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(54) INJECTION MOULDING MACHINE WITH MULTI-CHANNEL WAVE SCREW

(71) We, HPM CORPORATION, a Corporation organised and existing under the laws of the State of Ohio, United States of America, of 820 Marion Road, Mt. Gilead, Ohio 43338, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an injection molding machine.

The injection molding of synthetic resinous materials has long been known and a wide variety of devices have been used for plasticating material prior to its injection into a mold. Screws are particularly well suited for this purpose.

In order to obtain acceptable injection molded products, the plasticated synthetic material must have homogeneous properties. More particularly, the temperature distribution throughout the material must be highly uniform in order to avoid generating thermal stresses in the molded product. In addition, the plasticated material must be well mixed in those instances where additives such as colorants or reinforcing materials are mixed with the plasticated material prior to injection. Lack of adequate mixing where additives are used can effect not only the surface appearance of a molded article but also the structural integrity of the product.

Another difficulty to be avoided is the presence in completely plasticated particles of the particulate feed material in the accumulating reservoir of plasticated material in this machine. Such particles are detrimental and can obstruct internal passages of a mold causing unacceptable products to be molded.

Another complicating factor in the design of injection molding machine is the fact that the barrel and the rotatable reciprocable screw are cantilever-mounted. Accordingly, the processing portions of the screw cannot be increased in length to improve mixing and temperature distribution without regard to the effect that such a length increase would have on the overall design of the machine. Moreover, since the screw ordinarily reciprocates through a distance of approximately four times the screw diameter, a comparatively long length is required for the feed section of the screw in which the particulate material is initially received and compacted. The length of the feed section thus imposes a demand for high efficiency in downstream processing sections.

To improve plasticated material uniformity some injection molding machines include a screw provided with a mixing section in which the plasticated material is forced to mix with itself. The addition of a mixing section to an injection molding machine screw necessarily increases the length of that screw, the length of the surrounding barrel, the cost of the machine, and requires adjustment of the length and position of other processing section of the machine screw.

Accordingly, it will be seen that the need continues to exist for an injection molding machine having more efficient processing sections to produce a homogeneous reservoir of plasticated synthetic resinous material for injection molding purposes.

According to the present invention there is provided an injection molding machine operable during a plasticizing portion of a molding cycle to accept synthetic resinous material in particulate form and to plasticize the material to a moldable consistency and operable during an injection portion of the molding cycle to shape the plasticized material into a useful form, the machine comprising a barrel provided with a feed opening and a discharge opening, and a rotatable and reciprocable screw in the barrel, the screw including a screw section having a helical conveying flight defining a helical passage, a helical barrier flight dividing the helical passage into at least two helical flow channels, each flow channel having a base surface defining the depth of the flow channel, the base surface of each flow channel undulating in a radial direction so as to define cyclically occurring wave crests separated by cyclically occuring wave valleys along the helical direction, the barrier flight being radially shorter and axially narrower than the conveying section.

Also according to the present invention there is provided an injection molding machine comprising a rotatable reciprocable screw disposed within and cooperating with the inner wall of a barrel provided with an inlet and an outlet opening and wherein in operation particles of synthetic resinous material are introduced through the inlet opening and into a helical passage defined by conveying flight means of the screw, plasticated by rotation of the screw and advanced toward the outlet opening, the screw including a section for assuring complete melting and mixing of the resinous material, which screw section includes radially outwardly extending barrier flight means disposed intermediate the conveying flight means to divide the passage into flow channels extending side by side helically along the screw section, each of the flow channels having a depth which varies cyclically through a plurality of cycles along the helical length of such channel, the minimum depth portions of the flow channels on opposite sides of the barrier flight means defining wave crests which are displaced helically from each other, and the barrier flight means adjacent each wave crest being radially shorter than the conveying flight means to provide sufficient clearance between its radially outermost surface and the inner barrel wall to permit the flow thereover of molten resinous material from the flow channel containing a part, whose depth decreases along the flow channel to an adjacent part of the other flow channel, the outer width of the barrier flight means being shorter than that of the conveying flight means so that the shear energy imparted to molten material flowing over the barrier flight means is low.

Further according to the present invention there is provided a method of preparing a quantity of synthetic resinous material for injection into a mold without over-heating, comprising processing resinous material in a first zone to melt most of the material and advance it to a second zone, dividing the flow through the second zone into two parallel channels each of which has restricted cross-sectional areas at a plurality of locations along its length with the restricted areas in one channel being longitudinally offset from the restricted areas in the other channel and with the cross-sectional area of each channel varying cyclically over a plurality of substantially identical cycles, forcing incompletely melted resinous material in each of the channels to pass through the restricted areas in that channel to receive extra energy input for melting the same, and filtering a portion of the completely molten resinous material from one channel to the other in advance of each of the restricted areas to avoid the extra shear energy input associated with passage through the restricted areas and thereby to avoid over-heating of the melted material, the cycles reinforcing one another and collectively providing a steady material flow rate and pressure at the output end of the second zone, wherein the filtering step includes facilitating the flow of molten resinous material from one channel to the other while simultaneously restricting the flow of unmelted resinous material to promote the separation of molten from unmelted material so as to concentrate the passage of unmelted material through the restricted areas and thereby maximum heating of the unmelted material and minimize heating of the molten material.

