

**"SCREW FOR POLYMERIC MATERIAL EXTRUDER AND POLYMERIC MATERIAL
EXTRUDER COMPRISING SAID SCREW"**

TECHNICAL FIELD

The present invention concerns a screw for a polymeric
5 material extruders and a polymeric material extruder
comprising said screw.

BACKGROUND ART

Currently, the polymeric material single-screw extruders of
10 known type are not able to disperse a solid or liquid
substance in a polymer matrix, in an ideal manner.

In fact, the screw geometry of the single-screw extruders of a
known type does not lend itself to the ideal dispersion of
15 liquid or solid substances in a polymer matrix as it does not
generate an adequate elongational flow components for the
application.

In order to introduce elongational flow components, screw
20 extruders have been produced characterized by material flows
in a circumferential direction, i.e. normal to the screw
conveying threads, in which the circumferential flow section
gradually converges along the circumferential direction. In
this way, significant accelerations are imparted to the liquid
25 conveyed.

The sections of the screws in which the thread is configured
to also generate a circumferential flow are defined of the
shearing flight type.

30 Some examples of extruders of this type are described in the
documents US 5356208, US 6136246.

The opposite type of extruder is the scraping flight type.

Conventionally, the term shearing refers to hydrodynamic shear. This definition, therefore, underlines the speed and shear stress undergone circumferentially by the material through the space purposely designed between the thread and
5 the inner wall of the extruder cylinder.

The term scraping, on the other hand, indicates that the space between the thread and the inner wall of the extruder cylinder is almost null, i.e. only just sufficient to prevent wear due
10 to adhesion (seizure). In short, in this type of extruder the thread creates a sliding seal.

Obviously in extruders with scraping threads the aim is to prioritize the axial pumping function by reducing the
15 circumferential "losses" to zero, whereas in extruders with shearing threads, the aim is to prioritize the circumferential dispersion function, with the axial pumping function being of a secondary importance.

20 It is therefore clear that in single-screw extruders the material flow will always, or almost always, be in an axial direction and optionally also in a circumferential direction according to process requirements.

25 However, the circumferential flow determines a sudden bowing of the material during its circumferential travel near the thread. This bowing can sometimes give rise to undesired breakages of the material. This typically happens, for example, in the case of dispersion of fragile fibres, such as
30 glass or carbon fibres, in polymer material.

Furthermore, in general, the dispersion technique by means of circumferential flows have many other limitations.

35 Firstly, the maximum length of the path of the material along the circumferential coordinate is limited by the diameter of

the rotor.

Furthermore, as is known, the hydrodynamic stories of axial and circumferential flow do not coincide. To understand this concept, it must firstly be said that, depending on dispersion requirements, which vary from one application to another, the dispersion process can entail the liquid to be dispersed travelling one or more times along the circumferential trajectory of the screw. If the material never travels along the circumferential trajectory, the circumferential dispersion is null. If the material travels along the circumferential trajectory only once, the dispersion level will be minimum. If the material travels along the circumferential trajectory twice, the dispersion level increases, and so on.

Currently it is physically impossible to control the number of passages of the material in the circumferential direction. Let's consider, for example, two given liquid particles A and B which travel together in a shearing flight extruder. Said particles A and B will flow out of the extruder once and only once (axial flow), but whether and how many times said particles have travelled a circumferential path is neither evident nor controllable.

Let's suppose for example that, in a particular case, particle A has never travelled along the circumferential trajectory and particle B has travelled it three times. If for example the dispersion process of the materials A and B requires a minimum of two circumferential passages, A would not have undergone the minimum dispersion required whereas B would have undergone one too many.

Research studies (Z.Tadmor, I. Manas-Zloczower, Adv. Plast. Technol., 3, 213, 1983) have developed a statistical model called NPD (Number of Passages Distribution function), which has formulated theoretical criteria to determine the mean

circumferential flows necessary to obtain the desired number of circumferential passages.

For example, to satisfy the statistical probability that 99% of the material has travelled a circumferential path at least once, the circumferential flow is required to be 4.6 times greater than the axial ejection flow. If on the other hand there have to be at least two circumferential passages, then the circumferential flow must be much greater than 4.6 times the axial delivery flow, and so on.

Said solutions have multiple drawbacks.

Firstly, they require the use of very long extruders in order to guarantee the circumferential flow required to obtain the number of circumferential passages required by the application needs.

If we take into account that in many cases the ratio between circumferential flow and delivery flow must be greater than 6, it is easy to see how much longer the extruder has to be compared to the case in which the ratio is equal to 1. Furthermore, this automatically entails an undesired increase in the residence time of the material inside the extruder with concrete risks of thermal degradation.

Furthermore, the axial length of the circumferential dispersion zones automatically entails an increase in the volume of material contained in the screw with parallel increases in specific energy consumed during the process.

Above all, screws and extruders of this type are very costly due to their length and the torques to be applied on the screw shaft which, as known, are proportional to the volume of liquid contained in the screw.

Lastly, the statistical distribution of the dispersion quality tends to be very broad, since the liquid population fractions with an equal number of passages are numerous, for example eleven in the case of circumferential flow equal to 4.6 times the axial flow, all characterized by at least one passage but only one characterized by one single passage.

DISCLOSURE OF INVENTION

An objective of the present invention is therefore to produce an extrusion screw and an extruder which are free from the drawbacks highlighted here of the known art; in particular, one object of the invention is to produce a screw for the extrusion of polymeric materials and a polymeric material extruder that overcome the drawbacks highlighted above in a simple inexpensive manner, from both a functional and a construction point of view.

In accordance with the above objects, the present invention concerns an extrusion screw and an extruder as claimed in the respective claims 1 and 12.

BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the present invention will appear clear from the following description of a non-limiting embodiment example thereof, with reference to the figures of the accompanying drawings, in which:

- figure 1 is a lateral schematic view, with parts in section and parts removed for clarity, of a single-screw extruder according to the present invention;
- figure 2 is a lateral schematic view, with parts in section and parts removed for clarity, of an extruder screw according to the present invention;
- figure 3 is a plane development of the surface of the screw of figure 2 at 360°;
- figure 4 is a detail of the screw of figure 2;

- figure 5 is a detail of the screw of figure 2 according to a first variation;
- figure 6 is a detail of the screw of figure 2 according to a second variation;
- 5 - figure 7 is a detail of the screw of figure 2 according to a third variation;
- figure 8 is a lateral schematic view, with parts in section and parts removed for clarity, of a single-screw extruder according to a variation of the present invention.

10

BEST MODE FOR CARRYING OUT THE INVENTION

In figure 1 the reference number 1 indicates an extruder according to the present invention, which is configured to process one or more polymeric materials so as to produce an
15 extruded polymeric product along an advancing direction E.

For the sake of simplicity, the processed polymeric material and the polymeric product obtained are not visible in the attached figures.

20

By the term polymeric material, we mean all thermoplastic polymeric materials both in a completely melted condition and in a semi-melted or pasty condition.

