mould, injection moulding machine should rapidly fill while melt is still in fluid phase itself having sufficient injection power *(maximum injection rate x maximum injection pressure)*. So higher injection power machines are usually used for components of engineering significance to correctly fill, uniformly pack more resin tightly into impression gap, reduce shrinkage, increase gate temperature and avoid occurrence of short shots, surface defects, sink marks and ripples [23]. Higher power generation does consume more energy, in fact much less than the energy required for the added heating and cooling [5], so older machines are often limited by injection pressures to a maximum of 140 MPa; while most modern machines can delivery injection pressures of 500 MPa and even more by providing a selection of extruder barrels and screws, or shooting pots of smaller sizes. Nevertheless injection pressure of most machines typically range from 50 to 500 MPa. Accordingly using available machine power to maintain highest injection pressure gradience current research efforts intends to perturb injection pressure as an independent parameter over an infinite range to sensitise conduit taper. From the chosen 650T sprint machine specifications injection rate of $U_{\text{Injection}} = \{450,\ 1110\}\,\text{cc/sec}$ range and corresponding stroke volume range of $V_{\text{Stroke}} = \{2576,\ 8588\}\,\text{cc}$, to illustrate injection rate is hypothetically anchored at and intermediate value of 700cc/sec as well as 5000cc barrel stroke volume.

Comprehending from Figure 4 sprue conduit expansion is exponentially sensitive to available injection pressure extent. Due to inverse proportionality higher injection pressure is required to inject through smaller and narrow conduits compared to larger and wide ones [24], Figure 4 curve is consistent with this belief. Inferentially at low expansion situations below Figure 4 curve would risk air entrapment leading to burn marks as well as higher molded-in stresses. These excessive moulded in stresses would perpetuate as warpage, impact strength compromise and environmental stress cracking proneness. For contemporary moulding situations with critical tolerance, quality components such as syringes, where core shift concerns prevail. Both injection rate and injection pressure have to be simultaneously configured for smooth melt injection by appropriately setting screw movements *(both angular and linear)*. Conversely if sprue conduit expansion is wider above Figure 4 curve then injection pressure gradience would be inadequate leading to short shots, porosity, unacceptable shrinks, compromised stiffness, etc., Therefore to accomplish best feasible performance sprue conduit expansion should correspond to available injection pressure as illustrated in Figure 4 curve.

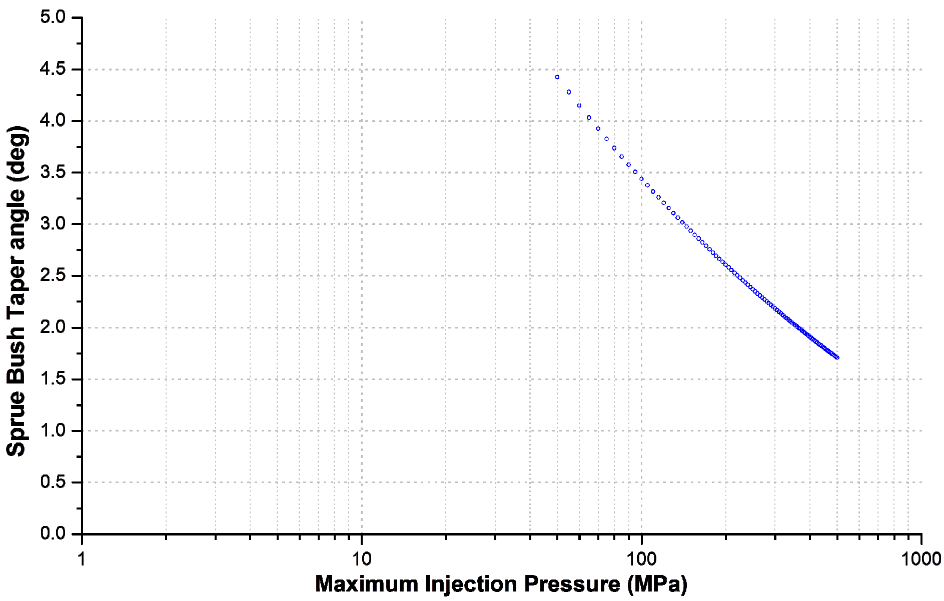

Figure 4 Sprue taper expansion relative to maximum injection pressure of the machine