In a conventional molding machine screw, a radially extending helical conveying flight defines a helical passage. In a multichannel wave screw i.e. a screw having at least two channels, this helical passage is divided by a radially extending helical barrier into flow channels. Each flow channel includes a base surface which undulates radially through a plurality of wave cycles along the length of the flow channel.

In this connection, the undulations of the base surface, *i.e.*, the wave cycles occur with the crest-to-crest wave length being uniform. To enhance the mixing of plasticated material with itself, crests of the wave cycles in one flow channel are displaced relative to the crests of wave cycles in the adjacent flow channel. In this fashion, plasticated material may pass over the helical barrier from one flow channel to the adjacent flow channel. By selecting the clearance between the barrel and the edge surface of the barrier so that unplasticated particles will continue to move along the flow channel into a wave crest area, unplasticated particles of material will be subjected to intensive shearing forces while passing over each crest in each flow channel. Accordingly, these unplasticated particles will be preferentially melted and plasticated.

So that the already plasticated material is not excessively heated as it passes through the clearance between the helical barrier and the surrounding barrel, the axial width of the helical barrier is selected to be substantially less than the axial width of the helical conveying flight.

By providing the undulations in the flow channels with a wave length which is less than the helical pitch length of the flow channel (*i.e.*, the distance extending helically along the screw for one 360° revolution around the screw axis), the plasticated synthetic resinous material will be subjected to intenisve shearing at the wave crests more frequently than the frequency of screw rotation. In this fashion, the axial length of the screw section may be reduced so as to effect an overall reduction in screw length without sacrificing homogeneity of the plasticated product.

To further intensify the degree of mixing effected by the undulating flow channels, the total flow area of two adjacent flow channels may vary cyclically along the helical passage. This variation makes the flow patterns even more complex and, may improve the homogeneity of the plasticated material.

Another variation which may be incorporated in the screw section is to provide the wave crests with increasing radial height in a downstream direction along each flow channel of the screw section. In this manner, the flow channels accomodate a higher proportion of unplasticated particles at the upstream end of the channel, and any pressure pulses associated therewith are relieved by the barrier land- clearance. Moreover, the unplasticated particles tend to decrease in size as they move downstream through the flow channel and the more severe shearing action exerted by the successive wave crests causes more rapid plastication of the material.

An embodiment of the present invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a view in partial cross section of an injection molding machine;

Figure 2 is an enlarged partial cross-sectional view of a section of the molding machine screw;

Figure 3 is a detailed view in cross-section showing characteristics of the flow channels;

Figure 4 is a cross-sectional view taken along the line 4—4 of Figure 2; and

Figures 5a and 5b are schematic illustrations of two different flow channels with radial variations exaggerated.

Before considering in detail the characteristics of the improved injection molding screw, it will be helpful to consider the features of a typical injection molding machine.

Turning now to Figure 1, an injection molding machine 10 is depicted which includes a barrel 12 having a longitudinally extending screw receiving bore 14. At one end of the barrel 12 is a discharge opening 16 which communicates with the bore 14 and with a mold 18. The mold 18 includes a first mold portion 20 and a second mold portion 22 which are relatively movable and which cooperate to define a mold cavity 24. The mold cavity 24 communicates with the discharge opening 16 through a sprue 26.

At the other end of the barrel 12, remote from the discharge opening 16, is a feed opening 28. The feed opening 28 communicates with the screw receiving bore 14 and may be disposed in a generally vertical posture, as illustrated. Positioned externally of the bore 28 and mounted on the barrel 12 is a suitable hopper 30 through which particulate feed material is supplied to the screw receiving bore 14 for plasticization.

Positioned between the discharge opening 16 and the feed opening 28 is a vent opening 32 that also communicates with the bore 14. The vent opening 32 allows gaseous volatiles including water vapor to escape from the screw receiving bore 14. The vent opening 32, the feed opening 28 and the discharge opening 16 may have any suitable cross sectional shape including circular.

Disposed within the screw receiving bore 14 is a screw 34. The screw 34 includes a first stage 36 which extends from the feed opening 28 to a decreasing root diameter portion 40 at a position adjacent the vent opening 32 and a second stage 38 which extends from the downstream end of the first stage 36 to the end of the screw 34 adjacent the discharge opening 16.