25 For example, some polymeric materials that can be processed by the extruder 1 according to the present invention are: polyolefins (LDPE, LLDPE, HDPE, PP, etc.), polystyrene, ABS, polyamides (for example 6, 66, 11, 12, etc.), PTFE, PBT, PEEK.

30 Another example of processable materials are some food liquids or viscous pastes, for example chocolate, or cosmetic products, like creams.

In the non-limiting example described and illustrated here,
35 the extruder 1 is a single-screw extruder configured to melt polymeric material and to disperse liquid, solid or fibrous

additives in said melted material (melt compounding). It is understood that the extruder 1 can also be used for extrusion processes that do not involve the use of additives (pure melting).

5

The extruder 1 extends along a longitudinal axis A and essentially comprises an extrusion cylinder 2, a screw 3, means for the actuation of a rotary movement of the screw 3 (not illustrated for the sake of simplicity in the attached
10 figures), one or more inlets 4 configured to feed the polymeric material to the cylinder 2, and an outlet 5.

The extruder 1 further comprises ancillary devices (not shown for the sake of simplicity in the attached figures) such as
15 electric resistances, temperature and pressure control instruments, rotary movement regulation means, etc.

The cylinder 2 is coaxial to the axis A and is hollow. In detail, the cylinder 2 is provided with an inner surface 6a
20 and an outer surface 6b. The inner surface 6a is shaped so as to define a housing seat 8.

The screw 3 is housed inside the housing seat 8 and comprises a nut 10 centred on the longitudinal axis A.

25

The screw 3 further comprises a thread 12, wound in a helix around the outer surface 7 of the nut 10.

In detail, the thread 12 protrudes from the outer surface 7 of
30 the nut 10 and is provided with two lateral sides 14.

The portion of outer surface 7 between the lateral sides 14 of the thread 12 defines a bottom 15.

35 The screw 3 has an outer diameter D, measured on the crest of the thread 12 (visible in figure 2).

In the non-limiting example described and illustrated here, the outer diameter D of the screw 3 is approximately 80 mm.

5 The outer diameter D of the screw 3 is preferably slightly smaller than the diameter of the housing seat 8 to perform the function of circumferential seal and at the same time avoid contact between the thread 12 and the cylinder 2 which could cause seizure.

10

In other words, the thread 12 is sized so as to provide a sliding seal within the housing seat 8.

The thread 12 is, therefore, of the scraping type.

15

Preferably, the difference between the diameter of the housing seat 8 and the outer diameter D of the screw 3 ranges between approximately 1/1000 of the outer diameter D and 30/1000 of the outer diameter D.

20

Moreover, the slight difference between the diameter of the housing seat 8 and the outer diameter D of the screw 3 favours axial transport of all the polymeric material by the thread 12 and prevents, as far as possible, the polymeric material from
25 crossing the space between the crest of the thread 12 and the inner surface 6a of the extrusion cylinder 2, along a circumferential trajectory.

Typically, if the thread 12 provides a sliding seal, the flow
30 of polymeric material that crosses the space between the crest of the thread 12 and the inner surface 6a of the extrusion cylinder 2 is lower than 1% of the axial extruder delivery flow rate.

35 Essentially, the bottom 15, the lateral sides 14 and the inner surface 6a of the extrusion cylinder 2 define an advancing

channel 17 for conveying the polymeric material.

The axial distance between the lateral sides 14 (also including the axial thickness of a thread) defines the pitch P
5 of the thread 12.

The distance between the lateral sides 14, understood as the normal distance to said sides, defines the width W of the advancing channel 17.

10

The pitch P of the thread 12, essentially, is the projection of the width W of the advancing channel 17 along the axial coordinate.

15 The distance measured in a radial direction between the bottom 15 and the inner surface 7 of the extrusion cylinder 2 defines the height H of the advancing channel 17.

The flow section, understood as the available section of the
20 advancing channel 17 for allowing the passage of the flow of material, to be determined by multiplying the height H by the width W.

Said flow section is substantially defined by the relation (P
25 $\cos \alpha - w$) H

- where α is the screw angle, i.e. the angle that ranges between the coordinate parallel to the thread 12 and a plane perpendicular to the axis A of the cylinder 2,
- w is the axial thickness of the thread 12,
- 30 • $P \cos \alpha - w$ coincides with the width W.

With reference to figure 2, the thread 12 comprises at least one first stretch 20 having a first helix winding direction and at least one second stretch 21 having a second helix
35 winding direction opposite the first direction.

The first winding direction is such as to obtain, in use, an axial advancement in the direction E of the polymeric material arranged in the advancing channel 17 towards the outlet 5 of the extruder 1 when the screw 3 is operated in an anticlockwise rotation direction for the observer positioned at O looking towards the outlet 5.

The second winding direction is such as to obtain, in use, an axial advancement in the direction opposite to the advancing direction E of the polymeric material arranged in the advancing channel 17 when the screw 3 is operated with the same anticlockwise rotation direction for the observer positioned at O looking towards the outlet 5.

In other words, the first winding direction is such as to obtain advancing of the material towards the outlet 5, while the second direction is such as to obtain a return of the material towards the inlet 4.

In the non-limiting example described here, the screw 3 is rotated anticlockwise observing the screw 3 from an observation point O (figure 1 and figure 2).

In the non-limiting example described and illustrated here, the first stretch 20 and the second stretch 21 of the thread 12 are adjacent.

In particular, the first stretch 20 and the second stretch 21 are preferably identical with the exception of the winding direction which is opposite.

In other words, the first stretch 20 of the thread 12 has a first angle of inclination α_1 and the second stretch has a second angle of inclination α_2 substantially identical in absolute value to the first angle of inclination α_1 and having opposite sign.

By angle of inclination we mean the screw angle, i.e. the angle between the coordinate parallel to the thread 12 and a plane perpendicular to the axis A.

5

Preferably, the angle of inclination α_1 of the first stretch 20 and the angle of inclination α_2 of the second stretch 21 are between approximately 5° and 65° .

10 In the non-limiting example described and illustrated here, the first stretch 20 of the thread 12 furthermore has a pitch P1 identical to the pitch P2 of the second stretch 21 of the thread 12.

15 The passage from the first winding direction of the first stretch 20 to the second winding direction of the second stretch 21 takes place in an area of the advancing channel 17 called inversion area which goes from a section S0 to a section S1 and is highlighted in figure 3.

20

The section S0 corresponds substantially to the section of the channel 17 in which the left-hand lateral side of the first stretch 20 terminates (left-hand for the observer travelling together with the material).

25

In use, the rotation of the screw 3 determines an advancing flow of the polymeric material along the first stretch 20 and a simultaneous return flow of the polymeric material along the second stretch 21. Said opposite flows meet substantially in
30 the section S1 also called inversion section S1 comprised in the inversion zone S0-S1.

Whatever the geometry of the first stretch 20, at the inversion section S1 a meeting of counteracting flows occurs which determines a pressure value as a function of the overall
35 geometry of the first stretch 20.

Higher pressure peaks are useful, for example, to discharge hydrodynamic stress on incompatible polymeric materials.