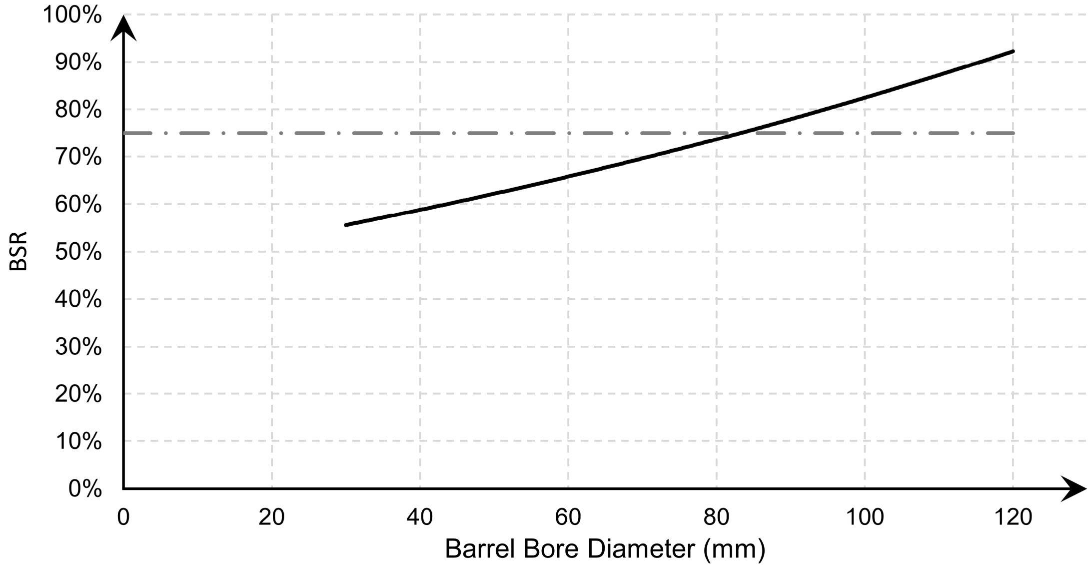

Figure 5 Preferable BSR versus barrel bore diameter (mm) relativity

C. Sensitivity to Barrel Volume

Occasionally machines are fitted with larger screw sizes to accommodate more shot weight, in such a case to accomplish required co-efficient of pressure recovery sprue conduit expansion will have to be configured relative to BSR to regulate operating pressure gradience. Barrel volume to sprue conduit combination choice adeptly allocates a particular residence time, typically ranging from 2 to 5 min, because less than 2min is rarely adequate to uniformly mix melt while beyond 5 min most resins would deteriorate causing burn marks or surface defects and/or mechanical properties. Hence barrel volume is a key decision apparent for moulding success particularly for sensitive materials like PC, ABS, PVC, Acetyls, Cellulosic, other flame retardants, etc that are prone to burning & degradation. So barrel bore size corresponding to BSR choice is currently a wisdom based decision relative to expertise in the field as well as laboratory [24]. Accordingly current research effort intends to perturb injection moulding machine's maximum injection pressure as an independent parameter over an infinite range to sensitise sprue conduit expansion. For which an intermediate value of 1500bar is chosen from 650T sprint machine with maximum injection pressure range of