The first stage 36 has a helical screw flight 36*a* extending along the length thereof which cooperates with the bore 14 to define a helical passage having a depth determined by the difference between the bore diameter and the corresponding screw root diameter. In registry with the feed opening 28, the first stage has a feed portion 36*b* that is operable to receive particulate feed material.

Downstream of the feed portion 36*b* is a transition portion 36*c* in which the depth of the helical passage decreases from a relatively large value in the feed portion 36*b* to a relatively small value in a first pumping portion 36*d*. The first pumping portion 36*d* is at the downstream end of the first stage 36 and has a first flow capacity defined by well known parameters (see, for example, Bernhardt, *Processing of Thermoplastic Materials* Van Nostrand Reinhold Co. 1959).

The second stage 38 also includes a helical screw flight 38*a* extending along the length thereof. The first and second flights 36*a*, 38*a* may be continuous. Accordingly, the screw 34 may be considered to have a helical conveying screw flight 36*a*, 38*a* extending substantially along its entire length within the bore 14.

At the upstream end of the second stage 38 is the short, decreasing root diameter portion 40 and a vent portion 38*b* which is in registry with the vent opening 32. The vent portion 38*b* has a root diameter which is smaller than that of the feed portion 36*b* so that the helical passage of the second stage 38 has a large flow capacity. In fact, the vent portion 38*b* is only partially filled during operation of the molding machine 10, so that an unfilled volume exists therein which communicates with the vent opening 32.

Downstream of the vent portion 38*b* is a relatively short transition portion 38*c* in which the depth of the helical passage decreases from a large value in the vent portion 38*b* to a comparatively small value in the second pumping portion 38*d*. The second pumping portion 38*d* has a greater flow capacity than does the first stage pumping portion 36*d*. In fact, the entire second stage 38 has a flow capacity exceeding the limited flow capacity of the first stage. In this manner, material will not accumulate in the second stage during steady state operation of the machine 10.

The screw 34 includes a portion 42 which protrudes from the barrel 12 at the end remote from the mold 18. The protruding screw portion 42 cooperates with apparatus 43 for rotating and reciprocating the screw within the screw receiving bore 14.

As part of the reciprocation apparatus, the screw 34 includes a piston end portion 50 which is reciprocably mounted within a suitable cylinder 52 that may be attached to the machine base 53. The cylinder 52 is divided into a first working chamber 54 and a second chamber 62 by the piston end portion 50. The first working chamber 54 receives pressurized hydraulic fluid through a conduit 56 from a pump 58 and a reservoir 60.

The screw rotating apparatus may comprise, for example, a driven shaft 44 having longitudinally extending teeth 46. The shaft 44 may be driven by a suitable conventional motor 48 mounted at the distal end of the cylinder 52. The teeth 46 are received in a conformingly shaped recess 55 in the piston 50 such that rotation of the shaft 44 is imparted to the piston 50 and the screw 34.

To prevent ingestion of gases through the vent opening 32, the injection molding machine may be provided with an exclusion means operatively associated with the barrel 12 and the vent opening 32 to inhibit the flow of atmospheric gases toward the vent opening 32. The exclusion means may include flood means to bathe the vent opening 32 with a suitable inert gas. When dealing with nylons, *i.e.* polyamides, either nitrogen or carbon dioxide are among the suitable inert gases that may be used. The particular inert gas selected would depend on the relative cost and availability of the various inert gases. While the molding machine described above is the two-stage vented type, the present invention is equally applicable to a single stage conventional molding machine.

To improve homogeneity of the plasticated material produced by the molding machine, the screw 34 is provided with one or more multichannel wave screw sections. Typically, such a multichannel wave screw section might be used as the second pumping section 38*d* or the first pumping section 36*d* or both. Alternatively, a multichannel wave screw section may also be used upstream of the second pumping section solely to enforce mixing. There is a condition on the location at which a wave screw is used: the material must already be sufficiently plasticated to have a melted phase and an unmelted phase.

A typical multichannel wave screw section will now be described for use as the first stage pumping section 36*d*.

Turning now to Figure 2, the helical screw flight 36*a*, which defines a material conveying flight, also defines a helical passage 100. This helical passage is defined by radially extending surfaces of the helical conveying flight 36*a*, by the root surface of the screw extending between the radially extending surfaces of the conveying flight 36*a* and by the screw receiving bore 14 of the barrel 12.

Positioned centrally in the helical passage 100 is a radially extending helical barrier 102. This helical barrier has a peripheral surface 104 (see Figure 3) that has an axial width W which is substantially less than the axial width W′ of the peripheral surface 106 of the conveying flight 36*a*. In particular, the width W of the surface 104 may for example be less than eight percent of the screw pitch, defined as the axial distance which the radial surface 108 advances during one 360° revolution about the axis of the screw 34. The screw may have a pitch of 1.25 to 1.50 times the screw diameter. In some allications, the width W of the helical barrier will lie in the range of one to four percent of the screw diameter. The axial width of the helical barrier 104 is selected such that it does not impart substantial shearing to plasticated material passing thereover. Such shearing forces generate heat and thus elevate the material temperature.