Lower pressure peaks are useful for example in the case of
5 dispersions of fragile fibres in the polymeric material. Fragile fibres, like carbon for example, can break if subjected to excessive hydrodynamic stress and excessively high pressures.

10 With reference to figure 4, preferably the advancing channel 17 is shaped so that the flow section is decreasing along at least one first portion 25 of the first stretch 20, increasing along at least one second portion 26 of the second stretch 21 and with a minimum flow section in the inversion zone S0-S1.

15 In the non-limiting example illustrated in figure 4, the minimum flow section occurs at an inversion section S1 (figure 3) comprised in the inversion zone S0-S1.

20 In this way there is a gradual reduction in the flow section along the first portion 25 and a gradual increase in the flow section along the second portion 26.

25 Preferably, the flow section of the advancing channel 17 along the first section 25 and the flow section along the second portion 26 are symmetrical with respect to the minimum flow section (coinciding in the non-limiting example described and illustrated here with the inversion section S1).

30 In this way, the geometry of the flow section at the beginning of the first section 25 is identical to the geometry of the flow section at the end of the second section 26.

35 The first portion 25 of the first stretch 20 defines a first dispersion chamber 28 of the advancing channel 17 while the second portion 26 of the second stretch 21 defines a second

dispersion chamber 29 of the advancing channel 17.

The first dispersion chamber 28 and the second dispersion chamber 29 define a dispersion zone 30.

5

The dispersion zone 30 has a helical length according to requirements.

10 Longer dispersion zones 30 can be useful for example to subject the material to longer residence times inside the dispersion zone 30, whereas shorter dispersion zones 30 can be useful for example to subject the material to shorter residence times inside the dispersion zone 30.

15 The helical length of the dispersion zone 30 can vary for example from a minimum of approximately $1/10$ of the outer diameter D of the screw 3 up to a maximum equal to 10 times the outer diameter D of the screw 3.

20 According to a first embodiment illustrated in figure 3, the advancing channel 17 has a height H decreasing along the first portion 25 of the first stretch 20, and a height H increasing along the second portion 26 of the second stretch 21. In the non-limiting example described and illustrated here, at the
25 first inversion section $S1$ the height of the advancing channel 17 is minimum H_{min} .

In other words, the screw 3 has a bottom 15, which has a radial height increasing along at least the first portion 25
30 of the first stretch 20, a radial height decreasing along at least the second portion 26 of the second stretch 21 and maximum radial height corresponding to at least one section comprised in the inversion zone $S0-S1$. In the non-limiting example described and illustrated here, in figure 4 the
35 maximum radial height occurs at the inversion section $S1$.

The variations in the height H along the first portion 25 of the first stretch 20 and along the second portion 26 of the second stretch 21 are preferably identical and have identical dH/dz gradient but opposite sign.

5

Preferably, the initial height H of the first portion 25 and the second portion 26 can typically range between a value of approximately 1 mm and a value of approximately $1/3$ of the outer diameter D of the screw 3. The initial value of H depends on the characteristics of the screw 3 and is defined by the mechanical limit beyond which there is the risk of breakage of the nut 10 of the screw 3.

Preferably, the height H of the first portion 25 and of the second portion 26 can decrease to a minimum value, ranging between approximately 0.1 mm and approximately 0.7 times the initial value of the height H of the first portion 25 and the second portion 26 respectively. Said minimum value will take account of the minimum flow desired at the rotation speed of the screw 3 employed.

Preferably, the pitch of the first dispersion chamber 28 is constant and the pitch of the second dispersion chamber 29 is constant.

25

Preferably, the pitch of the first dispersion chamber 28 is identical to the pitch of the second dispersion chamber 29.

Preferably, the pitch of the conveying channel 17 at the first inversion section $S1$ is equal to the pitch of the first dispersion chamber 28.

As indicated in the diagram of the pressure trend, the pressure reaches a maximum peak P_{max} at a section comprised in the inversion zone $S0-S1$. In the non-limiting example described and illustrated here in figure 4, the pressure

35

reaches maximum peak at the inversion section S1.

The transition zone with flow inversion S0-S1 can be sized according to the application purposes of the extruder 1 so as to have a desired pressure profile in the first stretch 20.

According to a variation not illustrated, in the inversion zone S0-S1 the channel 17 has initial depth $H_{\max}$, decreases to a minimum depth $H_{\min}$ and maintains the depth $H_{\min}$ constant for a predefined stretch and then increases again to the value $H_{\max}$.

According to other variations not illustrated, in the inversion zone S0-S1 the height is made to vary in different modes so as to reach a minimum value $H_{\min}$ in S1.

According to a further variation not illustrated, the minimum height $H_{\min}$ of the advancing channel 17 (corresponding to a maximum radial height of the bottom 15) can be upstream of the inversion section S1, for example in the inversion zone S0-S1.

According to a further variation the minimum height $H_{\min}$ of the advancing channel 17 (corresponding to a maximum radial height of the bottom 15) is reached at a point upstream of the inversion zone S0-S1. In this way, the maximum pressure peak is deliberately obtained in the vicinity of $H_{\min}$ upstream of S0, whereas in the stretch between S0 and S1 the maintenance of a reduced pressure is preferred.

According to a variation not illustrated, the variation in the flow section can be obtained solely by varying the pitch of the first dispersion chamber and the second dispersion chamber.

The pitch variation can be combined with the height variation of the first dispersion chamber and the second dispersion chamber to increase the pressure gradient to which the

material is subjected.

Figure 5 illustrates a further variation of the present invention in which the first dispersion chamber 28 has a height H having a decreasing and subsequently constant trend, whereas the second dispersion chamber 29 has a height H having a constant and subsequently increasing trend.

The sizing of the stretches with constant height allows a regulation of the maximum pressure that can be reached in the area of the reduction of the height of the channel 17 at $H_{\min}$. The more the length of the stretch with constant height H increases, the more the pressure $P_{\max}$ can increase in the vicinity of the beginning of the area of the channel 17 having $H_{\min}$.

In the non-limiting example described and illustrated here, the height H of the first dispersion chamber 28 and the height H of the second dispersion chamber 29 are symmetrical with respect to the inversion section S1.

As indicated in the pressure trend diagram, the pressure reaches a maximum peak $P_{\max}$ in the vicinity (just before) the beginning of the area of the channel 17 having $H_{\min}$.

Figure 6 and figure 7 illustrate two further variations of the present invention in which the height H of the first dispersion chamber 28 and the height H of the second dispersion chamber 29 are not symmetrical with respect to the inversion section S1.

In particular, figure 6 illustrates a variation in which the first dispersion chamber 28 has a height H having a decreasing and subsequently constant trend for a stretch e1, whereas the second dispersion chamber 29 has a height H having a constant trend for a stretch e2, and subsequently increasing. In the

stretches e_1 and e_2 the height of the channel 17 is the minimum height $H_{\min}$. The lengths e_1 and e_2 are sized to obtain a given increase in resistance to the flow and consequently a given maximum pressure $P_{\max}$.

5

In figure 6 the stretch e_1 is greater than the stretch e_2 while the height H along the stretch e_1 is equal to the height H along the stretch e_2 .

