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(54) **REDUCED SIZE RUNNER FOR AN INJECTION MOLD SYSTEM**

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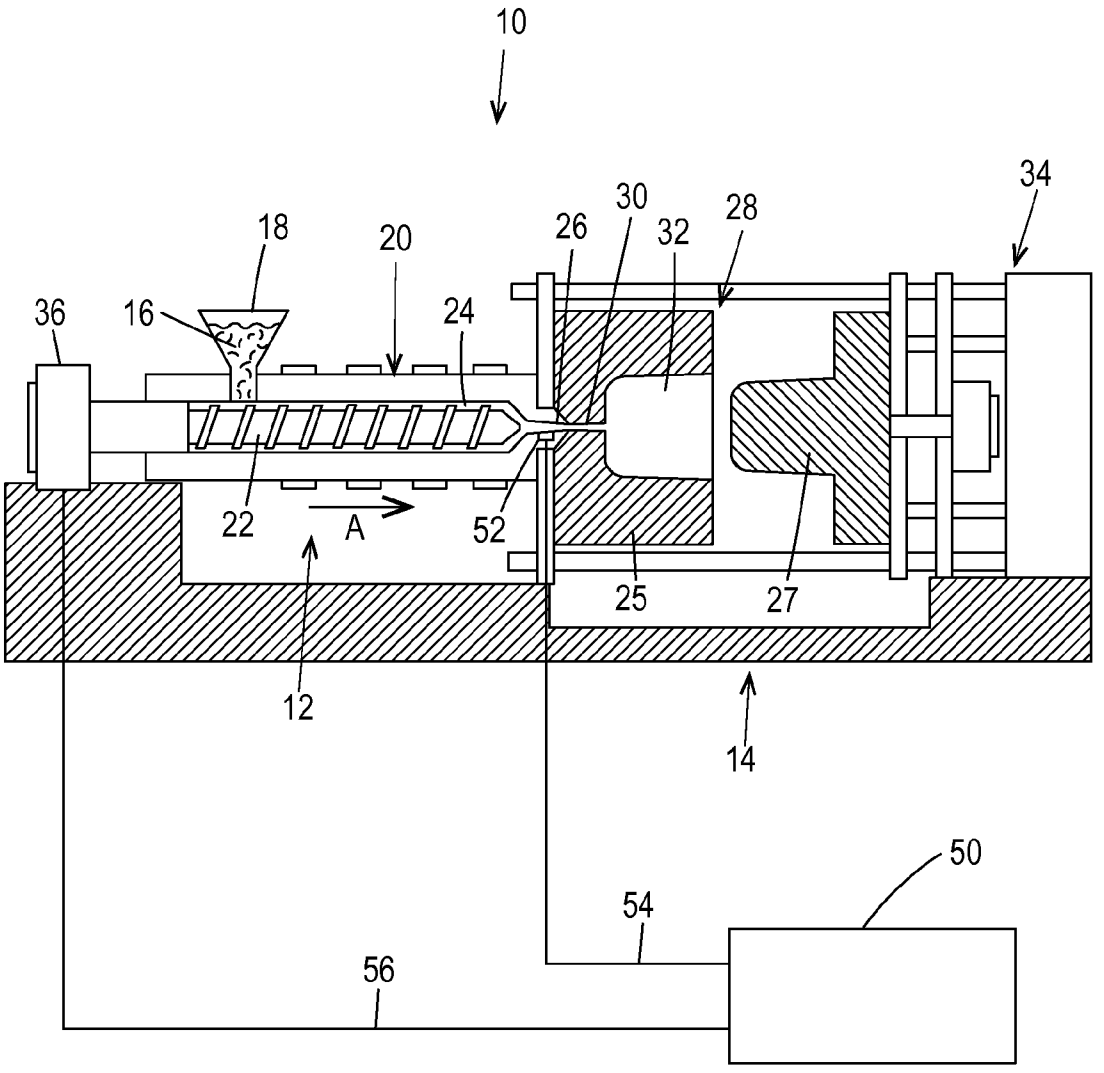
USPC **425/547**; 425/588

(57) **ABSTRACT**

A runner system for a multi-cavity injection molding system, the runner system having runners of reduced size.



