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(54) EXTRUSION METHOD AND APPARATUS

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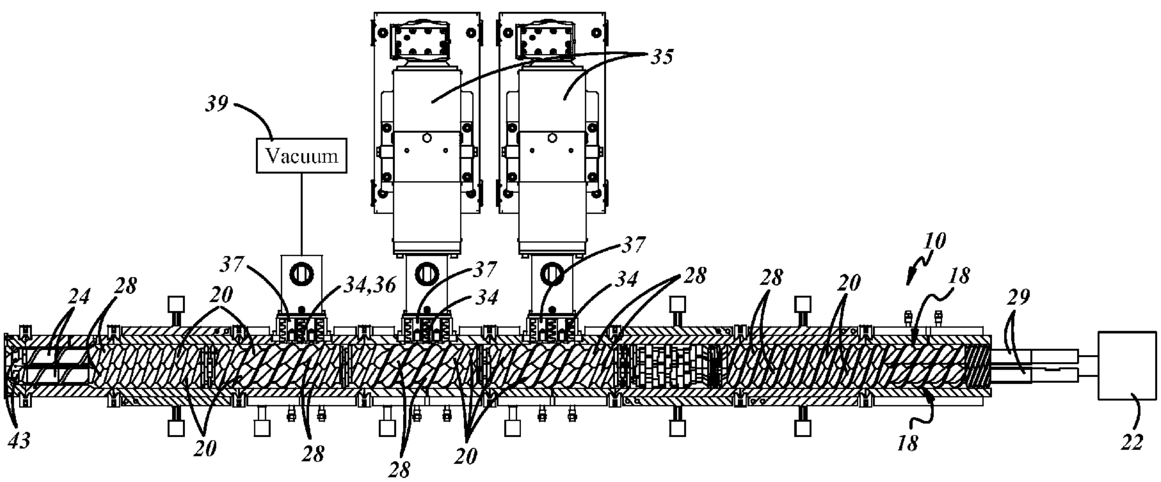
(57) ABSTRACT

An extrusion apparatus including a mixing chamber comprising two intersecting housing bores and an inlet positioned to receive material into the mixing chamber. Two screw shafts are supported for rotation about respective generally parallel axes and include respective screw sections positioned for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber. The apparatus supports screw shaft rotational speeds greater than approximately 800 rpm and includes screw shaft conveying portions that are rotatably cantilevered for self-journaled support within respective separate conveying chambers arranged generally parallel to one another downstream of the mixing chamber.