10 Figure 7 illustrates a variation in which the first dispersion chamber 28 has a height H having a decreasing trend whereas the second dispersion chamber 29 has a constant height H equal to the minimum height reached in the first dispersion chamber 28. The latter configuration can be applied, for example, to
15 prevent undesired accelerations of the semi-molten/pasty material in the terminal stretch of a plasticization section which often cause breakages and irregular feeds with consequent flow pulsations at the outlet of the extruder 1 and non-uniform quality. In this application case, the second
20 dispersion chamber 29 with constant height constitutes an effective brake for the fed material.

It should be noted that figures 4, 5, 6 and 7 are schematic two-dimensional reproductions that do not take into account
25 the real conformation of the channel 17 of the screw 3 in the inversion zone S_0 - S_1 . The representation of figure 3 aids in the understanding of the conformation of channel 17 in the inversion zone S_0 - S_1 .

30 It is understood that the conveying channel 17 can be shaped so that the passage section is defined so as to obtain combinations of speed and pressure profiles particularly suited to meeting the desired dispersive mixing requirements.

35 Preferably, the volume of the first dispersion chamber 28 is identical to the volume of the second dispersion chamber 29.

With reference to figure 2, the thread 12 of the screw 3 comprises at least one further first stretch 40 having the first helix winding direction and a further second stretch 41 having the second helix winding direction opposite the first direction.

In the non-limiting example described and illustrated here, the further first stretch 40 and the further second stretch 41 are adjacent and are identical to the first stretch 20 and the second stretch 21 respectively.

Also in this case, the passage from the first winding direction of the further first stretch 40 to the second winding direction of the further second stretch 41 occurs in an area of the advancing channel 17 called second inversion zone S2-S3.

Analogously to what was described previously for the first stretch 20 and the second stretch 21, the advancing channel 17 is shaped so that the flow section is minimum at a point of the second inversion zone S2-S3 or at a point upstream of the inversion zone S2-S3.

Preferably the further first stretch 40 is arranged downstream of the second stretch 21 in the advancing direction E of the screw 3.

In the non-limiting example described and illustrated here, a separating advancing portion 43 of the thread 12 is arranged between the second stretch 21 and the further first stretch 40.

The separating portion 43 is defined by a stretch of the thread 12 wound spirally in the first winding direction.

The separating portion 43 is configured so as to invert the flow direction downstream from the first dispersion zone 30 towards the outlet 5.

5 The length of the separating portion 43 can furthermore be adjusted so as to determine a desired offset between the advancing channel 17 at the first inversion section S0-S1 and the advancing channel at the second inversion section S2-S3. In this way, the bending thrusts which are discharged onto the
10 screw 3 at the first inversion section S1 and the second inversion section S2-S3 are balanced. The pressure peaks reached in the inversion sections can also reach values in the order of hundreds of bars, resulting in very substantial bending thrusts.

15 In the example illustrated in figure 1, the offset between the advancing channel 17 at the first inversion section S1 and the advancing channel at the second inversion section S2-S3 is 180°.

20 According to a variation not illustrated, the screw 3 comprises a plurality of dispersion zones in succession along the screw, all comprising a respective first stretch and a respective second stretch of the thread having opposite
25 winding directions.

Between one dispersion zone and another, a stretch of the screw is shaped so as to guide the conveying of the material towards the outlet. In other words, between one dispersion
30 zone and another, there is at least one separating portion sized and shaped so as to guide the flow in the direction of the outlet 5 and, if necessary, implement a radial offset of the subsequent dispersion zone.

35 In figure 1 upstream of the dispersion zone 30 along the advancing direction E, the thread 12 comprises a conveying

stretch 50, which has the same winding direction as the first stretch 20.

The conveying stretch 50 is sized and shaped so as to allow
5 the desired conveying flow.

In use, a quantity of solid thermoplastic material is fed through the inlet 4, preferably by means of a hopper 51, to the housing seat 8 in which the screw 3 rotates.

10

In the conveying stretch 50, the material is at least partly melted due to the friction generated between the extrusion cylinder 2 and the material.

15

Once melted, wholly or partly, the material proceeds along the advancing channel 17 and fills the first dispersion chamber 28, generating a pressure profile ranging from a minimum value to a maximum peak in the vicinity of the first inversion section S1. The material will go on to also fill the second
20 dispersion chamber 29 until the latter is almost full.

25

During the filling phase of the first dispersion chamber 28 and the second dispersion chamber 29, the flow of material is typically a transitory accumulation flow. In particular,
during the filling phase of the first dispersion chamber 28 and the second dispersion chamber 29 the accumulation flow is greater than zero, whereas the outlet flow from the second dispersion chamber 29 is zero.

30

By accumulation flow we mean the flow of material that accumulates in the first dispersion chamber 28 and in the second dispersion chamber 29.

35

Due to the inverted pitch, the first dispersion chamber 28 and the second dispersion chamber 29 must fill before allowing the flow downstream.

In this phase, the outflow from the second dispersion chamber 29 is substantially null.

5 As soon as the first dispersion chamber 28 and the second dispersion chamber 29 are full, a situation occurs in which the accumulation flow becomes null, while the outflow from the second dispersion chamber 29 will be equal to the inflow in the first dispersion chamber 28.

10

Once full, due to the conveying action of a conventional stretch of screw, the material can continue downstream even though the two sections remain constantly full of material and under pressure.

15

Essentially, in the filling phase the accumulation flow P_a is greater than zero and is equal to the inlet flow P_i into the first dispersion chamber 28 while the outflow P_u from the second dispersion chamber 29 is null. We can therefore say
20 that in this phase $P_i = P_a$ and $P_u = 0$.

20

Once the standard operating conditions have been reached (filling of the first dispersion chamber 28 and the second dispersion chamber 29), the accumulation flow P_a is null and
25 the outflow P_u from the second dispersion chamber 29 coincides with the inflow P_i to the first dispersion chamber 28. We can therefore say that in this second phase, at standard operating conditions, $P_a = 0$ and $P_u = P_i$.

25

30 Once the standard operating conditions have been reached, this structure allows, the control of the material residence time inside the first dispersion chamber 28 and the second dispersion chamber 29.

35 By simply varying the inflow to the first dispersion chamber 28 it is possible to regulate the residence time via the

following equation:

residence time = (volume first dispersion chamber 28 + volume second dispersion chamber 29) / volumetric inflow.

5 Due to the possibility of regulating the residence time and the speed of the screw 3 (which directly affects speed and shear stress), in addition to the geometry of the dispersion chambers, it is possible to set an optimal dispersion and mixing process which takes into account the nature of the
10 polymers mixed, the loads incorporated and the desired characteristics of the extruded material.

In the first dispersion chamber 28 and in the second dispersion chamber 29 thus configured, flows both parallel to
15 the thread 12 (shear and elongational) and transverse to the thread 12 (transverse recirculation) are generated in the advancing channel 17. These flows ensure optimal mixing in terms of both distribution and dispersion. In particular it has been found, with reference for example to figures 1 and 8,
20 that in the dispersion zone 30 in the stretch with decreasing height a significant backflow is favoured. In other words, during rotation of the screw, the material is continuously recirculated in the channel 17 having variable height (between the zones with minimum height $H_{\min}$ and initial maximum height
25 $H_{\max}$ and vice versa) favouring axial uniformity of the composition simultaneously with positive flow towards the outlet.