The helical barrier 104 divides the helical passage 100 into two parallel helically extending flow channels 110, 112. Each flow passage 110, 112 has a corresponding base surface 114, 116 which undulates in a radial direction as it progresses helically along the screw 34. Undulations of the base surfaces 114, 116 are preferably uniform, and define wave cycles having crests and valleys. The helical distance between crests of a flow channel may be called a wave cycle or wave length. Preferably, a plurality of wave cycles occur in each flow channel 110, 112, for example, more than four, in this manner, pressure pulses may be smoothed out and diminished in intensity. In addition, the number of wave cycles in flow channel 110 is preferably equal to the number of wave cycles in flow channel 112 so that each channel provides the same apparent flow restriction.

Turning now to Figure 4, a cross section through the screw 34 shows a preferred embodiment for the undulating flow channels. In flow channel 110, the bottom surface 114 has a wave crest 114*a* at the top of Figure 4. Similarly, the base surface 116 of flow channel 112 has a valley portion 116*b* at the bottom of Figure 4. While a cross-section through the helical screw primarily illustrates the two flow channels, Figures 5a and 5b schematically illustrates exaggerated radial variations of the base surface in each flow channel 110, 112, respectively, as the flow channel winds around the screw axis.

In this connection, Figure 5a may be considered to be an illustration of the radial variation of the base surface 114 between maximum radius portions, or wave crests at 114a and minimum radius portions, or valleys, 114b. It will be seen from Figure 5a that the helical length of one crest to crest wave cycle in the flow channel 110 corresponds to an angle of 180° about the axis of the screw. Moreover, it will be seen from Figure 5b that the helical length of one crest-to-crest wave cycle in flow channel 112 is also 180°. Figures 5a and 5b also show the relative orientation of the base surface portions 114, 116 at corresponding angular positions about the axis of the screw. Thus, the base surface 114 has a relative maximum 114a at the zero degree location whereas the base surface 116 has a relative minimum 116b at the zero degree location. The wave crests in the two-flow channels are this out of phase with one another.

With the wave crests 114a, 116a being angularly displaced from one another about the screw axis, the base surface 114 (see Figure 3) will be increasing in radius while the base surface 116 is decreasing in radius. Thus, as unplasticated particles moving through flow channel 110 approach a wave crest, the plasticated material will tend to flow over the barrier 102 into the adjacent flow channel 112. As a result, the intensive shear forces applied at the wave crest heat and plasticate the particles in flow channel 110 but do not operate on the already plasticated material to correspondingly increase its temperature.

The radial clearance between each wave crest 114a, 116a and the barrel may be selected to lie in the range of 0.05 to 0.10 times the square root of the diameter of the screw receiving bore 14. Moreover, the maximum depth of the flow channels 110, 114, which occurs at the valley 114b, 116b, may be selected to lie in the range of 2.5 to about 5 times the radial clearance which occurs at the wave crests.

Other modifications of the undulating screw surface may also be incorporated in the multichannel wave screw. For example, the downstream wave crests of each flow channel may provide successively smaller radial clearances so that upstream wave crests may accomodate larger concentrations of unplasticated particles. In addition, the helical length of the increasing radius part of the flow channel base surface may be greater than the helical length of the decreasing radius part of the flow channel base surface.

Alternatively, the wave crests may rise from a flat base surface portion which has a substantial helical length. More particularly, each wave cycle may include a helical length of increasing base surface radius, a helical length of decreasing base surface and a helical length of constant base surface radius. Preferably, the maximum base surface radius portion of one channel would be disposed adjacent to a constant base surface radius of the adjacent flow channel.

For convenience in describing the operation of the injection molding machine, (Figure 1) the injection molding machine cycle is described in terms of a plasticating portion in which the screw 34 is rotating and an injection portion in which the screw 34 is not rotating. Thus, injection portion, as used herein would encompass the injection stroke and the holding portion of many typical molding machine cycles.

In operation, particulate feed material of a synthetic resinous material is positioned in the hopper 30 (Figure 1) for processing and molding into an article whose configuration is defined by the cavity 24 in the mold 18. During steady flow operation in the plasticating portion, the particulate material drops into the first stage 36 of the screw 34 and enters the helical passage 80 of the feed section 36*b*, defined by the bore 14 and the relatively deep screw flights 36*a* of the screw 34.

The material is accepted by the feed section 36*b* and, while the screw 34 is rotated by the rotary drive apparatus 44, 46, 48, the material is conveyed forwardly (to the left in Figure 1) and into the transition section 36*c* of the first stage. In the first stage 36, the material is heated, compacted, masticated and plasticated while experiencing a shearing action between the screw flight 36*a* and the barrel bore 14. At the downstream end of the first pumping portion 36*d* the material has a moldable consistency.