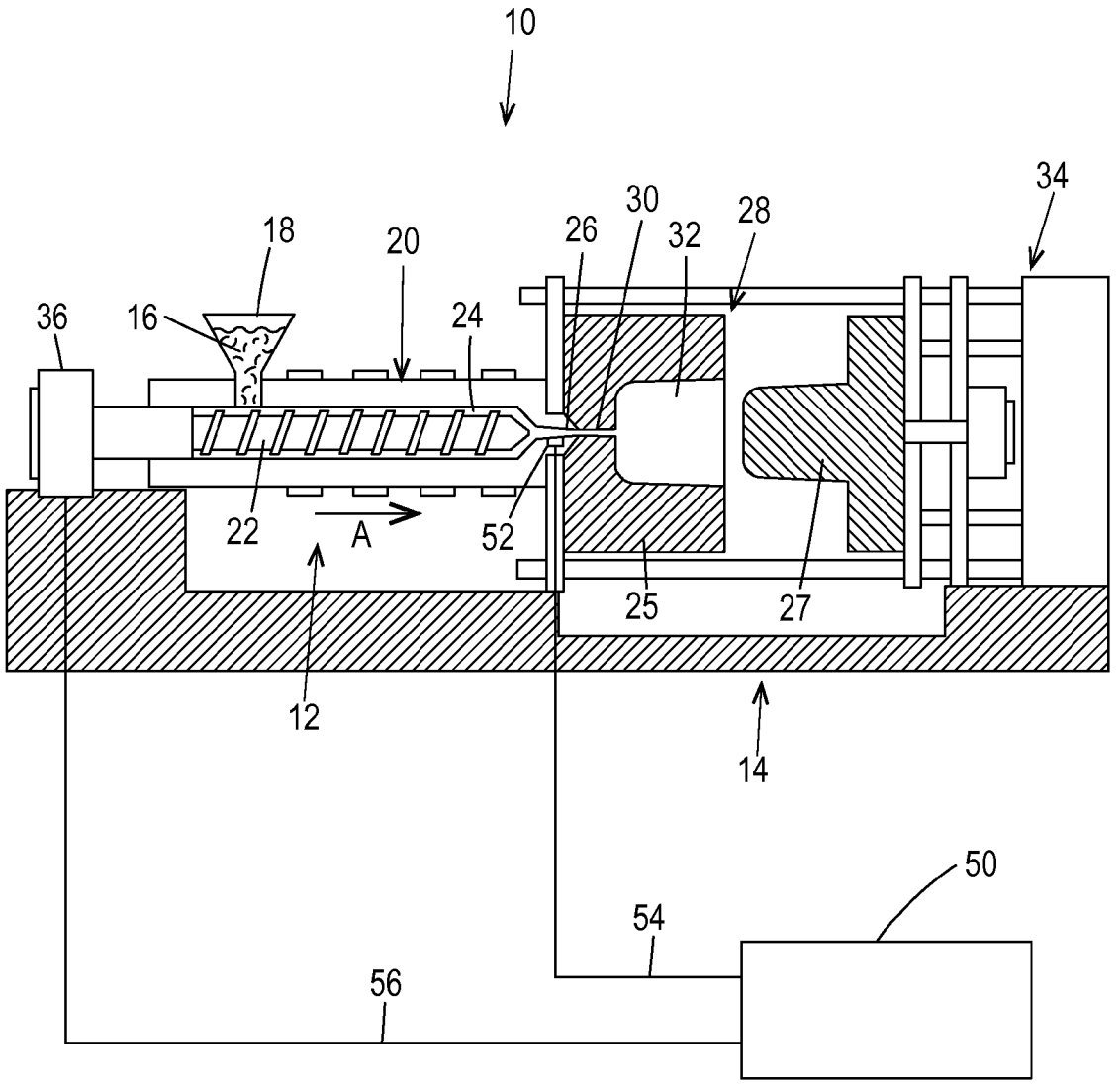


Fig. 1

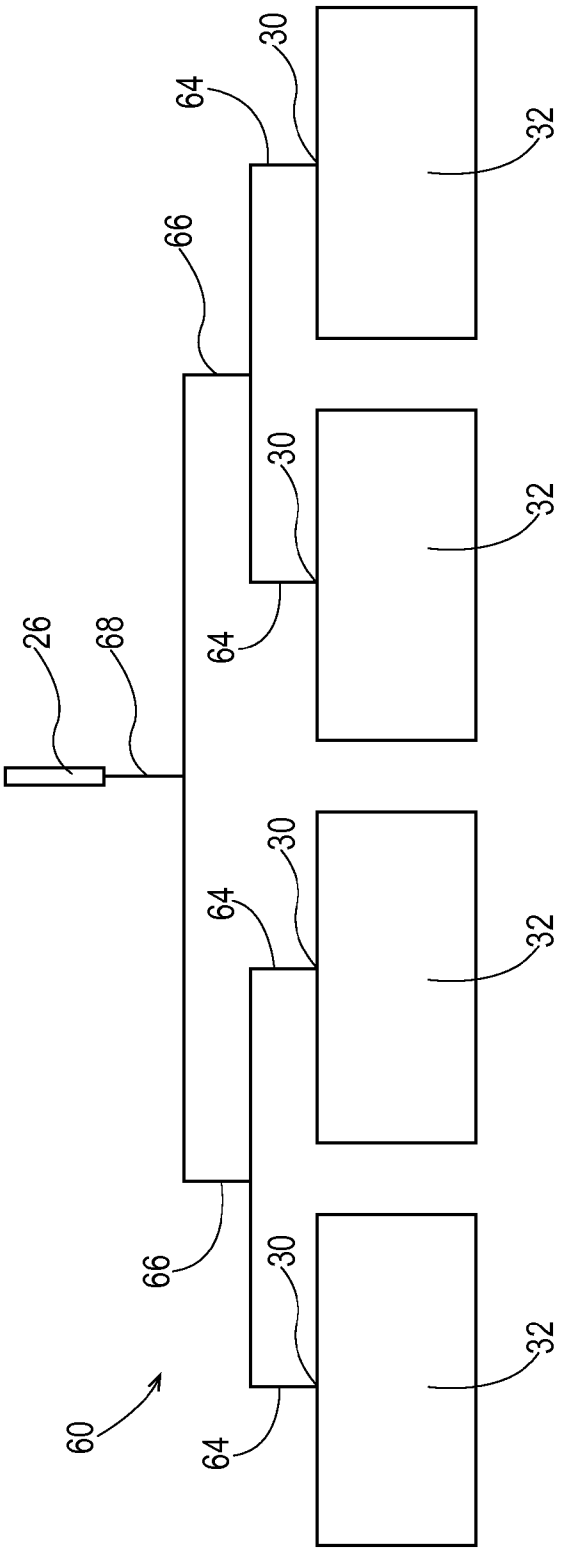


Fig. 2

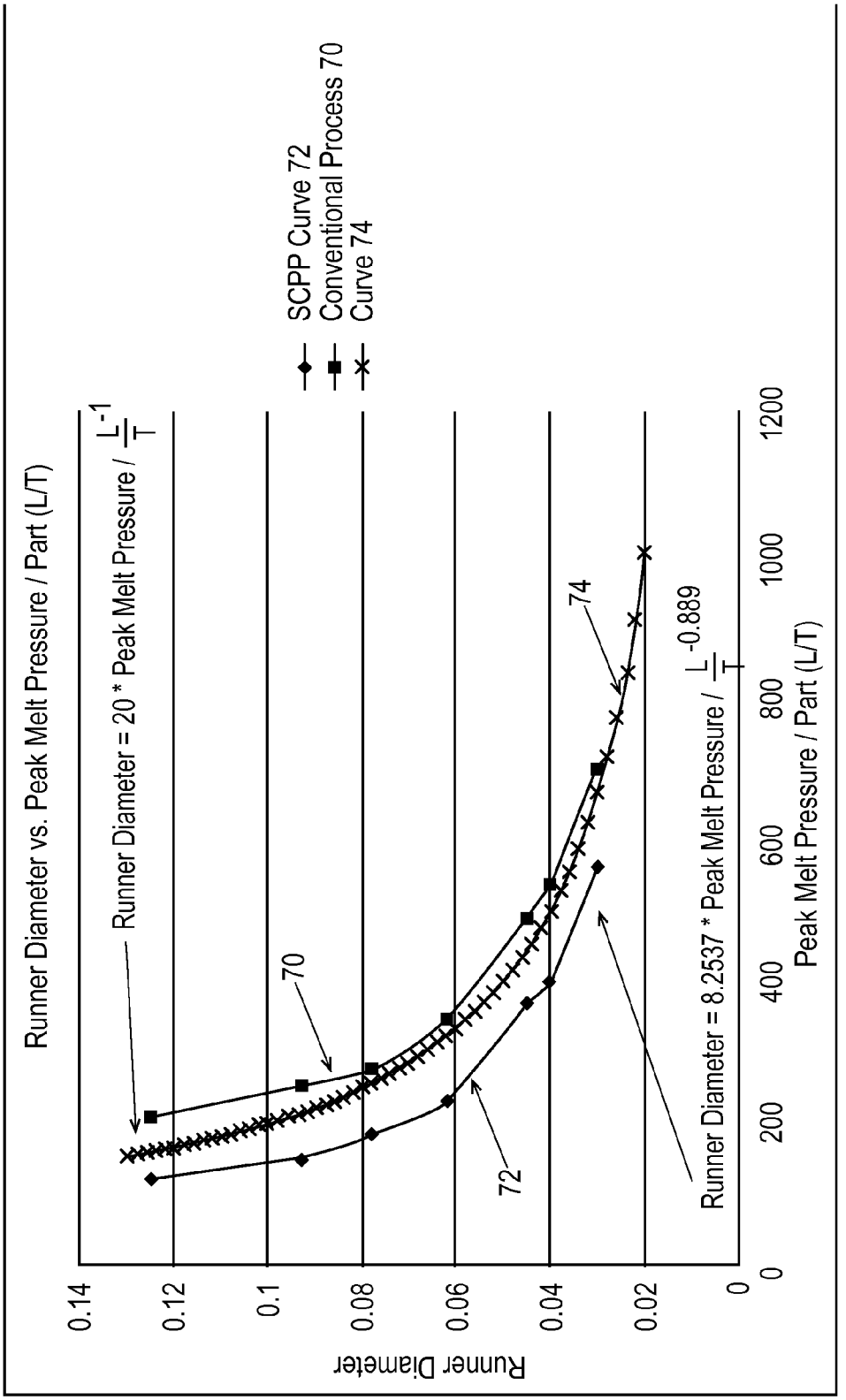

Runner Diameter vs. Peak Melt Pressure / Part (L/T)
Runner Diameter = 20 * Peak Melt Pressure / L/T -1
Runner Diameter = 8.2537 * Peak Melt Pressure / L/T -0.889
SCPP Curve 72
Conventional Process 70
Curve 74
70
72
74
Runner Diameter
Peak Melt Pressure / Part (L/T)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
200
400
600
800
1000
1200

Fig. 3

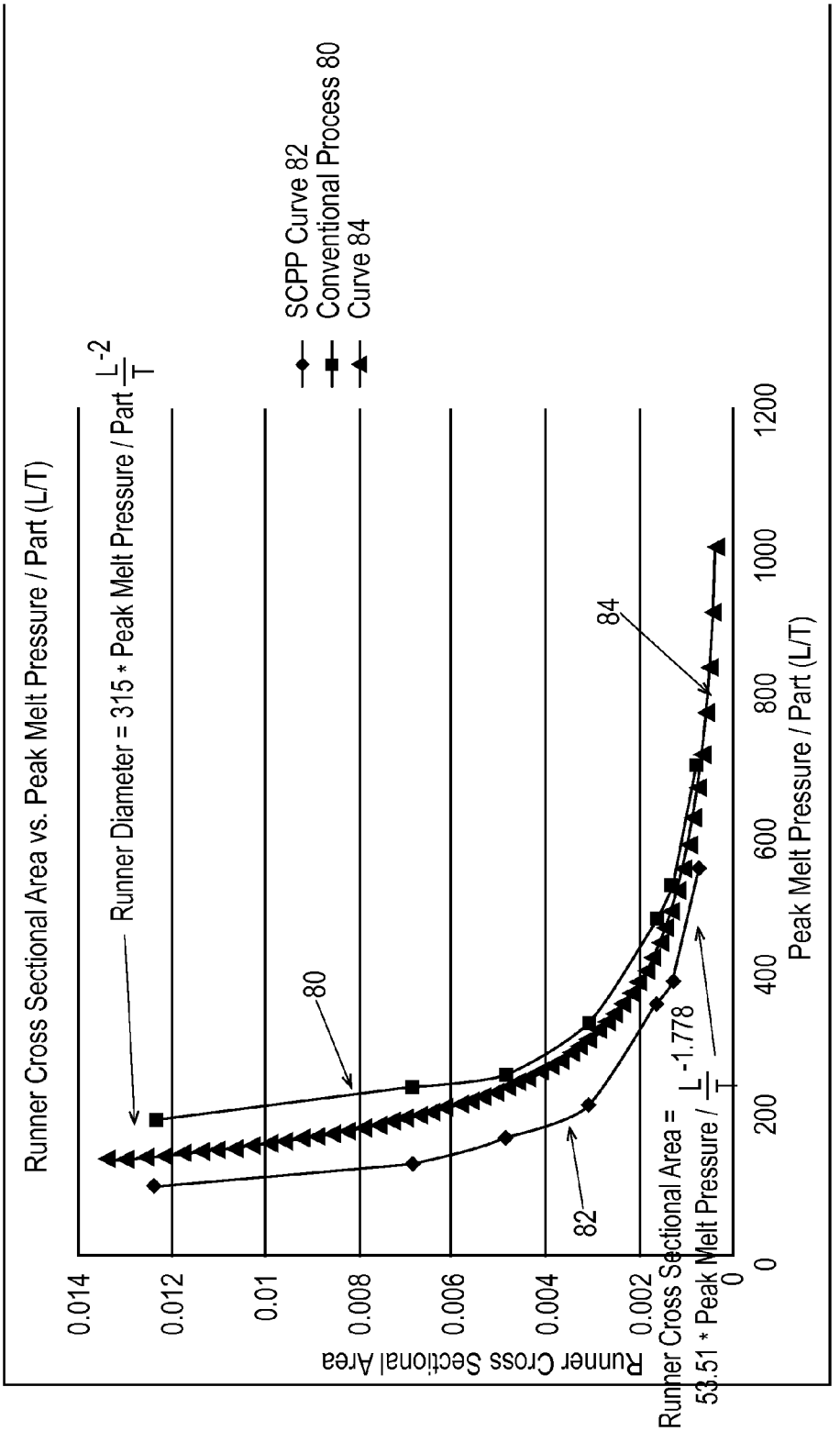

Runner Cross Sectional Area vs. Peak Melt Pressure / Part (L/T)
Runner Diameter = 315 * Peak Melt Pressure / Part L^-2/T
SCPP Curve 82
Conventional Process 80
Curve 84
Runner Cross Sectional Area
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
200
400
600
800
1000
1200
Peak Melt Pressure / Part (L/T)
80
82
84
Runner Cross Sectional Area = 53.51 * Peak Melt Pressure / L^-1.778/T

Fig. 4

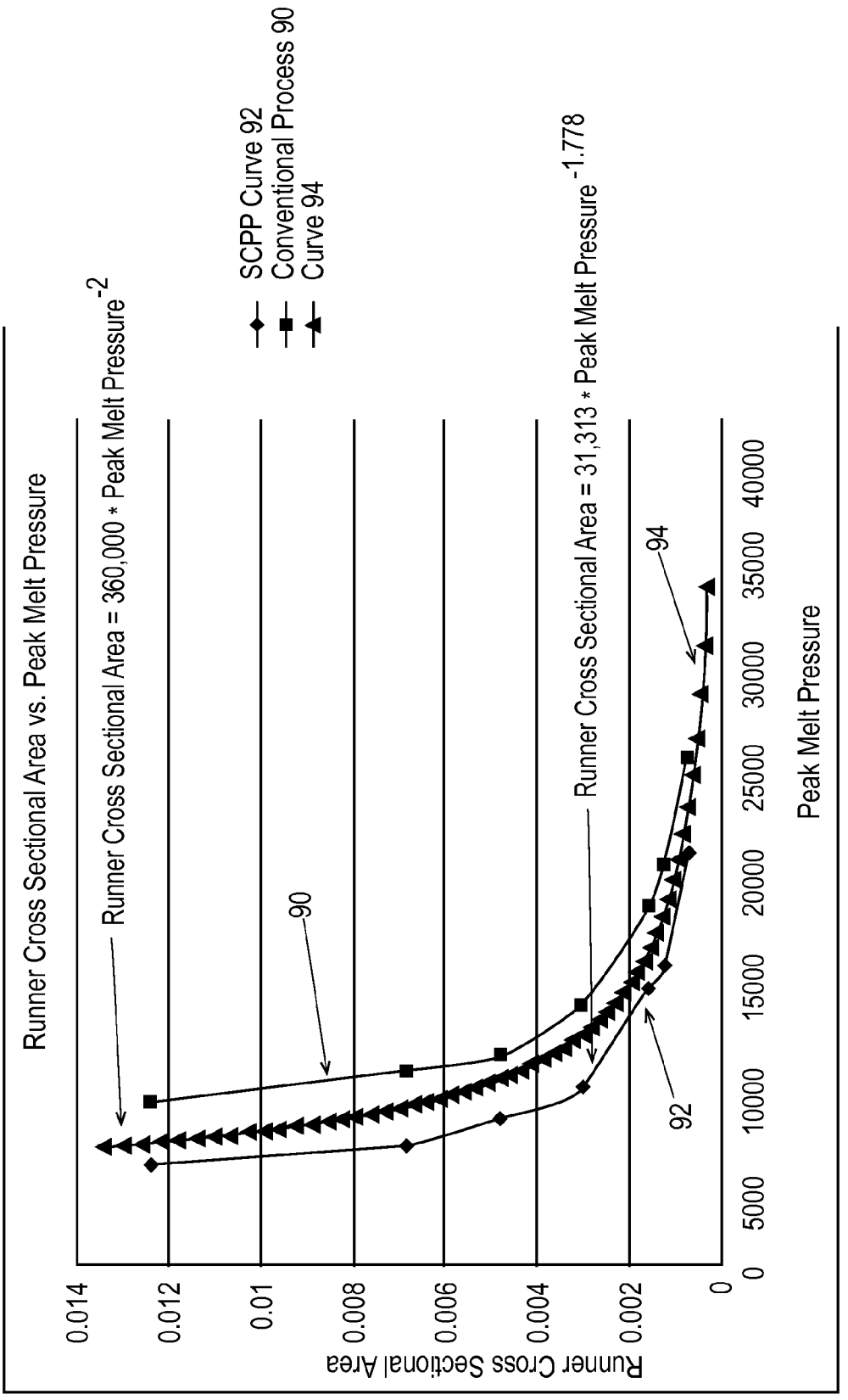

Runner Cross Sectional Area vs. Peak Melt Pressure
Runner Cross Sectional Area = 360,000 * Peak Melt Pressure -2
Runner Cross Sectional Area = 31,313 * Peak Melt Pressure -1.778
SCPP Curve 92
Conventional Process 90
Curve 94
90
92
94
Runner Cross Sectional Area
Peak Melt Pressure
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
5000
10000
15000
20000
25000
30000
35000
40000