According to a variation of the present invention, not
30 illustrated, the screw is provided with more than one thread.

For example, the screw can comprise two threads offset by 180° (this solution is normally known in the sector as "double-threaded screw"), or three threads offset by 120° ("triple-threaded screw"), or four threads offset by 90° ("quadruple-threaded screw").
35

Figure 8 illustrates an extruder 100 according to a variation of the present invention comprising an inlet 55 for feeding polymeric liquid and a further inlet 56 (shown by a broken line) for feeding solid or liquid loads.

The solid loads can be for example micro powders or nano powders, or typically elongated elements such as glass, carbon, aramid or natural fibres, or also granules, flakes or powders of thermoplastic material. The liquid loads are for example monomers or polymers in liquid form, and in general additives in liquid form.

The extruder 100 therefore does not have a section in which the melting of the polymer takes place, but is fed directly with polymer in the liquid state from an external source (not illustrated). The external source of polymeric liquid can be for example a screw extruder, or any other device that melts by friction feed.

Separation of the melting apparatus from the mixing apparatus allows for more flexible regulation of the speed of the screw 3 of the extruder 100 according to the present invention compared to the case in which liquefaction of the solid polymer is carried out in the same screw in which the dispersion zones are provided.

The extruder 100 further comprises a vent pipe 57, which contributes to the elimination of the volatile substances generated during the extrusion process.

In the extruder 1 and in the extruder 100 the outlet 5 is arranged along the axis A.

According to a variation not illustrated, the extruder outlet is orthogonal to the axis A. In this case both ends of the

screw are supported by appropriate groups of radial and/or axial bearings.

According to a variation not illustrated, the extruder
5 comprises two screws housed in the housing seat defined by the hollow extrusion cylinder. Said screws can be both interpenetrating and non-interpenetrating.

If they are interpenetrating, the reciprocal distance along
10 the converging stretch tends to decrease. In this case the cross section of the cylinder has the classic 8 shape.

If on the other hand they are non-interpenetrating, then the values of H_{initial} and H_{min} must be considered with reference to
15 the centre of the screws and the cross section of the cylinder assumes the classic figure of a double tangent circle. The two screws can be co-rotating or counter-rotating.

Advantageously, thanks to the screw 3 according to the present
20 invention, it is possible to have extruders in which the residence time inside the dispersion zone is controllable.

Advantageously, the solution proposed allows accurate and predictable control of the number of passages of the material
25 through the dispersion zones 30, corresponding to the number of dispersion zones 30 arranged in series.

Thanks to the configuration of the invention, all the material undergoes the same overall shear-elongation deformation.

30

This aspect has important consequences in respect to quality distribution and therefore guarantee and certification of the quality of the material flowing out of the extruder.

35 Furthermore, the screw according to the present invention can be designed so as to produce a particular configuration in

which the first dispersion stretch comprises a first portion consisting of a plurality of steps with gradually decreasing height to partially melt the solid polymer according to the known modelling criteria of a melting stretch of a conventional single screw followed by a second portion of said first stretch with constant or decreasing height. If the first stretch is designed so as to melt only a part of the solid introduced into the melting channel of the screw of the invention, in the last part of said first stretch and in the second stretch with inverted flow, particles of solid polymer mixed with melted polymer jointly subjected to a mixing process will be found, with the consequence that the transfer of thermal energy from melted to solid is much more efficient than in the melting stretch of a conventional single screw. In fact, in a conventional single screw, the area available for the transfer of thermal energy is the polymer-cylinder interface which is considerably smaller than the outer surface of the granules, which are still solid, surrounded by melted polymer being formed.

Due to the extruder 1, 100 and the screw 3 according to the present invention it is possible to improve the quality of the materials flowing out of the extruder also in the case of pure melting type applications. The extruder according to the present invention provides, at the outlet, material substantially free from defects normally known as fish eyes or black specks due to various causes, for example contaminants, imperfect polymerization points etc. which can be eliminated with appropriate shear-elongation stress.

The screw 3 and the single-screw extruder 1, 100 according to the present invention are furthermore advantageously low cost and have exceptional dispersion capacities of at least two materials (for example a polymeric material and a solid or liquid additive or two polymeric liquids).

Control of the material residence times allows processes in which the residence time and its statistical distribution are generally important and particularly critical, for example, in reactive compounding.

5

The extruder according to the present invention typically generates a mono-modal flow and therefore obliges 100% of the material to pass through the dispersion zones 30, as many times as the number of zones provided in the screw, thus guaranteeing a statistical distribution of the dispersion quality tending to zero. The known screw extruders, on the other hand, for example corotating twin-screw extruders, which perform the dispersion on circumferential coordinates, i.e. around the threads, typically generate bimodal flows. In turn, the presence of bimodal flows requires the modelling of axially very long dispersion zones capable of producing a circumferential flow 4.6 to 10 times greater, and more, than the delivery flow. This circumstance entails a substantial increase in the volume of material contained in the screw and consequently a significant increase in the mixing energy used.

20

Therefore, thanks to the possibility of practically absolute control of the material residence times in the extruder and the generation of monomodal flows, it is possible to optimize the specific consumption of energy, for example in terms of kWh/Kg. It is deemed that the energy saving can reach and exceed 50% of the consumption incurred for a similar dispersion quality obtainable with conventional technologies, in many applications.

30

The screw 3 according to the present invention can also be mounted on existing extruders.

Lastly it is obvious that modifications and variations can be made to the screw, extruder and method described here without departing from the scope of the attached claims.

35

CLAIMS

1. A screw for a polymeric material extruder; the screw
(3) comprising:
 - 5 a nut (10) extending along a longitudinal axis (A),
at least one thread (12) wound in a helix around the outer
surface (7) of the nut (10); the thread (12) having at least
one first stretch (20; 40) having a first helix winding
direction and at least one second stretch (21; 41) having a
10 second helix winding direction opposite the first helix
winding direction; wherein the thread (12) is defined by two
lateral sides (14) which protrude from the outer surface (7)
of the nut (10) and wherein the portion of outer surface (7)
between lateral sides defines a bottom (15); the bottom (15)
15 having at least one stretch with increasing radial height or
at least one stretch with increasing and subsequently constant
radial height along at least one first portion (26) of the
first stretch (20; 40).
- 20 2. The screw according to claim 1, wherein the first stretch
(20; 40) and the second stretch (21; 41) are adjacent.
3. The screw according to claim 1 or 2, wherein the first
stretch (20; 40) has a first angle of inclination (α_1),
25 preferably between approximately 5° and 65° .
4. The screw according to claim 3, wherein the second stretch
(21; 41) has a second angle of inclination (α_2) substantially
identical, in absolute value, to the first angle of
30 inclination (α_1) of the first stretch (20; 40).
5. The screw according to any of the preceding claims, wherein
the bottom (15) has at least one point at maximum radial
height ($H_{\min}$) along at least the first portion (26) of the
35 first stretch (20; 40).