The flow of synthetic resinous material from the transition section is divided between the flow channels 110, 112 (see Figure 2) as it enters the multichannel wave screw section. The plasticated material as well as the solid material in one of the flow channels 110, 112 eventually approaches the first wave crest.

Without a barrier flight 102, all of the plasticated material and the solid unplasticated material would pass through the restriction at each wave crest. Consequently, at the first few wave crests the particles squeezing through the restriction tend to exhibit rapidly varying partial blockage of the liquid path. Since there would be no way for the liquid plastic or plasticated material to communicate with an alternate flow path, small and rapid hydraulic pressure pulses would likely occur in the first few waves in situations where melting is fairly incomplete.

By contrast, in the multichannel wave screw section having a barrier flight which may have a clearance of 40 to 80 thousandths of an inch with the barrel wall, the plasticated material approaching a wave crest in one flow channel is in communication with an adjacent deeper channel across the barrier 102. Since significant amounts of the plasticated material can thus transfer to the deeper channel region, the formation of pressure pulses is minimized. Moreover, by removing plasticated material from the first flow channel, the unplasticated particles are able to wedge up into each wave crest restriction more easily. This assures more rapid plastication of the particles jammed into the wave crests.

After leaving the multichannel wave screw section, the plasticated material passes through the portion 40 and enters the vent portion 38*b* of the second stage 38. The passage in the vent portion 38*b* has a relatively large cross-sectional area so that, at any given time, the helical passage 84 has a volume substantially larger than the volume of plasticating material passing therethrough from the first pumping portion 36*d*. Accordingly, the helical passage 84 is only partially filled. Since the vent portion 38*b* communicates with ambient air through the vent opening 32, the presure existing in the vent portion 38*b* is substantially ambient pressure. As a result, the pressurized pockets of volatilized solvents, including water vapor, which are contained by the pressure upstream of the restrictor member 40, flash open exposure to the large volume and relatively low pressure in the vent portion 38*b*. The released materials are exhausted through the vent opening 32. As the pockets are released, the plasticated material is dried and devolatilized.

The devolatilized and dried plasticized synthetic resinous material moves forwardly through the vent portion 38*b* where it is further worked to release additional pockets of entrained vapor. Next the material enters the short transition portion 38*c* from which it passes into the second pumping portion 38*d*. The flow capacity of the second stage 38 is greater than that of the first stage 36 and, therefore, the second stage is able to convey a larger volume of plasticized material towards the mold 18.

Positioned at the distal end of the screw 34 may be a suitable conventional nonreturn valve 90 which allows the plasticated material to enter a cavity 92 defined by the bore 14, the discharge opening 16 and the distal end of the screw 34. The nonreturn valve 90 permits the material to enter the cavity 92 but prevents the material in the cavity 92 from moving upstream into the helical channel 84 of the second pumping portion 38*d*.

As the screw 34 rotates, material is continuously conveyed forwardly through the second pumping portion 38*d* and into the cavity 92. Simultaneously, the screw 34 translates rearwardly, to the right in Figure 1. enlarging the volume of the cavity 92 to accomodate additional plasticized material. This enlargement of the cavity 92 occurs during the plastication portion of the injection molding machine cycle. When a sufficient volume of material has been accumulated in the cavity 92 to fill the mold cavity 24, the plastication portion of the cycle ends and rotary drive apparatus stops rotation of the screw 34.

The injection portion of the cycle then begins and the first chamber 54 of the cylinder 52 is then pressurized such that hydraulic pressure acting on the piston 50 causes the screw 34 to translate towards the left end of the screw receiving bore 14. As the screw 34 translates the volume of the cavity 92 decreases and the nonreturn valve 90 prevents material trapped in the cavity from flowing upstream into the helical channel 84 of the second stage 38.

Pressure develops in the cavity 92 as a result of the screw movement and causes plasticized material to pass outwardly through the discharge opening 16 into the sprue 26 and the mold cavity 24. The hydraulic pressure in the first chamber 54 may be maintained at a lower level after the mold cavity 24 has been filled to ensure that sufficient material is injected and to maintain the requisite dimensional tolerances. At the end of the transition portion of the cycle, the rotary drive apparatus begins to rotate the screw to accumulate a new charge of material. In addition, the article formed during the previous cycle is removed from the mold in a conventional manner.

In practice, the wave crests for the multichannel wave screw section having a barrier can be made more restrictive than those of single channel wave screws. Results obtained during experimentation show that the twin channel, or multichannel, wave screw section can produce faster melting and greater flow stability than single channel wave screws. Furthermore a single design can give outstanding performance with a wide range of polymers.