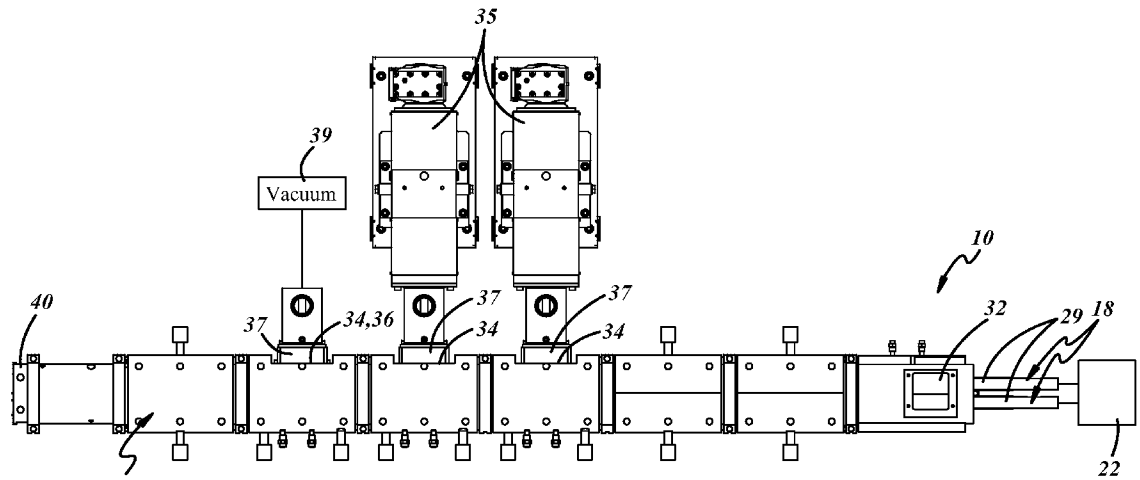



FIG. 1

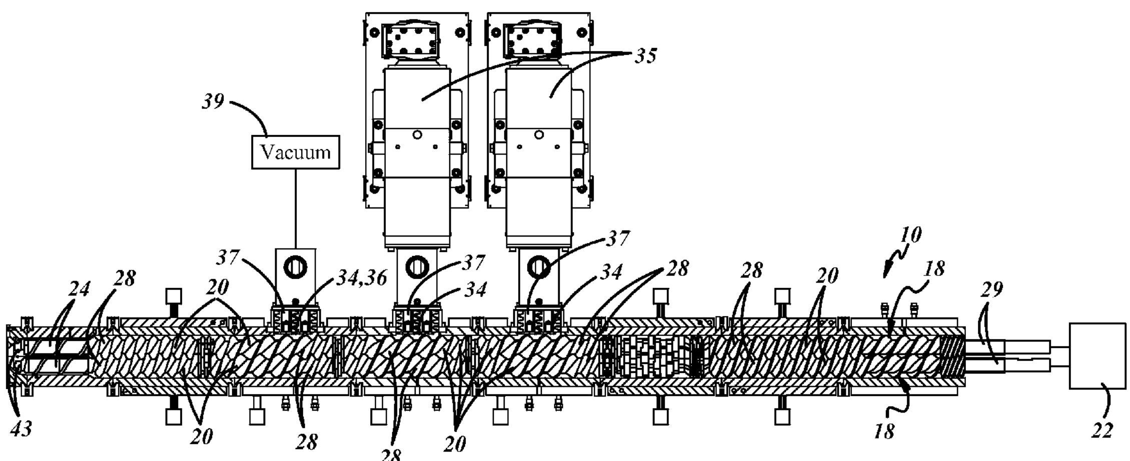

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FIG. 2

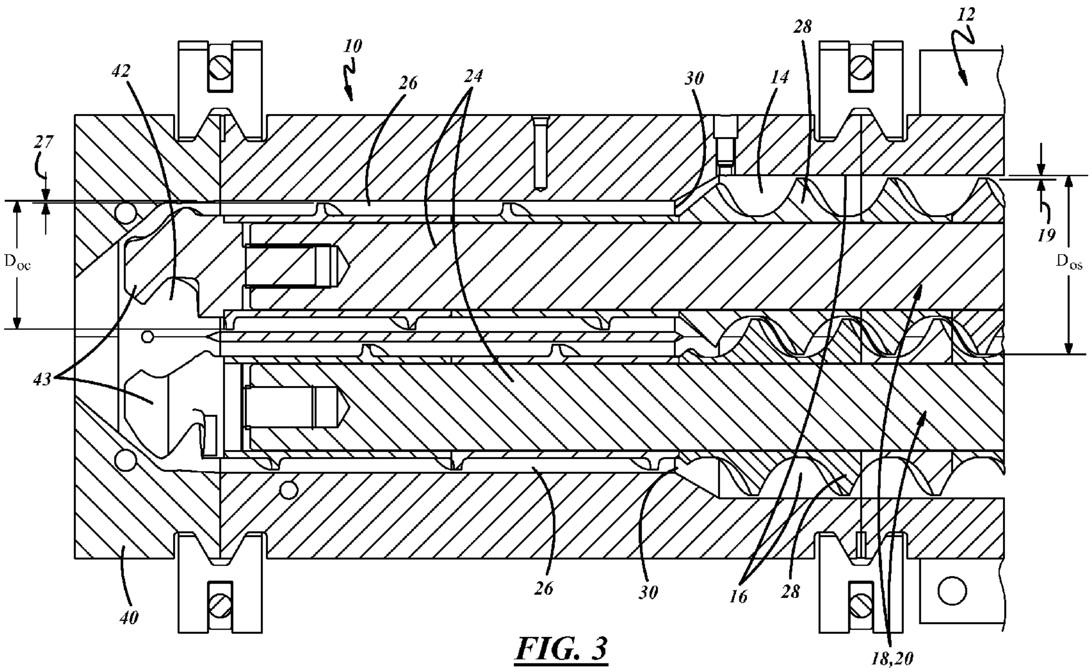


FIG. 3

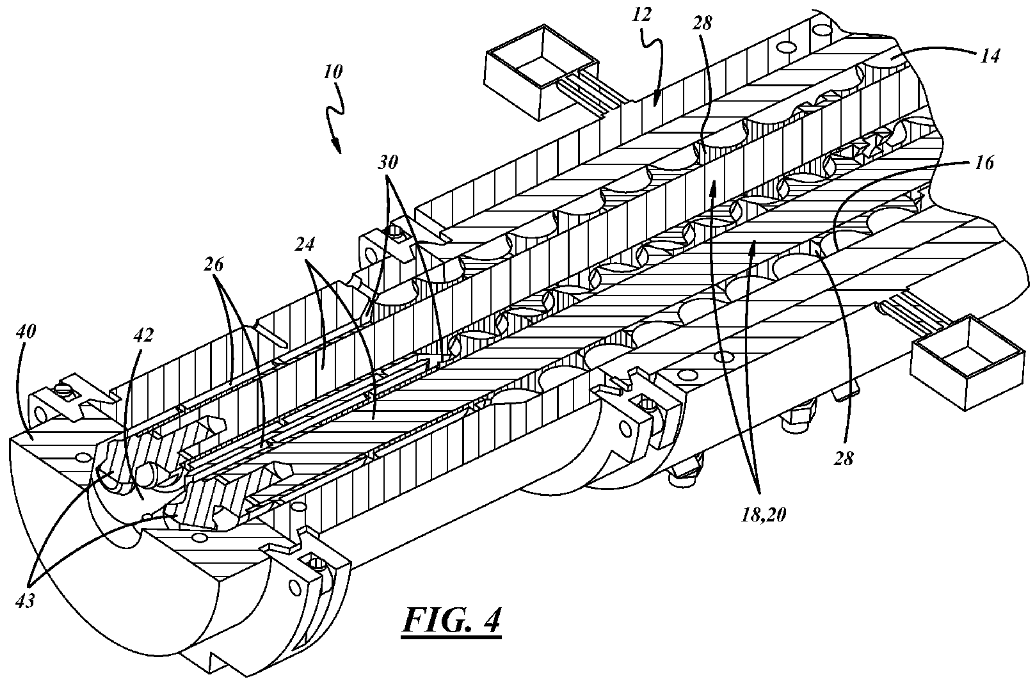


FIG. 4

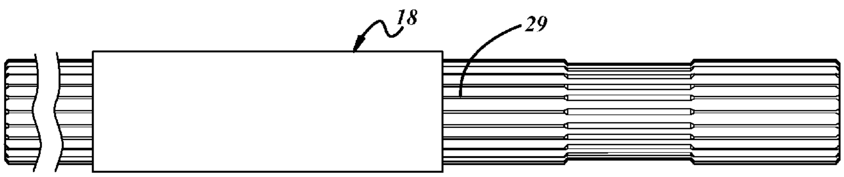


FIG. 5

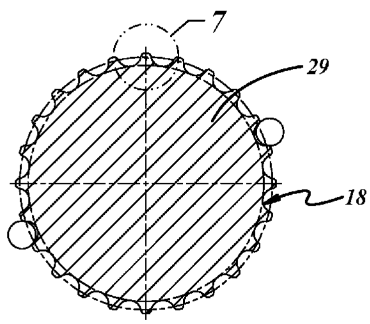


FIG. 6

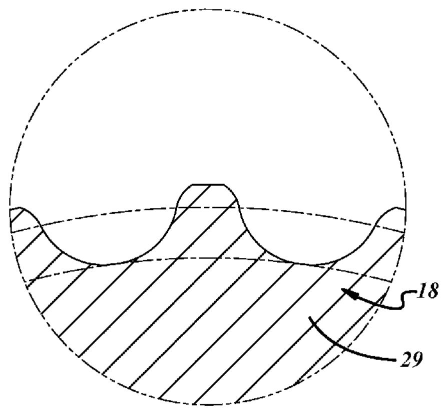


FIG. 7

# EXTRUSION METHOD AND APPARATUS

## BACKGROUND OF THE INVENTION

**[0001]** 1. Field of the Invention

**[0002]** This invention relates generally to a method and apparatus for forming an extrudate.

**[0003]** 2. Description of the Related Art Including Information Disclosed Under 37 CFR 1.97 and 1.98

**[0004]** It is known to form an extrudate using an extruder that includes a housing having a mixing chamber defined by a pair of parallel intersecting housing bores, and a pair of screw shafts supported for rotation about respective generally parallel axes and including respective screw sections positioned for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber. A drive mechanism is operably attached to the screw shafts and rotates the screw shafts in the same direction and in the same sense.