6. The screw according to any one of the preceding claims, wherein the bottom (15) has a constant and/or decreasing radial height along at least one second portion (26) of the second stretch (21; 41).

5

7. The screw according to any one of the preceding claims, wherein the thread (12) comprises at least one further first stretch (40; 20) having a first helix winding direction and at least one further second stretch (41; 21) having a second
10 helix winding direction opposite the first direction.

8. The screw according to claim 7, wherein the further first stretch (40; 20) and the further second stretch (41; 21) are substantially identical respectively to the first stretch
15 (20; 40) and to the second stretch (21; 41).

9. The screw according to claim 7 or 8, wherein the further first stretch (40; 20) and the further second stretch are adjacent (41; 21).

20

10. The screw according to any one of the claims from 7 to 9, wherein the thread (12) comprises a separating portion (43) between the second stretch (21; 41) and the further first stretch (40; 20).

25

11. The screw according to claim 10, wherein the separating portion (43) of the thread (12) has the first winding direction.

30

12. Polymeric material extruder comprising a hollow extruding cylinder (2) which defines a housing seat (8) and at least one screw (3) housed in the housing seat (8) and having the features claimed in any one of the preceding claims.

35

13. Extruder according to claim 12, wherein the difference between the diameter of the housing seat (8) and

the outer diameter (D) of the screw (3) is comprised between approximately 1/1000 of the outer diameter (D) and 30/1000 of the outer diameter (D).

5 14. Extruder according to claim 12, comprising a further screw housed in the housing seat (8).