Fig. 5

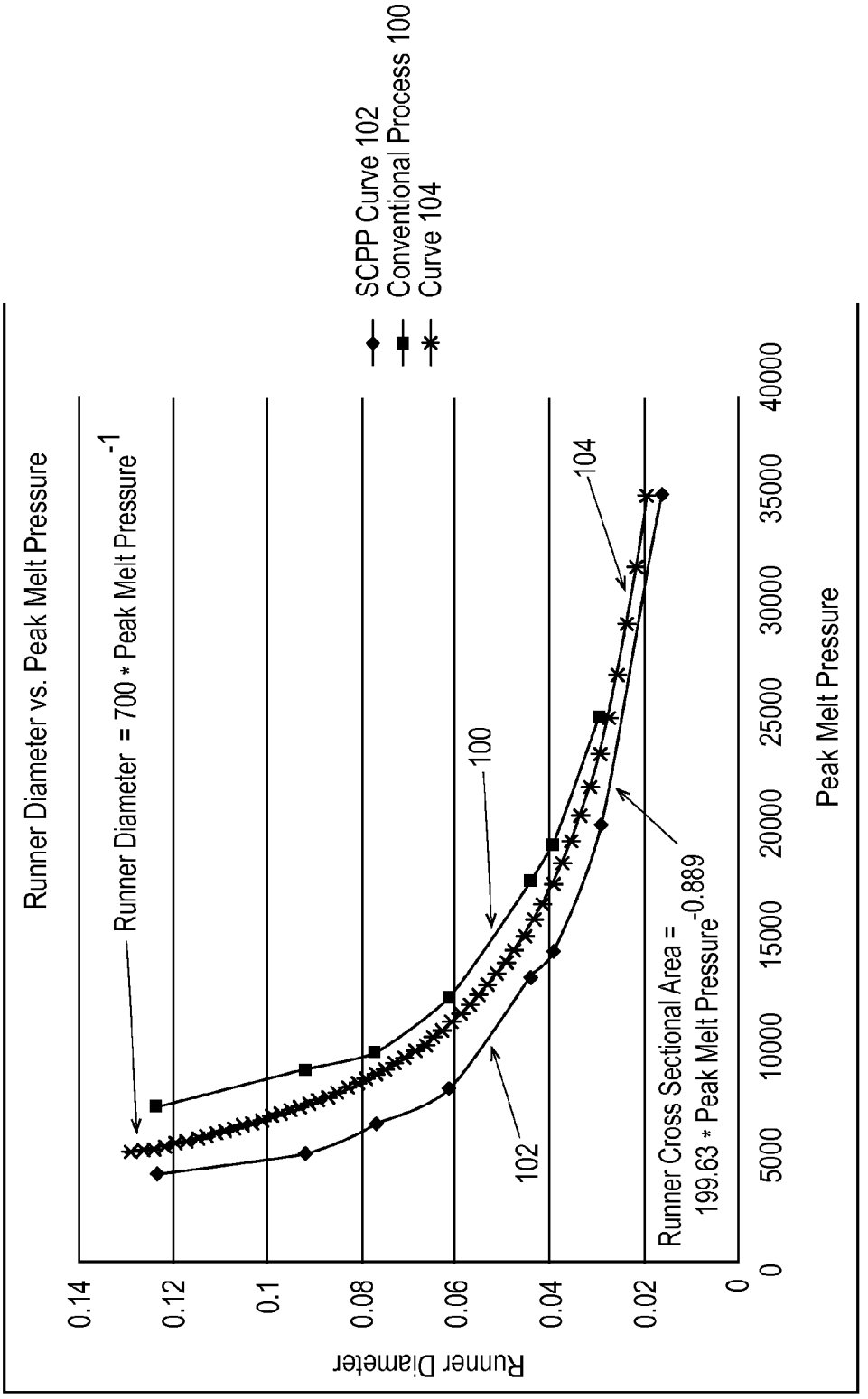

Runner Diameter vs. Peak Melt Pressure
Runner Diameter = 700 * Peak Melt Pressure^-1
SCPP Curve 102
Conventional Process 100 Curve 104
Runner Diameter
Peak Melt Pressure
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5000
10000
15000
20000
25000
30000
35000
40000
100
102
104
Runner Cross Sectional Area = 199.63 * Peak Melt Pressure^-0.889

Fig. 6

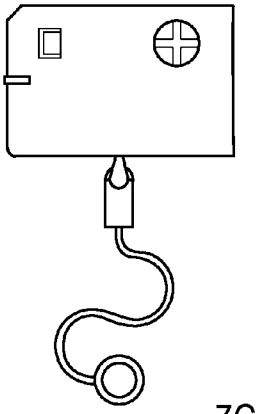


Fig. 7

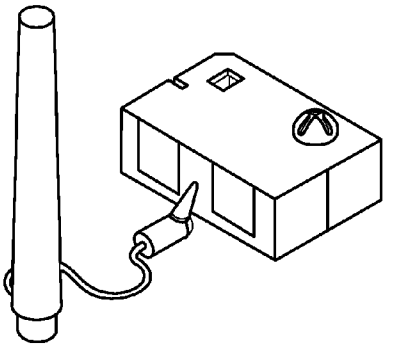


Fig. 7A

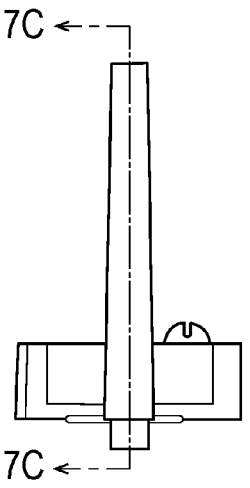


Fig. 7B

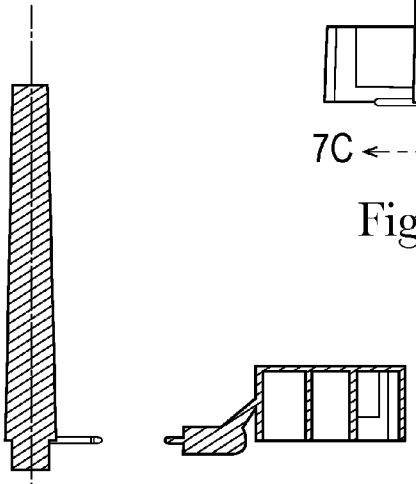


Fig. 7C

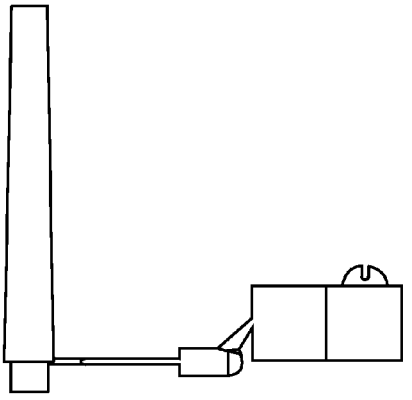


Fig. 7D

REDUCED SIZE RUNNER FOR AN INJECTION MOLD SYSTEM

FIELD OF THE INVENTION

[0001] This disclosure relates generally to apparatuses and methods for injection molding and, more particularly, to apparatuses and methods for producing injection molded parts at substantially constant pressure.

BACKGROUND OF THE INVENTION

[0002] Injection molding is a technology commonly used for high-volume manufacturing of parts made of meltable material, most commonly of parts made of thermoplastic polymers. During a repetitive injection molding process, a plastic resin, most often in the form of small beads or pellets, is introduced to an injection molding machine that melts the resin beads under heat, pressure, and shear. The now-molten polymer or resin is forcefully injected into a mold cavity having a particular cavity shape. The injected plastic is held under pressure in the mold cavity, cooled, and then removed as a solidified part having a shape that essentially duplicates the cavity shape of the mold. The mold itself may have a single cavity or multiple cavities. Each cavity may be connected to a flow channel through one or more gates that direct the flow of the molten resin into the cavity. Thus, a typical injection molding procedure comprises four basic operations: (1) heating the plastic in the injection molding machine to allow it to flow under pressure; (2) injecting the melted plastic into a mold cavity or cavities defined between two mold halves that have been closed; (3) allowing the plastic to cool and harden in the cavity or cavities while under pressure; and (4) opening the mold halves to cause the part to be ejected from the mold.

[0003] The molten plastic resin is injected into the mold cavity and the plastic resin is forcibly pushed through the cavity by the injection molding machine until the plastic resin reaches the location in the cavity furthest from the gate. The resulting length and wall thickness of the part is a result of the shape of the mold cavity.

[0004] Multi-cavity injection molds require a network of feeder channels to distribute molten plastic from the machine nozzle to each individual mold cavity. The feeder channels or runners can be permitted to cool, or can be actively cooled, such that for each molding cycle the runners are filled with molten polymer that solidifies in the runners, and is then removed from the mold as a solid mass of plastic in the shape of the runner or feeder channel network. This type of system is referred to in the art as a "cold runner" system. It is also possible to heat the feeder channel or runner network, such that for each molding cycle the polymer remains molten. The molten polymer remains in the feeder channels or runners after each molding cycle—this molten material is then injected in to the mold cavity upon initiation of the subsequent molding cycle. This type of system is referred to as a "hot runner" system. A "runner system" as used herein, if not preceded by the adjective "hot" or "cold", refers to either a hot runner system or a cold runner system, as well as to a hybrid "hot-to-cold" runner system.

[0005] In the case of a cold runner system, the hydraulic diameter of the runner or feeder channel in closest proximity to a mold cavity typically ranges from about 1.5 to about 3 times the nominal wall thickness of the molded article. See, e.g., Beaumont, Runner and Gating Design Handbook, second edition, page 152, Hanser Gardner Publications, 2007. Hydraulic diameter, or D_H, is a term commonly used in the art to refer not only to the inner diameter of round tubes, but also to an effective inner diameter of non-circular tubes or channels, which may be calculated by the formula=4A/P, where A is the cross-sectional area of the tube or channel and P is the wetted inner perimeter of the cross-section of the tube or channel. This hydraulic diameter is intentionally greater than the article nominal wall thickness (a term defined hereinafter), so that the runner will remain molten longer than the molded part, ensuring that molten plastic can continue to be fed through the feeder network until the mold cavity is completely filled and packed. If polymeric material within the feeder channel were to freeze prior to the mold cavity being completely packed, the molded article would shrink away from the mold cavity excessively, and the molded article would have poor surface finish quality and undesirably high dimensional variation.

[0006] In another convention for sizing cold runners, the runners are designed to have a hydraulic diameter of 1.5 mm greater than the nominal wall thickness of an article to be molded. See, e.g., How to Make Injection Molds, Third Edition, page 153, Carl Hanser, 1993 (Germany).

[0007] In designing runner systems, conventional design parameters call for the runner to begin near the injection unit machine nozzle at a larger cross-sectional area, then progressively step down in cross-sectional area, as the runner is divided to achieve the desired number of runners to reach each individual mold cavity. Importantly, conventional wisdom indicates that the flow runner hydraulic diameter must be increased from a minimum design hydraulic diameter (as determined above) that feeds the mold cavity, to a progressively increasing hydraulic diameter at each branch in the runner along the flow path back to the machine nozzle. This is particularly the case for cold runner systems, as in hot runner systems, since there is not the same need to promote freeze-off and minimize scrap of polymeric material within the runners by minimizing runner diameter as there is in a cold runner system, the hydraulic diameters of runners at different branches of a hot runner system may be more uniform than the progressively-smaller diameters of a cold runner system with increasing proximity to the mold cavity.

[0008] In describing a runner system, it is useful to consider the following terms: The term "main sprue" refers to the first runner leg that is adjacent to the machine nozzle and receives molten polymer (also referred to herein as molten polymeric material or thermoplastic material) from the molding machine. For a multi-cavity mold, the main sprue is divided into multiple "runner branches", such that the number of "final runner branches" is equal to the total number of gate locations (usually one gate per mold cavity). The term "runner branch" refers to each of the flow channels in a runner network. The term "final runner branch" refers to the runner branches that connect directly to the gate, which then connects to the mold cavity. The term "node" refers to a location in the runner network where a runner is divided into smaller runner branches. For example, when the main sprue is divided into four runner branches extending out to four individual mold gates, the intersection of the main sprue with the runner branches is referred to herein as a "node".

[0009] For a conventional molding process, the size of each of the runner branches is related using the formula $D_m=D_b*N^{1/3}$, where N is the number of runner branches extending from a feeder branch [D_m]. N is equal to the number

of times a feed runner [D_m] is divided into equal runner branches [D_b]. D_m and D_b are hydraulic diameters.