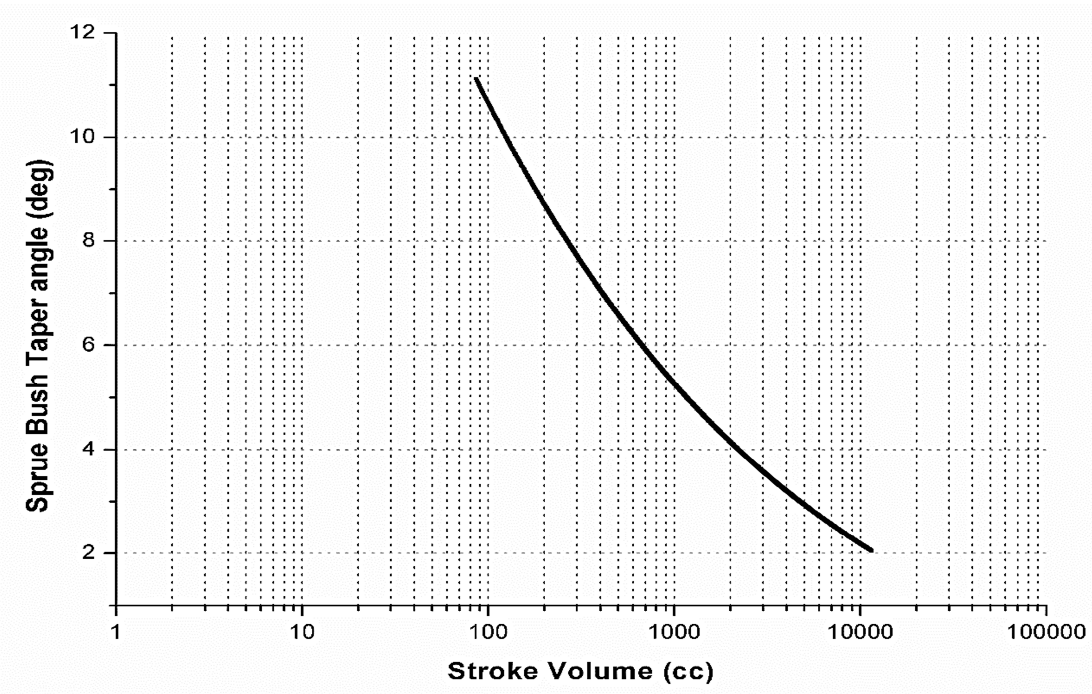

Figure 6 Sprue taper expansion relative to machine's barrel size

$P_{Max} = \{1260,\ 2230\}$ bar. Similarly 700cc/sec injection rate is chosen from $U_{Injection} = \{450,\ 1110\}$ cc / sec range.

Ideal BSR range is 20% to 80% for perfect moulding, because if BSR is less than 20% material residence time increases prolonging shear and heat action that may eventually lead to degradation. On the other hand if BSR is more than 80%, screw may retract even before mould opens that may lead to inadequate shot size, also less than two shot of material in the barrel does not allow melt temperature to be equilibrate during screw metering, as a result unmelted material may appear upon a plastic part affecting structural integrity [25]. Hence BSR should always be at 50%, however preferential choices relative to barrel size are as shown graphically in Figure 5 [16]. Accordingly we propose to have 75% BSR as preferential choices relative to barrel size for best balance preluding both. However under practical situation, for the combination of required component and available machine the ratio could also be sometimes beyond preferential limits, so corrective measures include slowing screw rpm, lowering back pressure, reducing barrel heat in feed zone, etc., beyond all these remedies the only remaining strategy is to widen sprue conduit expansion to counteract high residence time as plotted in Figure 6.

According to Figure 6, sprue conduit expansion is exponentially sensitive to barrel size fitted to the machine and has inverse proportionality to stroke volume with nominal influence on overall sprue conduit expansion. Under the circumstances explained above a stroke volume to conduit expansion combination above Figure 6 curve would compromise moulding quality, while a combination below Figure 6 curve would compromise mould performance, productivity, etc., Hence to accomplish best feasible performance by manipulating various barrels or adjusting stroke volume, it is hereby proposed to have a combination along this curve a best balance between efficiency and performance.

IV. Conclusion

Extensive sprue bush design criteria above manifests exemplary performance can be parametrically designed for a particular machine in future. Sprue conduit expansion sensitivity Eqn.(13) clearly discriminate influences of machine, material and moulding parameters. Attributing a series of factors identified in the discussion, to accomplish best performance, machine specifications have highly complex influence on sprue conduit design as well as its interaction. Although exponential in nature injection rate has direct proportionality, while maximum injection pressure and barrel size have has inverse proportionality to conduit expansion off parting plane. Off them injection rate was found to be relatively more influential than injection pressure and barrel size. Nevertheless perfection can be institutively factored in to sprue conduit design criteria to its extended best performance benefits, compliment many other gainable benefits through stretched competence, affective and cognitive synchronisation of in-situates like injection fill time, injection ramping speed for packing, operating temperatures and compatibility.

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