In accordance with the present invention the advantages are achieved without excessive heating of the plasticated material. The narrow configuration of the barrier flight imparts minimal energy input, and thus minimal heat, to the plasticated material. Therefore, the plasticated material passes across the barrier with minimal heat input and, in so doing avoids travel through a wave crest restriction and the heat input which would accompany such travel. The clearance between the barrier flight and the barrel promotes the transfer of plasticated material while resisting the transfer of unplasticated materials. Accordingly, the temperature, as well as temperature fluctuations, of the melt ot the screw outlet are maintained within an acceptable range.

The wave crest restrictions are maintained sufficiently shallow to assure that intensive shearing and heating of solid particles occurs.

By maintaining a non-uniform cross sectional area in the helical passage throughout a substantial extent of each wave cycle, the mixing action is further intensified.

Intensified mixing also takes place as a result of the asymmetrical arrangement wherein the wave portion of increasing radius is longer than the portion of decreasing radius.

Moreover by using a wave length which is less than 360°, for example two or three cycles per pitch of the screw, the intensity of the mixing and plastication is increased substantially. This increase in mixing and plastication permits the metering or pumping section to be shorter than heretofore possible while providing a more homogeneous and cooler material. In addition, the injection molding machine itself is shorter and less expensive.

Unbalanced side forces acting on the screw during plastication should be minimized by balancing the angular locations of the wave crests. For example, an integral number of wave cycles may be provided for each revolution of the plasticating screw. In this manner, the pressure forces exerted on the screw by the synthetic resinous material during plastication are substantially balanced both circumferentially and axially along the screw.

The angular extent of the wave length of flow channel undulations has been found to be important. For example, when the wave length becomes less than 120°, the multichannel wave screw performs primarily as a mixing section and does not generate significant amounts of hydraulic pressure in the plasticated material. On the other hand, with longer wave lengths significant pumping or pressurization of the plasticated materials can be produced in addition to the mixing function described above.

For injection molding machine purposes, a wave length less than 360°, *i.e.*, a quick cycle of undulations, is preferred since it permits the length of the processing section to be reduced thereby reducing the cost and length of the injection molding machine itself.

Since advantages are also provided by the multichannel wave screw in which the wave length exceeds 360°, the invention, in its broader aspects, will be understood to include an injection molding machine provided with such a screw.

In summary, a screw section of an injection molding machine constructed in accordance with the teachings of this application provides a homogeneous well-mixed plasticated output with comparatively low temperature that is essentially free of unplasticated particulate matter.

WHAT WE CLAIM IS:—

1. An injection molding machine operable during a plasticizing portion of a molding cycle to accept synthetic resinous material in particulate form and to plasticize the material to a moldable consistency and operable during an injection portion of the molding cycle to shape the plasticized material into a useful form, the machine comprising a barrel provided with a feed opening and a discharge opening, and a rotatable and reciprocable screw in the barrel, the screw including a screw section having a helical conveying flight defining a helical passage, a helical barrier flight dividing the helical passage into at least two helical flow channels, each flow channel having a base surface defining the depth of the flow channel, the base surface of each flow channel undulating in a radial direction so as to define cyclically occuring wave crests separated by cyclically occuring wave valleys along the helical direction, the barrier flight being radially shorter and axially narrower than the conveying flight.

2. An injection molding machine comprising a rotatable reciprocable screw disposed within and cooperating with the inner wall of a barrel provided with an inlet and an outlet opening and wherein in operation particles of synthetic resinous material are introduced through the inlet opening and into a helical passage defined by conveying flight means of the screw, plasticated by rotation of the screw and advanced toward the outlet opening, the screw including a section for assuring complete melting and mixing of the resinous material, which screw section includes radially outwardly extending barrier flight means disposed intermediate the conveying flight means to divide the passage into flow channels extending side by side helically along the screw section, each of the flow channels having a depth which varies cyclically through a plurality of cycles along the helical length of such channel, the minimum depth portions of the flow channels on opposite sides of the barrier flight means defining wave crests which are displaced helically from each other, and the barrier flight means adjacent each wave crest being radially shorter than the conveying flight means to provide sufficient clearance between its radially outermost surface and the inner barrel wall to permit the flow thereover of molten resinous material from the flow channel containing a part, whose depth decreases along the flow channel to an adjacent part of the other flow channel, the outer width of the barrier flight means being shorter than that of the conveying flight means so that the shear energy imparted to molten material flowing over the barrier flight means is low.

3. A machine according to claim 2, wherein the outer width of the barrier flight means is less than eight percent of the screw pitch.

4. A machine according to claim 2 and claim 3, wherein the outer width of the barrier flight means is from one percent to four percent of the screw diameter.

5. A machine according to any one of claims 2 to 4, wherein the clearance between the outermost surface of the barrier flight means and the inner wall of the barrel is from forty to eighty thousandths of an inch.