[0010] For example, for a runner system where the main sprue is divided into four branches to feed four final runners, N would equal 4. Thus, where D_b is equal to 6 millimeters, D_m is equal to $6*4^{1/3}$ power, or D_m is equal to about 9.524 millimeters.

[0011] In a second example, a runner system where the main sprue is divided into four equal branches, and each of the four equal branches is then divided into four equal final runner branches. The diameter of the main sprue would be determined by starting with the diameter of the final runner, then working back through the system to the main sprue. Thus, where the final runner diameter [D_b] is equal to 6 millimeters, the feeder runner diameter [D_m] is equal to $6*4^{1/3}$ power, or is equal to about 9.524 millimeters. The next feeder runner, which in this case would be the main sprue diameter, would then be calculated in the same manner starting with the diameter of about 9.524 millimeters. Thus, the diameter of the main sprue [D_m] is equal to $9.524*4^{1/3}$, or 15.118 millimeters. An equivalent calculation is Dm=Db*[the total number of final runners]$^{1/3}$. For example, the 16 cavity tool indicated in second example above, if calculated by this formula provides the same answer of 15.118 millimeters. Specifically 6 mm$*16^{1/3}$ equals 15.118 millimeters. This relationship holds true regardless of the numbers of nodes located between the main sprue and the final runners. Each interim runner branch step would be related by the formula $D_m=D_b*N^{1/3}$.

[0012] This results in a substantial volume of plastic being required to distribute the polymer to the injection mold cavities. In the case of a cold runner system, this large volume can extend the cycle times for some parts, increase clamp tonnage (because the larger the volume of the runner system, the higher the volume of polymer material between the machine nozzle and the mold cavities, and the more clamp tonnage that may likely be necessary to mold articles along with the volume of runner material), and this substantial volume of polymer is typically disposed of for each "shot" of polymer injected in to the cavity—since the cold runner is typically discarded as scrap or reground for re-use in subsequent injection molding cycles. In the case of a hot runner system, this volume of material is heated during each molding cycle, thus the higher the volume of the runner, the longer the polymer residence time, and the longer the polymer is exposed to heat that degrades the polymer. Furthermore, the more volume of material contained in the hot runner, the more material that must be purged from the system when changing the color of a polymer or changing from one polymer material to another polymer material. This leads to lost productivity during the material changeover process. For both hot and cold runners, it is desirable to reduce the total volume of material contained in the runner.

SUMMARY OF THE INVENTION

[0013] Embodiments of the present invention generally relate to systems, including runner systems, machines, products, and methods of producing products by injection molding and more specifically to systems, including runner systems, products, and methods of producing products by substantially constant pressure injection molding.

[0014] The term "low peak pressure" as used herein with respect to peak melt pressure of a thermoplastic or molten polymeric material means peak melt pressures in a vicinity of a nozzle of an injection molding machine of 6000 psi and lower. The peak melt pressure may be measured at locations in the runner system other than in a vicinity of the nozzle, such as in the main sprue, any of the runner branches, or in the vicinity of the gate at the entrance of the mold cavity.

[0015] The term "intermediate peak pressure" as used herein with respect to peak melt pressure of a thermoplastic or molten polymeric material means peak melt pressures in a vicinity of a nozzle of an injection molding machine of approximately 6,000 psi to approximately 15,000 psi.

[0016] The term "high peak pressure" as used herein with respect to peak melt pressure of a thermoplastic or molten polymeric material means peak melt pressures in a vicinity of a nozzle of an injection molding machine of greater than 15,000 psi.

[0017] The term "substantially low constant pressure" as used herein with respect to a melt pressure of a thermoplastic material means that deviations from a baseline melt pressure do not produce meaningful changes in physical properties of the thermoplastic material. For example, "substantially low constant pressure" includes, but is not limited to, pressure variations for which viscosity of the melted thermoplastic material does not meaningfully change. The term "substantially constant" in this respect includes deviations of approximately 30% from a baseline melt pressure. For example, the term "a substantially constant pressure of approximately 4600 psi" includes pressure fluctuations within the range of about 6000 psi (30% above 4600 psi) to about 3200 psi (30% below 4600 psi). A melt pressure is considered substantially constant as long as the melt pressure fluctuates no more than 30% from the recited pressure. The peak melt pressure could be as high as 6000 psi for a low peak pressure system.

[0018] The term "substantially intermediate constant pressure" as used herein with respect to a melt pressure of a thermoplastic material means that deviations from a baseline melt pressure do not produce meaningful changes in physical properties of the thermoplastic material. For example, "substantially intermediate constant pressure" includes, but is not limited to, pressure variations for which viscosity of the melted thermoplastic material does not meaningfully change. The term "substantially constant" in this respect includes deviations of approximately 30% from a baseline melt pressure. For example, the term "a substantially constant pressure of approximately 11,000 psi" includes pressure fluctuations within the range of about 14,300 psi (30% above 11,000 psi) to about 7,700 psi (30% below 11,000 psi). A melt pressure is considered substantially constant as long as the melt pressure fluctuates no more than 30% from the recited pressure. The peak melt pressure could be as high as 14,300 psi. It is found that when molten polymer is introduced to a mold at substantially constant pressure with peak melt pressures at approximately 6,000 psi or below, or between 6,000 psi and 15,000 psi, or between 15,000 and 20,000 psi, as opposed to the conventional mold systems not maintained at substantially constant pressure because such conventional systems are controlled by volumetric flow rate, the size (i.e., volume) of the runners from the nozzle to the mold cavities, and in particular, the size of the runners in closest proximity to the mold cavities, may be significantly smaller than runners in conventional high, variable pressure (sometimes referred to as spike pressure) injection molding systems. For a given length runner, the runner size may vary due to changes in the runner hydraulic cross-sectional area or the runner hydraulic diameter.

[0019] Decreasing the size of the runners has several benefits. In the case of cold runners, decreasing the runner size

advantageously increases options regarding the mold cavity spacing because the cavities may be spaced more closely to one another. Potentially, so much space between cavities can be saved in an overall mold such that the number of total cavities that can be provided in a given mold can be increased. Another advantage to a decreasing runner size in a cold runner system is that it reduces the energy needed to introduce molten polymer through the runner system and ultimately to the mold cavities.

[0020] An additional benefit of smaller feed channels or runners in a cold runner system as compared to conventional injection molding systems is that because the cold runner is ejected or otherwise removed at the end of a molding cycle, and reground for use in subsequent molding cycles, reducing the size of the runners reduces the size of those cold runners that need to be ejected or removed at the end of a molding cycle. By reducing the size of the runners, and thereby reducing the amount of material that needs to be reground, the integrity and quality of the resulting molded articles is increased, because the percentage of regrind in any given injection molding cycle is reduced.

[0021] For a hot runner system, a benefit of a reduced-sized runner is that there is less of a pressure drop from branch to branch of the runners (i.e., from runners closest to the nozzle to the runners closest to the mold cavities), permitting the injection molding system to maintain constant pressure and make more consistent parts. A reduced hot runner size translates to reduced molten polymer in the runner system, thereby reducing the polymer residence time, and shortening the duration of exposure to heat (minimizing polymer degradation). With less polymer material contained in the hot runner, less material would need to be purged from the system when changing the color of a polymer or changing from one polymer material to another polymer material, thereby reducing changeover time. As with a cold runner system, reduced runner size could provide benefits in spacing, and even overall number, of cavities in a given mold.

[0022] The manner in which these and other benefits of an injection molding system having a reduced runner size is achieved is explained in the following detailed description of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The embodiments set forth in the drawings are illustrative and exemplary in nature and not intended to limit the subject matter defined by the claims. The following detailed description of the illustrative embodiments can be understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

[0024] FIG. **1** illustrates a schematic view of a high productivity injection molding machine constructed according to the present disclosure;

[0025] FIG. **2** illustrates a schematic view of a multi-cavity injection molding system with multiple branches of runners provided between a nozzle and the mold cavities;

[0026] FIG. **3** illustrates a comparison of the relationship of hydraulic runner diameter to the quotient of peak melt pressure over L/T for a part molded at a substantially constant pressure;

[0027] FIG. **4** illustrates a comparison of the relationship of hydraulic runner cross-sectional area to the quotient of peak melt pressure over L/T for a part molded at a substantially constant pressure;

[0028] FIG. **5** illustrates a comparison of the relationship of hydraulic runner cross-sectional area to peak melt pressure for a part molded at a substantially constant pressure;

[0029] FIG. **6** illustrates a comparison of the relationship of hydraulic runner diameter to peak melt pressure for a part molded at a substantially constant pressure; and

[0030] FIG. **7** illustrates a top view of an experimental mold and part used to generate the data from which the comparison charts of FIGS. **3-6** were formed.

[0031] FIG. **7**A illustrates an isometric view of the experimental mold and part of FIG. **7**.

[0032] FIG. **7**B illustrates a front view of the experimental mold and part of FIG. **7**.

[0033] FIG. **7**C illustrates a cross-sectional view of the experimental mold and part of FIG. **7**.

[0034] FIG. **7**D illustrates a side view of the experimental mold and part of FIG. **7**.

DETAILED DESCRIPTION OF THE INVENTION

[0035] Referring to the figures in detail, FIG. **1** illustrates an exemplary substantially constant pressure (with peak pressures ranging from about 1,000 to <6000 psi, from about 6,000-about 10,000 psi, about 10,000 to about 15,000 psi, and about 15,000 to about 20,000 psi) injection molding apparatus **10** for producing thin-walled parts in high volumes (e.g., a class 101 or 102 injection mold, or an "ultra high productivity mold"). The injection molding apparatus **10** generally includes an injection system **12** and a clamping system **14**. A thermoplastic material may be introduced to the injection system **12** in the form of thermoplastic pellets **16**. The thermoplastic pellets **16** may be placed into a hopper **18**, which feeds the thermoplastic pellets **16** into a heated barrel **20** of the injection system **12**. The thermoplastic pellets **16**, after being fed into the heated barrel **20**, may be driven to the end of the heated barrel **20** by a reciprocating screw **22**. The heating of the heated barrel **20** and the compression of the thermoplastic pellets **16** by the reciprocating screw **22** causes the thermoplastic pellets **16** to melt, forming a molten thermoplastic material **24**. The molten thermoplastic material is typically processed at a temperature of about 130° C. to about 410° C.

[0036] The reciprocating screw **22** forces the molten thermoplastic material **24**, toward a nozzle **26** to form a shot of thermoplastic material, which will be injected into a mold cavity **32** of a mold **28**. The molten thermoplastic material **24** may be injected through a gate **30**, which directs the flow of the molten thermoplastic material **24** to the mold cavity **32**. The mold cavity **32** is formed between first and second mold parts **25**, **27** of the mold **28** and the first and second mold parts **25**, **27** are held together under pressure by a press or clamping unit **34**. For instance, the press or clamping unit **34** applies a clamping force in the range of approximately 1000 psi to approximately 6000 psi during the molding process to hold the first and second mold parts **25**, **27** together while the molten thermoplastic material **24** is injected into the mold cavity **32**. To support these clamping forces, the clamping system **14** may include a mold frame and a mold base, the mold frame and the mold base being formed from a material having a surface hardness of more than about 165 BHN and preferably less than 260 BHN, although materials having surface hardness BHN values of greater than 260 may be used as long as the material is easily machinable, as discussed further below.

[0037] Once the shot of molten thermoplastic material **24** is injected into the mold cavity **32**, the reciprocating screw **22** stops traveling forward. The molten thermoplastic material **24** takes the form of the mold cavity **32** and the molten thermoplastic material **24** cools inside the mold **28** until the thermoplastic material **24** solidifies. Once the thermoplastic material **24** has solidified, the press **34** releases the first and second mold parts **25**, **27**, the first and second mold parts **25**, **27** are separated from one another, and the finished part may be ejected from the mold **28**. The mold **28** may include a plurality of mold cavities **32** to increase overall production rates.