15. Use of the extruder according to any one of the claims from 12 to 14 to melt or mix polymeric materials.

FIG. 1

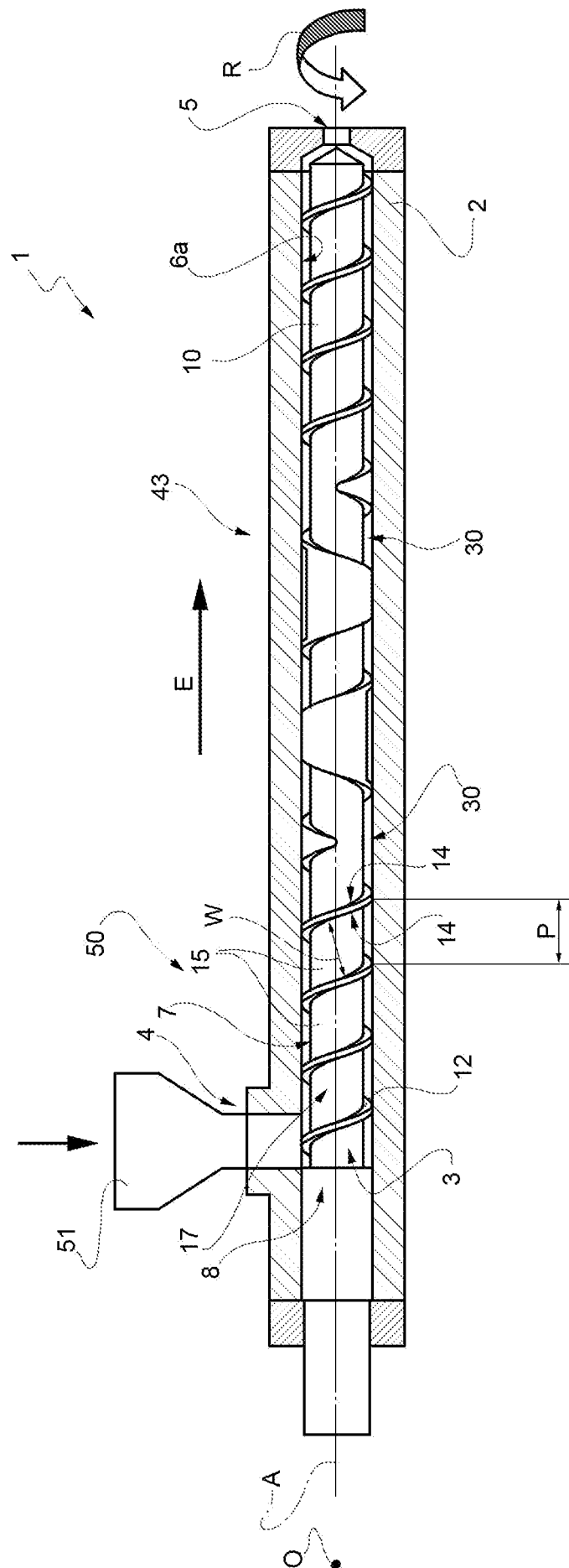


FIG. 2

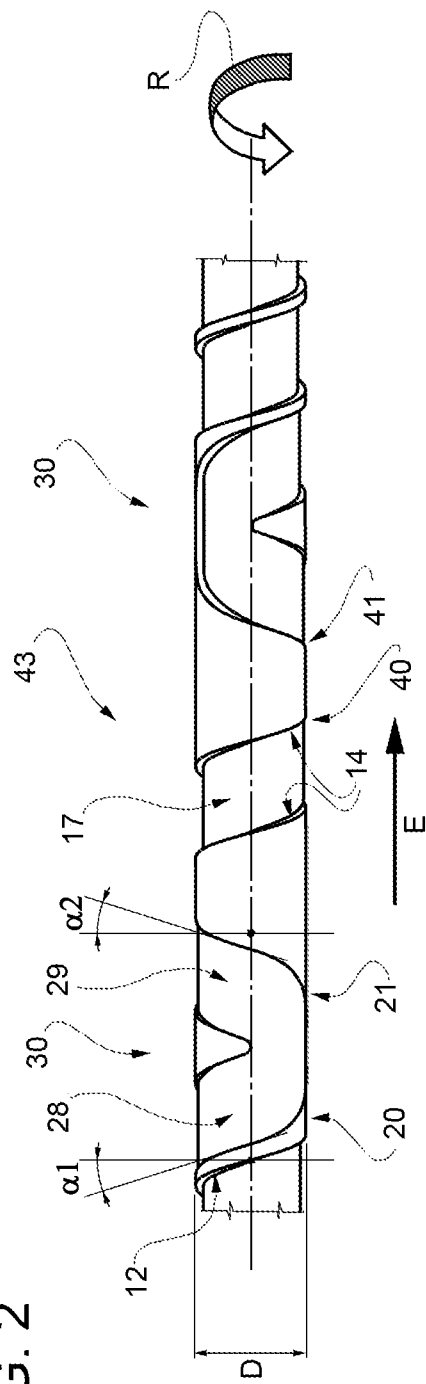


FIG. 3

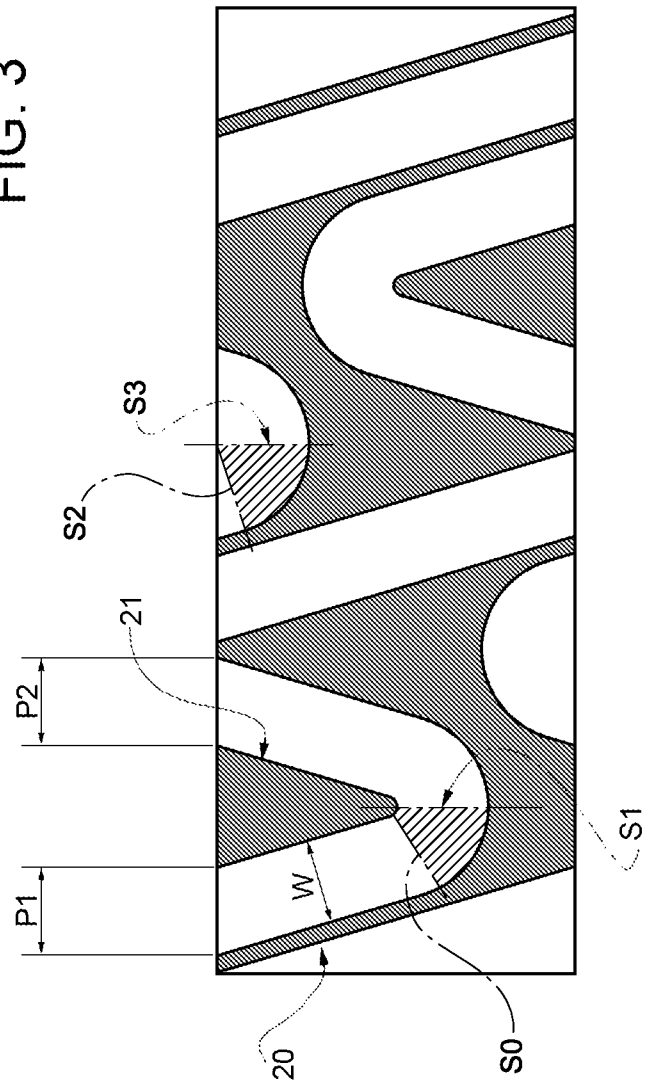


FIG. 4

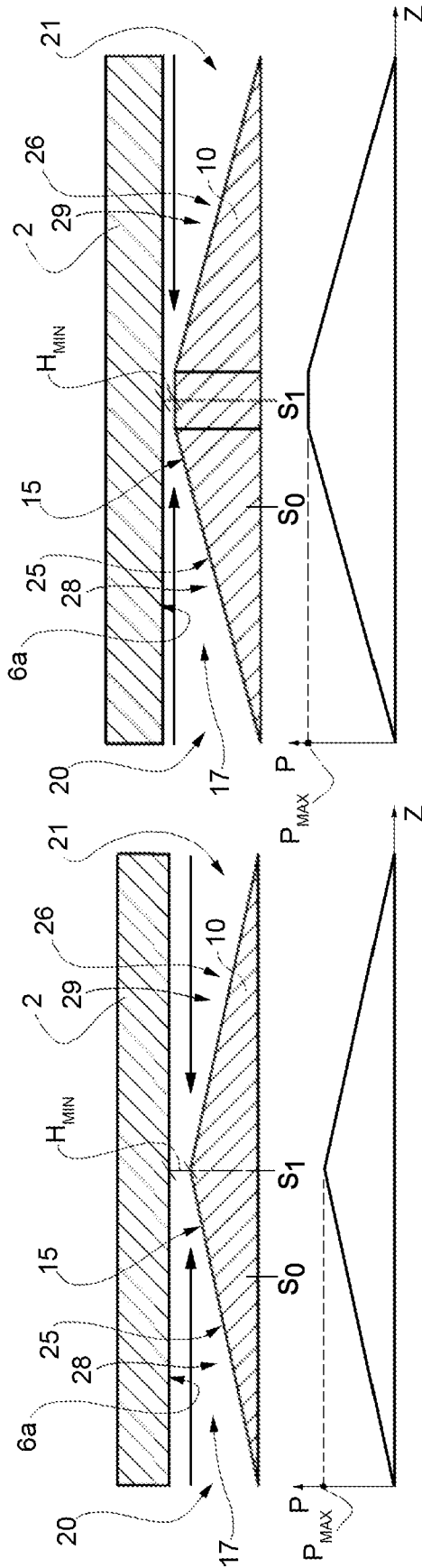


FIG. 5

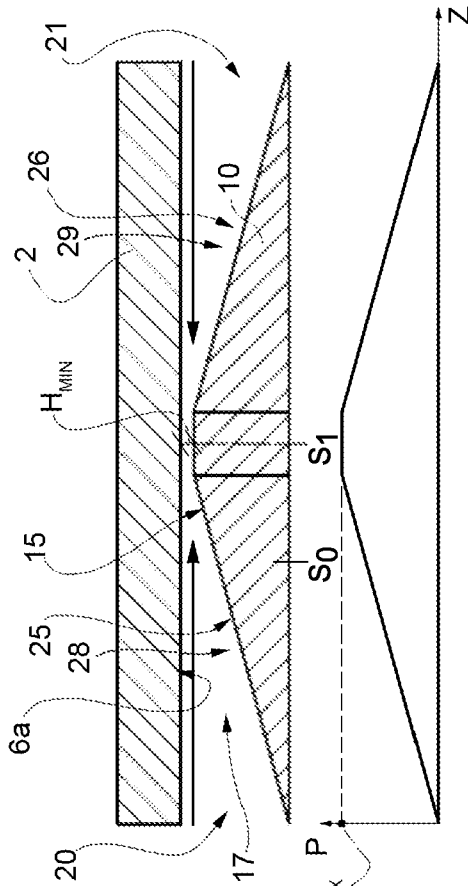


FIG. 6

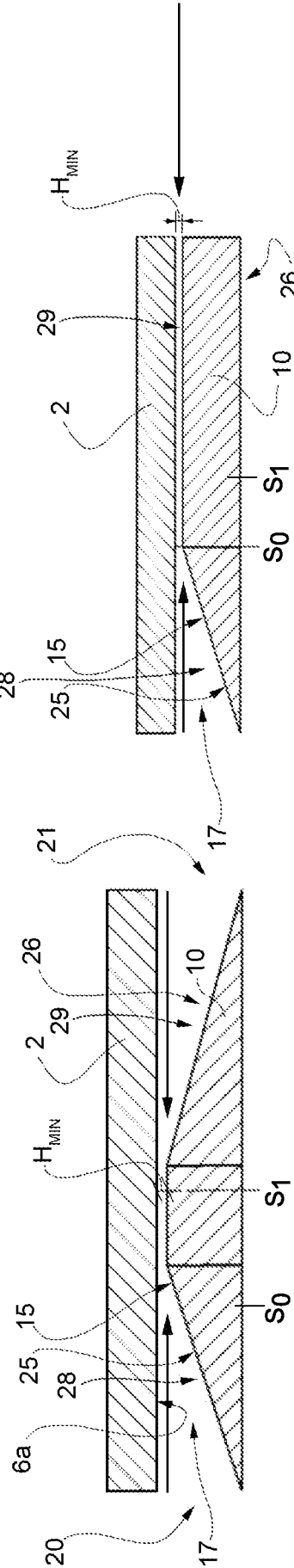


FIG. 7

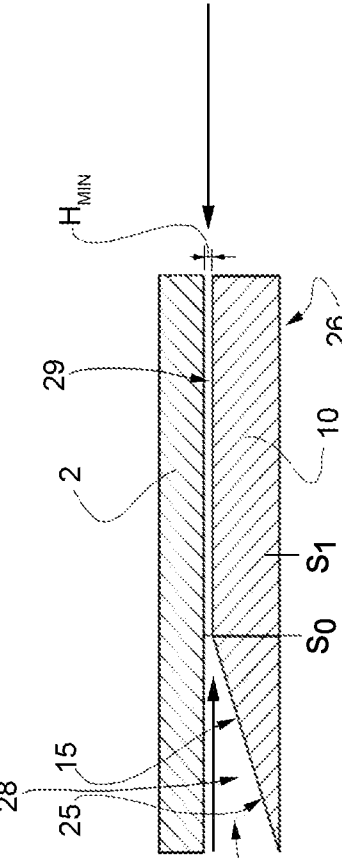
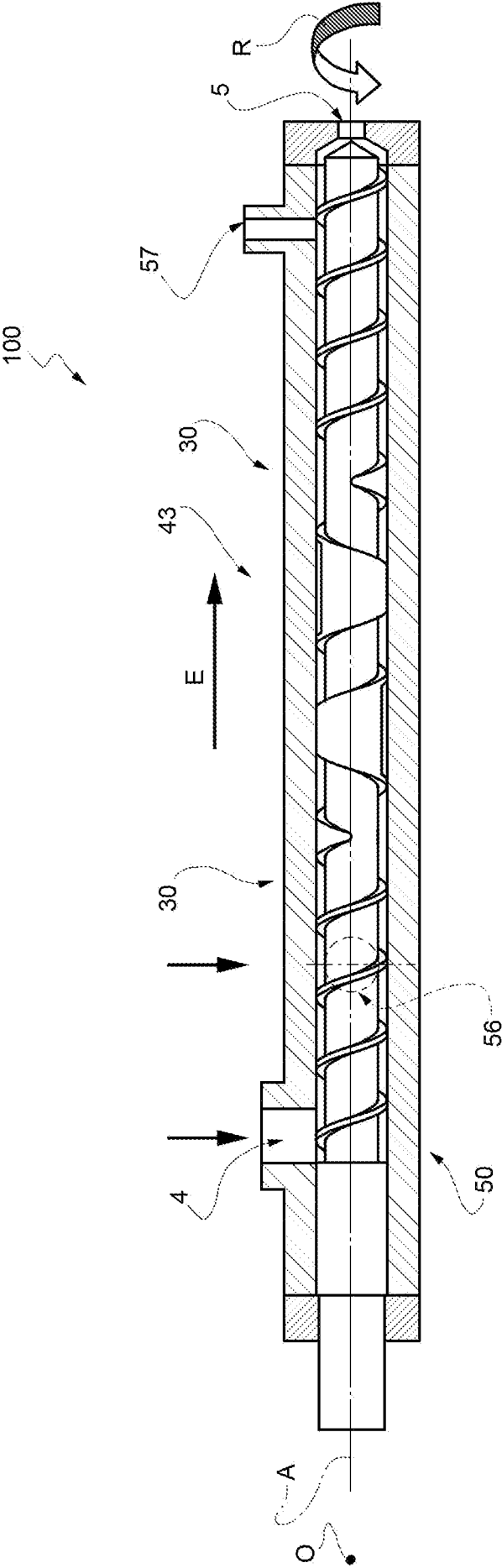


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/053248

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C47/60
ADD. B29B7/42

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29C B29B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CH 365 217 A (LONZA AG [CH]) 31 October 1962 (1962-10-31) page 1, line 49 - page 2, line 84 claims 1-5; figures 1-3 -----	1-15
A	US 4 246 224 A (LEHNEN J P [DE] ET AL) 20 January 1981 (1981-01-20) abstract; figure 1 -----	1-15
A	DE 10 2004 002159 A1 (FRAUNHOFER GES FORSCHUNG [DE]) 11 August 2005 (2005-08-11) abstract; figures 1,2 -----	1-15
X	US 5 419 634 A (BACHER H [AT] ET AL) 30 May 1995 (1995-05-30) column 4, line 25 - column 5, line 50 abstract; figure 1 ----- -/--	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

4 September 2017

Date of mailing of the international search report

13/09/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Brunold, Axel

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/053248

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2012 208647 A1 (LEHMANN T [DE]) 28 November 2013 (2013-11-28) abstract; figures 1,3 -----	1-15