6. A machine according to any one of claims 2 to 5, wherein the clearance between the inner wall of the barrel and at least a substantial number of the wave crests is from 0.05 to 0.10 times the square root of the diameter of the inner wall of the barrel.

7. A machine according to any one of claims 2 to 6, maximum depth of a channel is from 2.5 to 5 times the minimum depth of a channel.

8. A machine according to any one of claims 2 to 8, wherein each of the channel cycles includes a part whose depth increases along the channel, a part whose depth decreases along the channel, and a part whose depth is constant along the channel and wherein each wave crest in one of the channels is disposed adjacent a part of constant depth in the other channel.

10. A machine according to any one of claims 2 to 9, wherein the radially outer edge of the conveying flight means extends into such close proximity to the inner barrel wall as to substantially restrict the passage of quantities of solid resinous material therebetween, and wherein the barrier flight means and conveying flight means are substantially parallel and have a pitch such that the axial advance of each flight means in each 360 degrees about the screw axis is from 1.25 to 1.50 times the diameter described by the radially outer surface of the conveying flight means.

11. A machine according to any one of claims 2 to 10, wherein the channel cycles each include a part of increasing base surface radius, a part of decreasing base surface radius, and a part of constant base surface radius, wherein each maximum base surface radius portion in one channel is disposed adjacent a part of constant base surface radius in the other channel.

12. A machine according to any one of claims 2 to 11, wherein each cycle of each channel is asymmetrical in that the extent of a part of increasing radius is less than the extent of decreasing radius of the cycle.

13. A machine according to any one of claims 2 to 12, wherein the radial depth of each channel is continuously varying in the helical direction throughout the length of a cycle.

14. A machine according to any one of claims 2 to 13, wherein there is an integral number of wave cycles in each flow channel for each pitch length of the helical passage so as to balance side forces exerted on the screw by the synthetic resinous material during operation.

15. A machine according to claim 14 wherein the plurality of wave cycles in the one flow channel corresponds to the plurality of wave cycles in the other flow channel so that the flow restriction presented by both flow channels is the same.

16. A machine according to claim 14 or claim 15, wherein each wave cycle has a helical length that extends 180 degrees about the screw axis.

17. A machine according to claim 14 or claim 15, wherein there are at least three wave cycles in each flow channel for each pitch length of the helical passage.

18. A machine according to any one of claims 2 to 17, wherein the screw section is operable in conjunction with the barrel to pressurize the synthetic resinous material.

19. A method of preparing a quantity of synthetic resinous material for injection into a mold without over-heating, comprising processing resinous material in a first zone to melt most of the material and advance it to a second zone, dividing the flow through the second zone into two parallel channels each of which has restricted cross-sectional areas at a plurality of locations along its length with the restricted areas in one channel being longitudinally offset from the restricted areas in the other channel and with the cross-sectional area of each channel varying cyclically over a plurality of substantially identical cycles, forcing incompletely melted resinous material in each of the channels to pass through the restricted areas in that channel to receive extra energy input for melting the same, and filtering a portion of the completely molten resinous material from one channel to the other in advance of each of the restricted areas to avoid the extra shear energy input associated with passage through the restricted areas and thereby to avoid overheating of the melted material, the cycles reinforcing one another and collectively providing a steady material flow rate and pressure at the output end of the second zone, wherein the filtering step includes facilitating the flow of molten resinous material from one channel to the other while simultaneously restricting the flow of unmelted resinous material to promote the separation of molten from unmelted material so as to concentrate the passage of unmelted material through the restricted areas and thereby maximize heating of the unmelted material and minimize heating of the molten material.

20. An injection molding machine substantially as herein described with reference to the accompanying drawings.

21. A method of preparing a quantity of synthetic resinous material for injection into

a mold without overheating, substantially as herein described with reference to the accompanying drawings.

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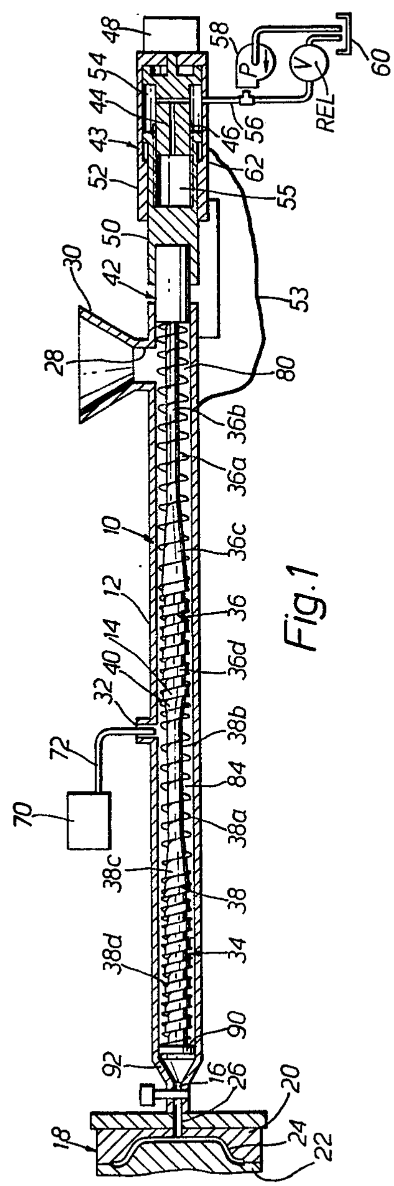
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36c
12
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14
36d
40
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22