[0038] A controller **50** is communicatively connected with a sensor **52** and a screw control **36**. The controller **50** may include a microprocessor, a memory, and one or more communication links. The controller **50** may be connected to the sensor **52** and the screw control **36** via wired connections **54**, **56**, respectively. In other embodiments, the controller **50** may be connected to the sensor **52** and screw control **56** via a wireless connection, a mechanical connection, a hydraulic connection, a pneumatic connection, or any other type of communication connection known to those having ordinary skill in the art that will allow the controller **50** to communicate with both the sensor **52** and the screw control **36**.

[0039] In the embodiment of FIG. **1**, the sensor **52** is a pressure sensor that measures (directly or indirectly) melt pressure of the molten thermoplastic material **24** in the nozzle **26**. The sensor **52** generates an electrical signal that is transmitted to the controller **50**. The controller **50** then commands the screw control **36** to advance the screw **22** at a rate that maintains a substantially constant melt pressure of the molten thermoplastic material **24** in the nozzle **26**. While the sensor **52** may directly measure the melt pressure, the sensor **52** may measure other characteristics of the molten thermoplastic material **24**, such as temperature, viscosity, flow rate, etc, that are indicative of melt pressure Likewise, the sensor **52** need not be located directly in the nozzle **26**, but rather the sensor **52** may be located at any location within the injection system **12** or mold **28** that is fluidly connected with the nozzle **26**. If the sensor **52** is not located within the nozzle **26**, appropriate correction factors may be applied to the measured characteristic to calculate the melt pressure in the nozzle **26**. In yet other embodiments, the sensor **52** need not be fluidly connected with the nozzle. Rather, the sensor could measure clamping force generated by the clamping system **14** at a mold parting line between the first and second mold parts **25**, **27**.

[0040] Although an active, closed loop controller **50** is illustrated in FIG. **1**, other pressure regulating devices may be used instead of the closed loop controller **50**. For example, a pressure regulating valve (not shown) or a pressure relief valve (not shown) may replace the controller **50** to regulate the melt pressure of the molten thermoplastic material **24**. More specifically, the pressure regulating valve and pressure relief valve can prevent overpressurization of the mold **28**. Another alternative mechanism for preventing overpressurization of the mold **28** is to activate an alarm when an overpressurization condition is detected.

[0041] Molded parts are generally considered to be thin-walled when a length of a flow channel L divided by a thickness of the flow channel T is greater than 100 (i.e., L/T>100), but less than 1000. For mold cavities having a more complicated geometry, the L/T ratio may be calculated by integrating the T dimension over the length of the mold cavity **32** from a gate **30** to the end of the mold cavity **32**, and determining the longest length of flow from the gate **30** to the end of the mold cavity **32**. The L/T ratio can then be determined by dividing the longest length of flow by the average part thickness. In the case where a mold cavity **32** has more than one gate **30**, the L/T ratio is determined by integrating L and T for the portion of the mold cavity **32** filled by each individual gate and the overall L/T ratio for a given mold cavity is the highest L/T ratio that is calculated for any of the gates. In some injection molding industries, thin-walled parts may be defined as parts having an L/T>100, or having an L/T>200, but <1000. The length of the flow channel L is the longest flow length as measured from the gate **30** to the end **104** of the mold cavity. Thin-walled parts are especially prevalent in the consumer products industry.

[0042] High L/T ratio parts are commonly found in molded parts having average thicknesses less than about 10 mm. In consumer products, products having high L/T ratios generally have an average thickness of less than about 5 mm. For example, while automotive bumper panels having a high L/T ratio generally have an average thickness of 10 mm or less, tall drinking glasses having a high L/T ratio generally have an average thickness of about 5 mm or less, containers (such as tubs or vials) having a high L/T ratio generally have an average thickness of about 3 mm or less, bottle cap enclosures having a high L/T ratio generally have an average thickness of about 2 mm or less, and individual toothbrush bristles having a high L/T ratio generally have an average thickness of about 1 mm or less. The high productivity injection molding processes and devices disclosed herein are particularly advantageous for parts having a thickness of 5 mm or less and the disclosed processes and devices are more advantageous for thinner parts.

[0043] Thin-walled parts with high L/T ratios present certain obstacles in injection molding. For example, the thinness of the flow channel tends to cool the molten thermoplastic material before the material reaches the flow channel end **104**. When this happens, the thermoplastic material freezes off and no longer flows, which results in an incomplete part. To overcome this problem, traditional injection molding machines inject the molten thermoplastic material at high variable pressures, typically greater than a peak pressure of 15,000 psi, so that the molten thermoplastic material rapidly fills the mold cavity before having a chance to cool and freeze off. This is one reason that manufacturers of the thermoplastic materials teach injecting at high variable pressures. Another reason traditional injection molding machines inject at high pressures is the increased shear, which increases flow characteristics, as discussed above. These high variable injection pressures require the use of very hard materials to form the mold **28** and the feed system, among other things. Moreover, the thin walled parts may include one or more special features, such as a living hinge, a filament, a closure, a dispenser, a spout, a bellows, and an actuator, that must be filled before the material freezes.

[0044] When filling at substantially constant pressure, it was generally thought that the filling rates would need to be reduced relative to conventional filling methods. This means the polymer would be in contact with the cool molding surfaces for longer periods before the mold would completely fill. Thus, more heat would need to be removed before filling, and this would be expected to result in the material freezing off before the mold is filled. It has been unexpectedly discovered that the thermoplastic material will flow when subjected

to substantially constant pressure conditions despite a portion of the mold cavity being below the no-flow temperature of the thermoplastic material. It would be generally expected by one of ordinary skill in the art that such conditions would cause the thermoplastic material to freeze and plug the mold cavity rather than continue to flow and fill the entire mold cavity. Without intending to be bound by theory, it is believed that the substantially constant pressure conditions of embodiments of the disclosed method and device allow for dynamic flow conditions (i.e., constantly moving melt front) throughout the entire mold cavity during filling. There is no hesitation in the flow of the molten thermoplastic material as it flows to fill the mold cavity and, thus, no opportunity for freeze-off of the flow despite at least a portion of the mold cavity being below the no-flow temperature of the thermoplastic material.

[0045] Additionally, it is believed that as a result of the dynamic flow conditions, the molten thermoplastic material is able to maintain a temperature higher than the no-flow temperature, despite being subjected to such temperatures in the mold cavity, as a result of shear heating. It is further believed that the dynamic flow conditions interfere with the formation of crystal structures in the thermoplastic material as it begins the freezing process. Crystal structure formation increases the viscosity of the thermoplastic material, which can prevent suitable flow to fill the cavity. The reduction in crystal structure formation and/or crystal structure size can allow for a decrease in the thermoplastic material viscosity as it flows into the cavity and is subjected to the low temperature of the mold that is below the no-flow temperature of the material.

[0046] Referring to FIG. **2**, which schematically illustrates portions of a multi-cavity injection molding system, a plurality of mold cavities **32** are provided, in each of which a distinct article or part is to be injection molded. A system of feeder channels or runners **60** is provided between a nozzle **26** and gates **30**. The runners **64** of a first branch set, also referred to herein as the final runners, are the runners disposed in closest proximity to the mold cavities **32**. Each of the runners **66** of a second branch set of runners are in fluid communication with at least two of the runners **64** of the first branch set of runners. The runners **66** of the second branch set of runners are disposed one step, or branch level, more remote from the gates **30** of the mold cavities **32** (and thus one step, or branch level, closer to the nozzle **26**) than the runners **64** of the first branch set of runners.

[0047] A main runner **68** is in fluid communication with each runner **66** of the second branch of runners, with the main runner **68** being the runner in closest proximity to the nozzle **26**, and thus most remote from the gates **30** of the mold cavities **32**. The main runner **68** may be the main sprue of the system. As used herein, runners and other structural elements in fluid communication with one another need not be in direct fluid communication, but merely must have the capability of molten polymeric material moving from one to the other, whether directly or indirectly.

[0048] While FIG. **2** illustrates a four-cavity mold with three runner branches, it is recognized that additional mold cavities **32** and branch sets of runners may be provided intermediate a first runner branch set of runners **64** in closest proximity to a plurality of mold cavities and a main runner **68** in closest proximity to a nozzle **26**. In addition, while FIG. **2**, for convenience, is illustrated in two dimensions, it is recognized that runner systems may be designed and manufactured to split off at each branch in a number of directions. For instance, while the main runner **68** in closest proximity to the nozzle **26** is illustrated as a single runner, the nozzle **26** may alternatively split immediately into a set of main runners that split into, for example, four directions. While even numbered cavity distributions are often used for ease manufacturing and mold layout, alternate configurations including odd number of splits, leading to any number of total cavities, whether even or odd. If one were to desire a non-even numbered cavity distribution, a substantially constant pressure injection molding process would facilitate that.

[0049] In the design of conventional multi-cavity injection molding systems, various rules of thumb or industry-accepted benchmarks have been developed for determining appropriate runner size for a given part to be molded. As discussed in the Background of the Invention section, some of these include:

[0050] The hydraulic diameter of the runner or feeder channel in closest proximity to a mold cavity should range from about 1.5 to about 3 times the nominal wall thickness of the molded article. See, e.g., Beaumont, Runner and Gating Design Handbook, second edition, page 152, Hanser Gardner Publications, 2007.

[0051] The hydraulic diameter of the runner or feeder channel in closest proximity to a mold cavity should be at least 1.5 mm greater than the nominal wall thickness of a part to be molded. See, e.g., How to Make Injection Molds, third edition, page 153, Carl Hanser, 1993 (Germany).

[0052] The hydraulic diameter of the main runner **68** [d_{main}] (which is the runner closest to the machine nozzle) and the hydraulic diameter of each runner **66**, **64** of the subsequent (i.e., lower-numbered) runner branches [d_{branch}], is related by the formula $d_{main}=d_{branch}\times N^{1/3}$, where N is the number of runner branches needed between the machine nozzle **26** and a single mold cavity **32**.

[0053] As used herein, the term "nominal wall thickness" is defined as the theoretical thickness of a mold cavity if the mold cavity were made to have a uniform thickness. The nominal wall thickness may be approximated by the average wall thickness. The nominal wall thickness may be calculated by integrating length and width of the mold cavity that is filled by an individual gate. It is recognized that articles or parts molded in a mold cavity can vary in thickness across the length of the part. In some instances, the thickness of a part in its gate region(s) (i.e., in the portion(s) of the part positioned in the mold cavity at the location(s) where molten polymeric material was introduced from a feeder channel or runner system through gate(s) **30** and into the mold cavity **32**) is significantly thinner than the thickness of the overall part. As it is found that the hydraulic diameter of a runner can be minimized when designed based on relationships to the wall thickness of the part at the gates, as opposed to a nominal wall thickness of an overall part, this disclosure refers to a "gate thickness" of the article or part to be molded in a given mold cavity **32**. However, it is recognized that for parts having a substantially constant thickness throughout, including in the gate location, the formulas and relationships described herein could likewise refer to the nominal wall thickness of the mold cavity.

[0054] It is found that by operating a multi-cavity injection molding system at a substantially constant pressure, at peak pressures below 20,000 psi, runner size may be reduced relative to injection molding systems operating at variable pressure. Such an injection molding system may utilize coated or uncoated molds manufactured of a high thermal conductivity

material, such as aluminum, aluminum alloy, or beryllium copper. Alternatively, lower thermal conductivity coated or uncoated molds, such as steel or steel alloys, in multi-cavity injection molding can be operated at substantially constant pressure. Adjacent and surrounding mold plates may also be made of materials including aluminum, aluminum alloy, beryllium copper, steel, or steel alloy. All of these substantially constant pressure injection molding systems enable effective use of reduced-size runners as compared to conventional injection molding systems operating at variable pressure. Because the substantially constant pressure injection molding process requires significantly less force and energy to introduce molten polymeric material into a runner system, the hydraulic diameters of individual feed channels or runners throughout that runner system, including at least those in closest proximity to the mold cavities **32**, but in many cases, even the main runner **68** closest to the nozzle **26**, can be significantly smaller than the hydraulic diameters of runners that would be designed for a conventional injection molding system in accordance with the aforementioned industry-accepted runner design calculations.