A	CN 103 963 265 A (TIANJIN HANKE TECHNOLOGY CO LTD [CN]) 6 August 2014 (2014-08-06) figure 1 -----	1-15
A	CN 103 978 662 A (TIANJIN HANKE TECHNOLOGY CO LTD [CN]) 13 August 2014 (2014-08-13) figures 1,2 -----	1-15
X	AT 511 208 A4 (STARLINGER & CO GMBH [AT]) 15 October 2012 (2012-10-15) page 1, paragraph 1 page 5, paragraph 7 - page 8, paragraph 4 abstract; figures 1-4 -----	1-15
X	CN 103 481 492 A (HUANG MEICHANG [CN] ET AL) 1 January 2014 (2014-01-01) abstract; figures 1-3 -----	1-15
X	TW 396 105 B (BACHER H [AT] ET AL) 1 July 2000 (2000-07-01) figures 1-3 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2017/053248

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CH 365217	A	31-10-1962	NONE	

US 4246224	A	20-01-1981	CA 1110420 A	13-10-1981
			DE 2738308 A1	08-03-1979
			EP 0000872 A1	07-03-1979
			ES 472805 A1	16-03-1979
			IT 1106277 B	11-11-1985
			JP S5443988 A	06-04-1979
			US 4246224 A	20-01-1981

DE 102004002159	A1	11-08-2005	NONE	

US 5419634	A	30-05-1995	AT 134563 T	15-03-1996
			AU 664564 B2	23-11-1995
			BR 9206425 A	07-11-1995
			CA 2116659 A1	18-03-1993
			DE 59205518 D1	04-04-1996
			DK 0600924 T3	22-07-1996
			EP 0600924 A1	15-06-1994
			ES 2086760 T3	01-07-1996
			JP 2583823 B2	19-02-1997
			JP H06506413 A	21-07-1994
			TW 210975 B	11-08-1993
			US 5419634 A	30-05-1995
			WO 9304841 A1	18-03-1993
			ZA 9206169 B	03-03-1993

DE 102012208647	A1	28-11-2013	NONE	

CN 103963265	A	06-08-2014	NONE	

CN 103978662	A	13-08-2014	NONE	

AT 511208	A4	15-10-2012	AT 511208 A4	15-10-2012
			WO 2013013916 A1	31-01-2013

CN 103481492	A	01-01-2014	NONE	

TW 396105	B	01-07-2000	NONE	