Fig.1

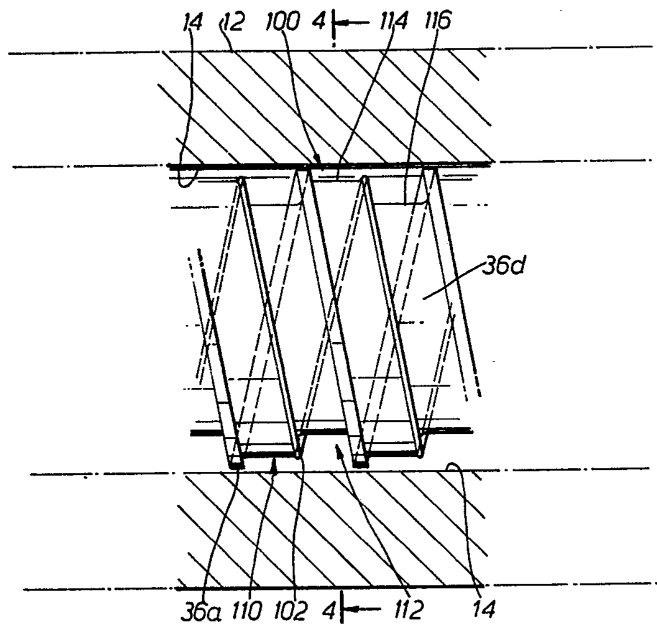
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Fig. 2

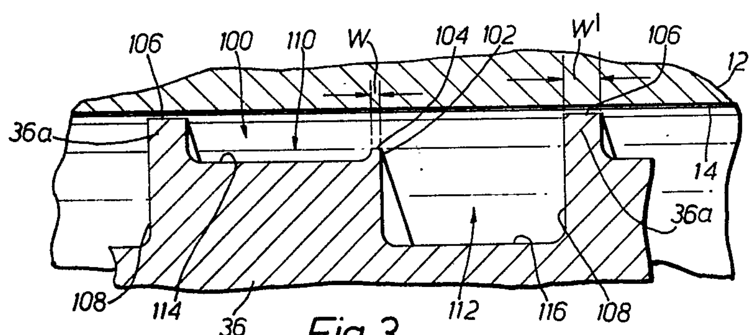
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Fig. 3

Fig.4

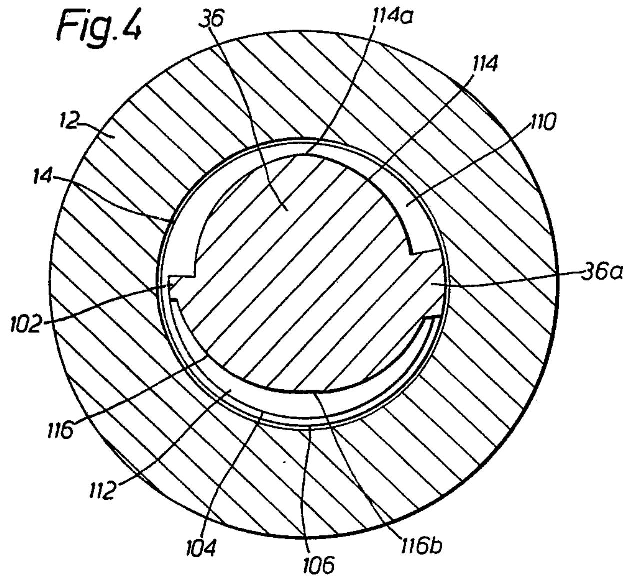

Fig.5a

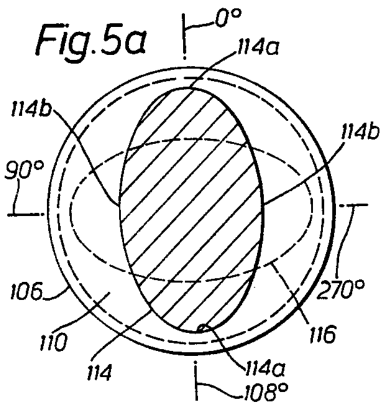

Fig.5b