[0055] For example, it is found that the hydraulic diameter of the main runner **68** [d_{main}] and the hydraulic diameter of each runner **36**, **34** of the subsequent runner branches [d_{branch}], in a substantially constant injection molding system of the present disclosure, may be related by the formula $d_{main}=d_{branch}\times N^{1/3.1}$, where N is the number of runner branches needed between the machine nozzle **26** and a single mold cavity **32**. Alternately, they may be related by the formula $d_{main}=d_{branch}\times N^{1/8}$.

[0056] Furthermore, the hydraulic diameter of the runners **64** of the first branch set of runners may be less than the gate thickness (i.e., less than the nominal wall thickness of a mold cavity for a part having substantially the same thickness throughout, including at the gate(s)), which is contrary to the conventional teachings of designing runners such that the hydraulic diameters thereof are about 1.5 to about 3 times the nominal wall thickness, or 1.5 mm larger than the nominal wall thickness, of a part molded in the mold cavity. Not only can the hydraulic diameter of the runners **64** of the first branch set of runners may be less than the gate thickness, but they can be less than 93% of the gate thickness.

Example 1

[0057] A test was performed to determine how runner sizes could be designed for use with a substantially constant pressure injection molding process as compared to a conventional variable pressure injection molding process. The test was performed using 20MFI Braskem Polypropelene Homopolymer FT200WV (with no colorant). The test was performed using an Engel 100TL 100-ton hydraulic tiebarless injection molding press. The test was performed with a mold temperature at a constant 65° F. The Melt Temperature was 420° F. For the conventional variable pressure process, a mold viscosity test was performed to establish the injection rate. A set point of 4.5 in/second was used for each run, or volumetrically, 2.65 in^3/sec (43.43 cm^3/sec).

[0058] For the substantially constant pressure process, or "SCPP", the pressure and time were controlled to achieve the given part weight of 2.51 grams without freezing the gate or runner that would lead to short shots.

[0059] A steel prototyping/experimental mold as depicted in FIG. **7** was used, with cold runner inserts of the following hydraulic diameters and respective runner L/T ratios: 0.030" (100), 0.040"(75), 0.045"(67), 0.062"(48), 0.078"(38), 0.093"(32), and 0.125"(24). The runner length was a constant 3" and the runner had a full round profile. For this test, the part L/T was 35 with nominal wall thickness 0.043 inch.

[0060] The focus of the test was to determine processing parameters and pressures required to produce a qualitatively acceptable injection molded part. A part was determined to be qualitatively acceptable by measuring its final part weight and inspecting it for the absence of flash or sink. If the injection molding process conditions failed to fully pack the part (i.e., there was a short shot), the part was deemed unacceptable. Data measurements were taken in the form of peak melt pressure measured at the injection nozzle, and peak post gate pressure, which were recorded, and the corresponding pressure loss across the part.

[0061] During the test, parts were held to within 0.5% of the processes being compared (i.e., substantially constant pressure processes versus variable pressure or conventional processes). On average, conventional pressures were approximately 29% higher than that of the substantially constant pressures, with the percent difference increasing slightly as runner diameter increased.

[0062] Peak pressures were recorded using a Dynisco Melt Transducer located in the nozzle. Post gate pressures were recorded using a Kistler 2.5 mm Kistler Pressure/Temperature sensor running through a 5073 programmable charge amp, also from Kistler.

TABLE 1

Experimental Results of:
Conventional Process Control[&&] and Substantially Constant Pressure Process Control[##]
versus
Cold Runner Diameter[%%]

Col A	Col B	Peak Melt Pressure (psi)		Peak Melt Pressure/Part L/T (psi per dimensionless part L/T ratio)		Molded Part Quality	
Actual Runner Diameter[a] (inches)	Calc Runner Cross-Sectional Area[b] ($inches^2$)	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control
0.03	0.000707	25067	20151	696.3	559.8	Fail	Pass
0.04	0.001257	19272	14411	535.3	400.3	Marginal	Pass
0.045	0.001590	17576	13243	488.2	367.9	Pass	Pass
0.062	0.003019	12401	8270	344.5	229.7	Pass	Pass
0.078	0.004778	9904	6644	275.1	184.6	Pass	Pass

TABLE 1-continued

Experimental Results of:
Conventional Process Control[&&] and Substantially Constant Pressure Process Control[##]
versus
Cold Runner Diameter[%%]

Col A	Col B	Peak Melt Pressure (psi)		Peak Melt Pressure/Part L/T (psi per dimensionless part L/T ratio)		Molded Part Quality	
Actual Runner Diameter[a] (inches)	Calc Runner Cross-Sectional Area[b] (inches^2)	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control	Conventional Process Control (~Constant Volumetric Rate)	Substantially Constant Pressure Control
0.093	0.006793	9114	5385	253.2	149.6	Pass	Pass
0.125	0.012271	7486	4332	207.9	120.3	Pass	Pass

Notes

[&&]An (approximate) constant volumetric setting was employed for the Conventional Process Control

[##]A transducer sensor in the melt in the vicinity of the nozzle provided data to a substantially constant pressure process controller for controlling to a substantially constant pressure.

[%%]Diameter of the sprue was held constant and is 0.23 inch.

[a]In this experiment runner cross-section was circular in shape therefore actual runner diameter = hydraulic runner diameter.

[b]In this experiment runner cross-section was circular in shape therefore actual runner cross-sectional area = hydraulic runner cross-sectional area. This column is calculated from Col A via formula for area of a circle.

Molded Part Quality Key:

Pass = parts at that condition met the full part weight target of 2.51 grams and there was no flashing or sink in the parts.

Fail = parts at that condition resulted in short shots and did not meet the full part weight target of 2.51 grams.

Marginal = parts at that condition met full the part weight target of 2.51 grams, but there was flashing and sink in the parts.

[0063] For each runner diameter, ten parts were each made for the Conventional Process Control and Substantially Constant Pressure Control conditions. The reported data is the average of the ten parts produced at each test condition.

[0064] Single cavity mold with cold runner system. Runner length constant at 3 inches.

[0065] A runner system for a multi-cavity mold for a substantially constant pressure injection molding system may therefore be designed with each runner **64** of the branch runner set closest to the mold cavities **32** having a hydraulic diameter of less than 1.5 times the gate thickness, and preferably in a range of 0.5-1.5 times the gate thickness, and for systems operating at relatively lower pressures, more preferably in a range of 0.5 to 0.9 times a gate thickness.

[0066] Based on the above-described comparative test for conventional injection molding systems as well as for injection molding systems intended for operation at substantially constant pressure, various relationships between hydraulic runner diameter for the runner **64** of the branch runner set closest to the mold cavities **32** and peak melt pressure, as well as between cross-sectional area of the runner **64** of the branch runner set closest to the mold cavities **32** and peak melt pressure, are definable.

[0067] Turning to FIG. **3**, a comparison of the relationship of hydraulic runner diameter to the quotient of peak melt pressure over L/T for a part is illustrated. The data from which the comparison plot was generated is provided in the following table:

Curve 74		Peak Melt Pressure/Part (L/T)		
	Runner			
Runner Dia	Diameter = 20 * Peak Melt Pressure/L/T^{-1}	SCPP (Curve 72)	Conventional	Actual Runner Dia
0.02	1000	559.8	696.3	0.03
0.022	909.0909091	400.3	535.3	0.04

-continued

Curve 74		Peak Melt Pressure/Part (L/T)		
	Runner			
Runner Dia	Diameter = 20 * Peak Melt Pressure/L/T^{-1}	SCPP (Curve 72)	Conventional	Actual Runner Dia
0.024	833.3333333	367.9	488.2	0.045
0.026	769.2307692	229.7	344.5	0.062
0.028	714.2857143	184.6	275.1	0.078
0.03	666.6666667	149.6	253.2	0.093
0.032	625	120.3	207.9	0.125
0.034	588.2352941			
0.036	555.5555556			
0.038	526.3157895			
0.04	500			
0.042	476.1904762			
0.044	454.5454545			
0.046	434.7826087			
0.048	416.6666667			
0.05	400			
0.052	384.6153846			
0.054	370.3703704			
0.056	357.1428571			
0.058	344.8275862			
0.06	333.3333333			
0.062	322.5806452			
0.064	312.5			
0.066	303.030303			
0.068	294.1176471			
0.07	285.7142857			
0.072	277.7777778			
0.074	270.2702703			
0.076	263.1578947			
0.078	256.4102564			
0.08	250			
0.082	243.902439			
0.084	238.0952381			
0.086	232.5581395			
0.088	227.2727273			
0.09	222.2222222			
0.092	217.3913043			
0.094	212.7659574			
0.096	208.3333333			
0.098	204.0816327			

-continued

Curve 74		Peak Melt Pressure/Part (L/T)		
Runner Dia	Runner Diameter = 20 * Peak Melt Pressure/L/T^{-1}	SCPP (Curve 72)	Conventional	Actual Runner Dia
0.1	200			
0.102	196.0784314			
0.104	192.3076923			
0.106	188.6792453			
0.108	185.1851852			
0.11	181.8181818			
0.112	178.5714286			
0.114	175.4385965			
0.116	172.4137931			
0.118	169.4915254			
0.12	166.6666667			
0.122	163.9344262			
0.124	161.2903226			
0.126	158.7301587			
0.128	156.25			
0.13	153.8461538			

[0068] The curve **70**, depicted as the "Conventional" curve farthest to the upper right, represents the relationship of hydraulic runner diameter to [peak melt pressure/(part LIT)] for a conventional injection molding system or process. The curve **72**, depicted as the "SCPP" curve farthest to the lower left, represents the relationship of hydraulic runner diameter to [peak melt pressure/(part L/T)] for a substantially constant injection molding system or process of the present disclosure. The curve **74** intermediate curves **70** and **72** represents an average of the data points between the data used to generate the Conventional and SCPP curves **70** and **72**. A regression curve was fit to the average data to derive a power equation used to generate the data at all the runner diameters in the range of 0.020" to 0.130". As this data supports, a runner system for a multi-cavity mold for a substantially constant pressure injection molding system may be designed and manufactured such that the hydraulic runner diameter (D_H) of the runner closest to a molding cavity is less than or equal to 20 times a peak melt pressure at which polymer is injected by the injection molding system, divided by $(L/T)^{-1}$, where L/T is a length-to-thickness ratio of a part to be molded in at least one cavity of the multi-cavity molding system, or formulaically:

$$D_H \leq 20 * \text{Peak Melt Pressure}/(L/T)^{-1}$$

[0069] The hydraulic diameter of the runner closest to a molding cavity must be sufficiently large so as to permit the flow of molten polymeric material therethrough and into the respective mold cavity. Therefore, there is a practical minimum hydraulic diameter for the runner. This practical minimum is on the order of 0.5 times the gate thickness for the part to be molded. Preferably, the hydraulic runner diameter of the runner closest to a molding cavity is less than or equal to 8.25 times the peak melt pressure, divided by $(L/T)^{-0.889}$ runner diameter, or formulaically:

$$D_H \leq 8.25 * \text{Peak Melt Pressure}/(L/T)^{-0.889}$$

[0070] Turning now to FIG. **4**, a comparison of the relationship of hydraulic runner cross-sectional area to the quotient of peak melt pressure over L/T for a part is illustrated. The data from which the comparison plot was generated is provided in the following table:

Curve 84				
Cross Sectional Area = 315 * Peak Melt Pressure/Part (L/T)	Runner Cross Sectional Area	Curve 82 SCPP	Conventional	Actual Cross Sectional Area
1000.00	0.000314159	559.76	696.30	0.000706858
909.09	0.000380133	400.31	535.32	0.001256637
833.33	0.000452389	367.86	488.22	0.001590431
769.23	0.000530929	229.72	344.47	0.003019071
714.29	0.000615752	184.56	275.11	0.004778362
666.67	0.000706858	149.58	253.17	0.006792909
625.00	0.000804248	120.33	207.94	0.012271846
588.24	0.00090792			
555.56	0.001017876			
526.32	0.001134115			
500.00	0.001256637			
476.19	0.001385442			
454.55	0.001520531			
434.78	0.001661903			
416.67	0.001809557			
400.00	0.001963495			
384.62	0.002123717			
370.37	0.002290221			
357.14	0.002463009			
344.83	0.002642079			
333.33	0.002827433			
322.58	0.003019071			
312.50	0.003216991			
303.03	0.003421194			
294.12	0.003631681			
285.71	0.003848451			
277.78	0.004071504			
270.27	0.00430084			
263.16	0.00453646			
256.41	0.004778362			
250.00	0.005026548			
243.90	0.005281017			
238.10	0.005541769			
232.56	0.005808805			
227.27	0.006082123			
222.22	0.006361725			
217.39	0.00664761			
212.77	0.006939778			
208.33	0.007238229			
204.08	0.007542964			
200.00	0.007853982			
196.08	0.008171282			
192.31	0.008494867			
188.68	0.008824734			
185.19	0.009160884			
181.82	0.009503318			
178.57	0.009852035			
175.44	0.010207035			
172.41	0.010568318			
169.49	0.010935884			
166.67	0.011309734			
163.93	0.011689866			
161.29	0.012076282			
158.73	0.012468981			
156.25	0.012867964			
153.85	0.013273229			

[0071] The curve **80**, depicted as the "Conventional" curve farthest to the upper right, represents the relationship of hydraulic runner cross-sectional area to [peak melt pressure/(part LIT)] for a conventional injection molding system or process. The curve **82**, depicted as the "SCPP" curve farthest to the lower left, represents the relationship of hydraulic runner cross-sectional area to [peak melt pressure/(part L/T)] for a substantially constant injection molding system or process of the present disclosure. The curve **84** intermediate curves **80** and **82** represents an average of the data points between the data used to generate the Conventional and SCPP

curves **80** and **82**. As this data supports, a runner system for a multi-cavity mold for a substantially constant pressure injection molding system may be designed and manufactured such that the hydraulic runner cross-sectional area of the runner closest to a molding cavity is less than or equal to 315 times a peak melt pressure at which polymer is injected by the injection molding system, divided by $(L/T)^{-2}$, where L/T is a length-to-thickness ratio of a part to be molded in at least one cavity **32** of the multi-cavity molding system, or formulaically:

$$\text{Hydraulic Cross-Sectional Runner Area} \leq 315 * \text{Peak Melt Pressure}/(L/T)^{-2}$$

[0072] Preferably, the hydraulic runner cross-sectional area of the runner closest to a molding cavity is less than or equal to 53.51 times the peak melt pressure, divided by $(L/T)^{-1.778}$, or formulaically:

$$\text{Hydraulic Cross-Sectional Runner Area} \leq 53.51 * \text{Peak Melt Pressure}/(L/T)^{-1.778}$$

[0073] Turning now to FIG. **5**, a comparison of the relationship of hydraulic cross-sectional runner area to peak melt pressure is illustrated. The data from which the comparison plot was generated is provided in the following table:

Runner Cross Sectional Area vs Peak Melt Pressure

Actual Cross Sectional Area Tested (in^2)	SCPP Curve 92	Conventional Pressure	Curve 94 Cross Sectional Area = 360,000 * Peak Melt Pressure^{-2}	Runner Cross Sectional Area
0.000706858	20151.4	25066.7	33851.37501	0.000314159
0.001256637	14410.9	19590.5	30773.97728	0.000380133
0.001590431	13242.6	17575.9	28209.47918	0.000452389
0.003019071	8269.8	12401	26039.51924	0.000530929
0.004778362	6644.9	9904.2	24179.55358	0.000615752
0.006792909	5385.2	9114.4	22567.58334	0.000706858
0.012271846	4331.8	7486.3	21157.10938	0.000804248
			19912.57354	0.00090792
			18806.31945	0.001017876
			17816.51316	0.001134115
			16925.68751	0.001256637
			16119.70239	0.001385442
			15386.98864	0.001520531
			14717.98914	0.001661903
			14104.73959	0.001809557
			13540.55001	0.001963495
			13019.75962	0.002123717
			12537.5463	0.002290221
			12089.77679	0.002463009
			11672.88794	0.002642079
			11283.79167	0.002827433
			10919.79839	0.003019071
			10578.55469	0.003216991
			10257.99243	0.003421194
			9956.286768	0.003631681
			9671.821432	0.003848451
			9403.159726	0.004071504
			9149.020274	0.00430084
			8908.256582	0.00453646
			8679.839747	0.004778362
			8462.843753	0.005026548
			8256.43293	0.005281017
			8059.851194	0.005541769
			7872.412794	0.005808805
			7693.494321	0.006082123
			7522.527781	0.006361725
			7358.994568	0.00664761
			7202.420216	0.006939778
			7052.369794	0.007238229
			6908.44388	0.007542964
			6770.275003	0.007853982
			6637.524512	0.008171282
			6509.87981	0.008494867
			6387.051889	0.008824734
			6268.773151	0.009160884
			6154.795457	0.009503318
			6044.888395	0.009852035
			5938.837722	0.010207035
			5836.443968	0.010568318
			5737.521189	0.010935884
			5641.895835	0.011309734
			5549.40574	0.011689866
			5459.899196	0.012076282
			5373.234129	0.012468981

-continued

Runner Cross Sectional Area vs Peak Melt Pressure				
Actual Cross Sectional Area Tested (in^2)	SCPP Curve 92	Conventional Pressure	Curve 94 Cross Sectional Area = 360,000 * Peak Melt Pressure^{-2}	Runner Cross Sectional Area
			5289.277346	0.012867964
			5207.903848	0.013273229

[0074] The curve **90**, depicted as the curve farthest to the upper right, represents the relationship of hydraulic runner cross-sectional area to peak melt pressure for a conventional injection molding system or process. The curve **92**, depicted as the curve farthest to the lower left, represents the relationship of hydraulic runner cross-sectional area to peak melt pressure for a substantially constant injection molding system or process of the present disclosure. The curve **94** intermediate curves **90** and **92** represents an average of the data points between the data used to generate the Conventional and SCPP curves **90** and **92**. As this data supports, a runner system for a multi-cavity mold for a substantially constant pressure injection molding system may be designed and manufactured such that the hydraulic runner cross-sectional area of the runner closest to a molding cavity is less than or equal to the quotient of 360,000 divided by the square of the peak melt pressure, or formulaically:

$$\text{Hydraulic Cross-Sectional Runner Area} \leq 360{,}000 / (\text{Peak Melt Pressure})$$

[0075] Preferably, the hydraulic runner cross-sectional area of the runner closest to a molding cavity is less than or equal to 31,313 times (peak melt pressure)$^{-1.778}$, or formulaically:

$$\text{Hydraulic Cross-Sectional Runner Area} \leq 31{,}313 * (\text{Peak Melt Pressure})^{-1.778}$$

[0076] Turning to FIG. **6**, a comparison of the relationship of hydraulic runner diameter to peak melt pressure is illustrated. The data from which the comparison plot was generated is provided in the following table:

Runner Diameter vs. Peak Melt Pressure				
SCPP Curve 102			Curve 104	
Runner Diameter (in)	Peak Melt Pressure (psi)	Conventional Peak Melt Pressure (psi)	Runner Diameter (in)	Melt Pressure = 700 * (Runner Dia)$^{-1}$
0.017	35000	—	0.02	35000
0.03	20151.4	25066.7	0.022	31818.18182
0.04	14411	19271.6	0.024	29166.66667
0.045	13243	17576	0.026	26923.07692
0.062	8270	12401	0.028	25000
0.078	6644	9904	0.03	23333.33333
0.093	5385	9114	0.032	21875
0.125	4332	7486	0.034	20588.23529
			0.036	19444.44444
			0.038	18421.05263
			0.04	17500
			0.042	16666.66667
			0.044	15909.09091
			0.046	15217.3913
			0.048	14583.33333
			0.05	14000
			0.052	13461.53846

-continued

Runner Diameter vs. Peak Melt Pressure				
SCPP Curve 102			Curve 104	
Runner Diameter (in)	Peak Melt Pressure (psi)	Conventional Peak Melt Pressure (psi)	Runner Diameter (in)	Melt Pressure = 700 * (Runner Dia)$^{-1}$
			0.054	12962.96296
			0.056	12500
			0.058	12068.96552
			0.06	11666.66667
			0.062	11290.32258
			0.064	10937.5
			0.066	10606.06061
			0.068	10294.11765
			0.07	10000
			0.072	9722.222222
			0.074	9459.459459
			0.076	9210.526316
			0.078	8974.358974
			0.08	8750
			0.082	8536.585366
			0.084	8333.333333
			0.086	8139.534884
			0.088	7954.545455
			0.09	7777.777778
			0.092	7608.695652
			0.094	7446.808511
			0.096	7291.666667
			0.098	7142.857143
			0.1	7000
			0.102	6862.745098
			0.104	6730.769231
			0.106	6603.773585
			0.108	6481.481481
			0.11	6363.636364
			0.112	6250
			0.114	6140.350877
			0.116	6034.482759
			0.118	5932.20339
			0.12	5833.333333
			0.122	5737.704918
			0.124	5645.16129
			0.126	5555.555556
			0.128	5468.75
			0.13	5384.615385

[0077] The curve **100**, depicted as the "Conventional" curve farthest to the upper right, represents the relationship of hydraulic runner diameter to peak melt pressure for a conventional injection molding system or process. The curve **102**, depicted as the "SCPP" curve farthest to the lower left, represents the relationship of hydraulic runner diameter to peak melt pressure for a substantially constant injection molding system or process of the present disclosure. The curve **104** intermediate curves **100** and **102** represents an average of the data points between the data used to generate the Conventional and SCPP curves **100** and **102**. As this data supports, a runner system for a multi-cavity mold for a substantially

constant pressure injection molding system may be designed and manufactured such that the hydraulic runner diameter of the runner closest to a molding cavity is less than or equal to 700 divided by the peak melt pressure, or formulaically:

$$D_H \leq 700 * \text{Peak Melt Pressure}^{-1}$$

[0078] Preferably, the hydraulic runner diameter of the runner closest to a molding cavity is less than or equal to 199.63 times the peak melt pressure)$^{-0.889}$, or formulaically:

$$D_H \leq 199.63 * \text{Peak Melt Pressure}^{-0.889}$$

[0079] In a multi-branch, multi-cavity injection molding system of the present disclosure, it is also found that for a hot runner manifold, even when operating at substantially constant pressure, there is some pressure drop from the inlet of the feed system to the outlet of the feed system. As mentioned above, by running at substantially constant pressures (as opposed to variable peak pressures), it is found that the runner size may be reduced, resulting in significant benefits. A particular benefit of reduced runner size in a hot runner system is that a frequent concern when operating a hot runner system is the fact that because molten polymeric material is compressible, there is some lag or hysteresis after stopping actuation of the reciprocating screw **22** (or plunger) of the injection molding system, after which the momentum of the still-molten polymeric material, and release of potential energy due to compression, cause that material to continue to flow toward the mold cavities. The larger the volume of the runners, the more pronounced this continued flow following screw or plunger stoppage phenomenon. Conversely, by reducing the size of the runners in a hot runner system, the effects of continued molten polymeric material flow following stoppage of the reciprocating screw **22** or plunger are abated.

[0080] When designing a hot runner system according to the formula $D_m=D_b*N^{1/3}$, where N equals the number of branches extending from a node. Using this formula, the sum of the cross sectional area of the final runner branches [A_b] is substantially higher than the cross sectional area at the feed system inlet or the main sprue [A_m]. The relationship of D_m to D_b can further be expressed by the formula $D_m=D_b*$[the total number of final runners]$^{1/3}$. This relationship holds true regardless of the number of final runner branches, so long as the runner sizes are determined using the formula $D_m=D_b*N^{1/3}$ as discussed above. Based on this relationship, it can further be determined that the ratio of A_b to A_m will always follow the proportions shown in the table below, where D_b is shown for a 6 millimeter system and for a 3 millimeter system to illustrate that the relationship always holds. Therefore, a system having a hot runner in closest proximity to a mold cavity with a minimum hydraulic diameter at least sufficiently large so as to permit the flow of molten polymeric material therethrough and into the mold cavity, and less than 6 millimeters, is achievable with the substantially constant pressure injection molding process of the present disclosure. A_m and A_b are hydraulic cross sectional areas. Two tables are shown below. Table 2 involves the conventional minimum final hot runner hydraulic diameter of 6 mm for thermoplastic materials. Table 3 provides one example of a smaller final runner hydraulic diameter made possible constant pressure processing using thermoplastic materials.

TABLE 2

# of Final Runners	D_{main}*	A_m	A_b	Ab/Am Ratio
4	9.52	71.211	113.040	1.587
8	12.00	113.040	226.080	2.000
16	15.12	179.440	452.160	2.520
32	19.05	284.843	904.320	3.175
64	24.00	452.160	1808.640	4.000
128	30.24	717.759	3617.280	5.040
256	38.10	1139.372	7234.560	6.350

*Assumes a 6 millimeter final runner diameter.

TABLE 3

# of Final Runners	D_{main}**	A_m	A_b	Ab/Am Ratio
4	4.76	17.803	28.260	1.587
8	6.00	28.260	56.520	2.000
16	7.56	44.860	113.040	2.520
32	9.52	71.211	226.080	3.175
64	12.00	113.040	452.160	4.000
128	15.12	179.440	904.320	5.040
256	19.05	284.843	1808.640	6.350

**Assumes a 3 millimeter final runner diameter.

[0081] The use of constant pressure processing enables this ratio to be reduced, which in turn reduces the pressure loss that will occur in the feed system. This is possible, since a mold cavity can be filled at a substantially lower flow rate, and thus polymer can be forced through the feed system at much lower pressures according to Bernoulli's Principle. This ratio can be reduced, such that the ratio of A_b to A_m is lower than the standard ratio applied in the table above. For example, if a 3 millimeter final runner diameter is used, while maintaining the main runner diameter the same as for a standard 6 millimeter final runner system, then the resulting A_b to A_m ratio is shown in the table below.

TABLE 4

# of Final Runners	A_b/A_m Ratio***
4	0.397
8	0.500
16	0.630
32	0.794
64	1.000
128	1.260
256	1.587

***Where A_b is for a 3 millimeter final runner diameter, and A_m is calcucated for a main runner diameter for a system having a 6 mm final runner using the formula $D_m = D_b * N^{1/3}$.

[0082] This demonstrates that a runner system can be designed such that there is considerably less pressure loss across the runner network when a substantially constant pressure process is used. Based on the experimental data shared in Table 1, above, the ratio of A_b/A_m in Table 4 can be reduced to 1:1, or even less. Thus, a runner system for a substantially constant pressure process can be designed such that reduced pressure loss contribution occurs across the runner network as a result of an increase in cross-sectional flow area. It is understood that some losses may occur related to the frictional losses in the system, and also that shear thinning behaviors of the flowing liquid will also affect the pressure required to flow through the system. However, the relationship associated

with the cross sectional hydraulic flow diameters shown above will continue to be true regardless of these other factors.

[0083] For a multi-branch, multi-cavity substantially constant pressure injection molding system having a system of hot runners arranged as a system of feeder channels or runners **60** such as illustrated schematically in FIG. **2**, it is found that the hot runner system may be designed and manufactured such that the cross-sectional area of the main runner **68** is equal to the cross-sectional area of each of the runners **64** in the first runner branch set of runners in closest proximity to a plurality of mold cavities **32**, times a constant K, or formulaically:

$$A_{main}=A_{final\ branch}*K$$

Where $A_{main}=\pi(D_{H\ main}/2)^2$ and

$$A_{final\ branch}=\pi(D_{H\ final\ branch}/2)^2$$

the formula becomes $\pi(D_{H\ main}/2)^2=\pi(D_{H\ final\ branch}/2)^2*K$,

which simplifies to: $D_{H\ main}{}^2=D_{H\ final\ branch}{}^2*K$

[0084] As discussed in U.S. patent application Ser. No. 13/476,073, entitled "Non-Naturally Balanced Feed System for an Injection Molding Apparatus", the entire disclosure of which is incorporated herein by reference, it is possible to provide flow channels or runner systems in an asymmetric pattern between nozzle **26** and gates **30**. Another benefit of the reduced-runner sizes contemplated by the present disclosure is the ability to optimize the distribution of multiple mold cavities in a single mold by combining the benefits of a non-naturally balanced feed system with feed channels of reduced hydraulic diameter or cross-section as compared to conventional injection molding systems.

[0085] It is noted that the terms "substantially," "about," and "approximately," unless otherwise specified, may be utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. These terms are also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue. Unless otherwise defined herein, the terms "substantially," "about," and "approximately" mean the quantitative comparison, value, measurement, or other representation may fall within 20% of the stated reference.

[0086] It should now be apparent that the various embodiments of the products illustrated and described herein may be produced by a substantially constant pressure molding process. While particular reference has been made herein to products for containing consumer goods or consumer goods products themselves, it should be apparent that the molding method discussed herein may be suitable for use in conjunction with products for use in the consumer goods industry, the food service industry, the transportation industry, the medical industry, the toy industry, and the like. Moreover, one skilled in the art will recognize the teachings disclosed herein may be used in the construction of stack molds, multiple material molds including rotational and core back molds, in combination with in-mold decoration, insert molding, in mold assembly, and the like.

[0087] While particular embodiments have been illustrated and described herein, it should be understood that various other changes and modifications may be made without departing from the spirit and scope of the claimed subject matter. Moreover, although various aspects of the claimed subject matter have been described herein, such aspects need not be utilized in combination. It is therefore intended that the appended claims cover all such changes and modifications that are within the scope of the claimed subject matter.

[0088] The dimensions and values disclosed herein are not to be understood as being strictly limited to the exact numerical values recited. Instead, unless otherwise specified, each such dimension is intended to mean both the recited value and a functionally equivalent range surrounding that value. For example, a dimension disclosed as "40 mm" is intended to mean "about 40 mm."

[0089] Every document cited herein, including any cross referenced or related patent or application, is hereby incorporated herein by reference in its entirety unless expressly excluded or otherwise limited. The citation of any document is not an admission that it is prior art with respect to any invention disclosed or claimed herein or that it alone, or in any combination with any other reference or references, teaches, suggests or discloses any such invention. Further, to the extent that any meaning or definition of a term in this document conflicts with any meaning or definition of the same term in a document incorporated by reference, the meaning or definition assigned to that term in this document shall govern.

[0090] While particular embodiments of the present invention have been illustrated and described, it would be obvious to those skilled in the art that various other changes and modifications can be made without departing from the spirit and scope of the invention. It is therefore intended to cover in the appended claims all such changes and modifications that are within the scope of this invention.

What is claimed is:

1. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, each runner of the set in closest proximity to a mold cavity having a hydraulic diameter of 0.5-1.5 times a gate thickness for a part to be molded in at least one cavity of the multi-cavity molding system.

2. The runner system of claim **1**, wherein each runner of the set in closest proximity to a mold cavity has a hydraulic diameter of 0.5-0.9 times a gate thickness of a part to be molded in at least one cavity of the multi-cavity molding system.

3. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, each runner of the set in closest proximity to a mold cavity having a hydraulic diameter less than or equal to 20 times a peak melt pressure at which polymer is injected by the injection molding system, divided by $(L/T)^{-1}$, where L/T is a length-to-thickness ratio of a part to be molded in at least one cavity of the multi-cavity molding system.

4. The runner system of claim **3**, wherein the hydraulic diameter of each runner of the set in closest proximity to a mold cavity is at least sufficiently large so as to permit the flow of molten polymeric material therethrough and into the respective mold cavity.

5. The runner system of claim **4**, wherein the hydraulic diameter of each runner of the set in closest proximity to a mold cavity is at least 0.5 times a gate thickness of a part to be molded in at least one cavity of the multi-cavity molding system.

6. The runner system of claim **3**, wherein the hydraulic diameter is less than or equal to 8.25 times the peak melt pressure divided by $(L/T)^{-0.889}$.

7. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, each runner of the set in closest proximity to a mold cavity having a cross-sectional area less than or equal to a quotient of 700 divided by a peak melt pressure at which polymer is injected by the injection molding system.

8. The runner system of claim **7**, wherein each runner of the set in closest proximity to a mold cavity having a cross-sectional area less than or equal to a product of 199.63 times $(\text{peak melt pressure})^{-0.889}$.

9. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, each runner of the set in closest proximity to a mold cavity having a cross-sectional area less than or equal to 315 times a peak melt pressure at which polymer is injected by the injection molding system, divided by $(L/T)^{-2}$, where L/T is a length-to-thickness ratio of a part to be molded in at least one cavity of the multi-cavity molding system.

10. The runner system of claim **9**, wherein each runner of the set in closest proximity to a mold cavity has a cross-sectional area less than or equal to 53.51 times the peak melt pressure divided by $(L/T)^{-1.778}$.

11. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, each runner of the set in closest proximity to a mold cavity having a cross-sectional area given by the formula: hydraulic cross-sectional runner area$\leq$360,000/$(\text{peak melt pressure})^2$, where "peak melt pressure" is the peak melt pressure at which polymer is injected by the injection molding system.

12. The runner system of claim **11**, wherein each runner of the set in closest proximity to a mold cavity has a hydraulic cross-sectional runner area given by the formula: hydraulic cross-sectional runner area$\leq$31,313*$(\text{peak melt pressure})^{-1.778}$.

13. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, including

a first branch set of runners, each of the runners of the first branch set of runners being in closest proximity to a respective one of the mold cavities;

a second branch set of runners, each of the runners of the second branch set of runners being in fluid communication with at least two of the runners of the first branch set of runners; and

a main runner in fluid communication with each runner of the second branch set of runners, wherein the main runner has a hydraulic diameter equal to at least the product of the hydraulic diameter of each of the runners of the first branch set of runners times the product of the number of branch sets of runners including the main runner raised to a power of ⅛.

14. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, including

a first branch set of runners, each of the runners of the first branch set of runners being in closest proximity to a respective one of the mold cavities;

one or more additional branch sets of runners, each of the runners of the next-successive branch set of runners being in fluid communication with at least two of the runners of the next-lowest branch set of runners, each of said one or more additional branch sets of runners being identifiable as an integer value indicative of its level that is one higher than the branch set of runners in next-closer proximity to the mold cavities; and

a main runner having a branch value of one higher than the highest value of the one or more additional branch sets of runners, the main runner being in fluid communication with each runner of that highest value of the one or more additional branch sets of runners, wherein the main runner has a hydraulic diameter equal to at least the product of the minimum diameter of each of the runners of the first branch set of runners times the branch value of the main runner raised to a power of ⅛.

15. A runner system for a multi-cavity injection molding system, the runner system comprising a set of runners, including

a first branch set of runners, each of the runners of the first branch set of runners being in closest proximity to a respective one of the mold cavities;

one or more additional branch sets of runners, each of the runners of the next-successive branch set of runners being in fluid communication with at least two of the runners of the next-lowest branch set of runners, each of said one or more additional branch sets of runners being identifiable as an integer value indicative of its level that is one higher than the branch set of runners in next-closer proximity to the mold cavities; and

a main runner having a branch value of one higher than the highest value of the one or more additional branch sets of runners, the main runner being in fluid communication with each runner of that highest value of the one or more additional branch sets of runners, wherein the main runner has a hydraulic diameter equal to a hydraulic diameter of one of the runners of the first branch set of runners times a constant (K).

16. A multi-cavity injection molding system having a plurality of hot runners therein, wherein a hydraulic diameter of at least one of the runners in closest proximity to one of the mold cavities is at least sufficiently large so as to permit the flow of molten polymeric material therethrough and into the respective mold cavity and is less than 6 mm.

* * * * *