**[0005]** For example, U.S. Pat. No. 6,042,260 issued 28 Mar. 2000 to Heidemeyer et al., discloses an extruder that includes a pair of screw shafts supported for rotation in a housing and including respective screw sections positioned for co-wiping intermeshing rotation within respective housing bores of a mixing chamber in the housing, The screw sections each have an outside diameter to inside diameter (OD-ID) ratio of "greater than or equal to" 1.55. A drive mechanism rotates screw shafts are rotated in the same direction and in the same sense at rotational speeds of "at least" 800 rpm and at a torque density of "at least" 11 Nm/cm$^3$). To support the screw shaft for rotation, the screw sections of the screw shafts and the housing bores are sized to leave only a small screw-to-chamber wall clearance, i.e., a small gap between the screw sections of the screw shafts and the respective housing bores of the mixing chamber. However, such a small tolerance can result in significant shear heating in the vicinity of the screw sections—especially at shaft rotation speeds in excess of 800 rpm.

**[0006]** What would be desirable would be an extruder designed to reduce shear heating in the vicinity of the screw sections to acceptable levels, even at shaft rotation speeds in excess of 800 rpm.

## BRIEF SUMMARY OF THE DISCLOSURE

**[0007]** An extrusion apparatus is provided for forming an extrudate. The apparatus includes a mixing chamber comprising two parallel intersecting housing bores and two screw shafts supported for rotation about respective generally parallel axes and including respective screw sections positioned for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber. The apparatus is configured to support screw shaft rotational speeds greater than approximately 800 rpm. The screw shafts also include respective conveying portions rotatably cantilevered for self-journaled support within respective separate conveying chambers arranged generally parallel to one another downstream of the mixing chamber. This self-journaled support arrangement reduces shear heating in the vicinity of the screw sections by allowing for a larger screw-to-chamber wall clearance in the mixing chamber.

**[0008]** Also, a method is provided for forming an extrudate. According to this method one can form an extrudate by providing a housing including a mixing chamber comprising two parallel intersecting housing bores and including separate conveying chambers arranged generally parallel to one another downstream of the mixing chamber, supporting screw sections of two screw shafts for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber and conveying portions of the screw shafts for rotation within the separate conveying chambers of the housing, feeding material into the mixing chamber, mixing the material within the mixing chamber and conveying the mixture downstream through the mixing chamber and along the respective conveying chambers by rotating the screw shafts in the same sense at a rotational speed in the range of 800 to 1800 rpm.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

**[0009]** These and other features and advantages will become apparent to those skilled in the art in connection with the following detailed description and drawings of one or more embodiments of the invention, in which:

**[0010]** FIG. **1** is a top view of a twin-screw extruder constructed according to the invention and with two side feeders and a de-gassing port connected and in communication with a mixing chamber of the extruder;

**[0011]** FIG. **2** is a partial cross-sectional view of the twin-screw extruder of FIG. **1**;

**[0012]** FIG. **3** is a cross-sectional top view of one end of the twin-screw extruder of FIGS. **1** and **2** showing a downstream conveying section and profile die connected to a downstream end of a mixing chamber section of the extruder;

**[0013]** FIG. **4** is a cross-sectional perspective view of the twin-screw extruder of FIGS. **1** and **2**, again showing the downstream conveying section and profile die connected to the downstream end of the mixing chamber;

**[0014]** FIG. **5** is a top view of a sinusoidally splined engagement section of one of two screw shafts of the twin-screw extruder of FIGS. **1** and **2**;

**[0015]** FIG. **6** is a cross-sectional end view of the engagement section of FIG. **5**; and

**[0016]** FIG. **7** is a magnified view of a portion of the screw shaft engagement section shown in circle **7** of FIG. **6**.

## DETAILED DESCRIPTION OF INVENTION EMBODIMENT(S)

**[0017]** An apparatus for forming an extrudate is generally shown at **10** in the drawings. The apparatus **10** may include a housing **12** including a mixing chamber **14** comprising two parallel generally cylindrical intersecting housing bores **16**. Two screw shafts **18** are supported for rotation about respective generally parallel axes and include respective screw sections **20** positioned for co-wiping intermeshing rotation within the respective housing bores **16** of the mixing chamber **14**. A drive mechanism **22** is operably attached to the screw shafts **18** and is actuable to rotate the screw shafts **18** in the same direction and in the same sense at rotational speeds in the range of approximately 100 to 1800 rpm. The drive mechanism **22** may be of any suitable model and may be obtained from any one of a number of different manufacturers including Flender Antriebstechnik, Eisenbeiss GmbH, Zambello Riduttori, P.I.V., and Thyssen Henschel Power Transmission.

**[0018]** Operating in the high end of this rotational speed range can lead to significant shear heating in the vicinity of the screw sections **20** to the potential detriment of extrudate that the apparatus **10** is producing. Therefore, to reduce shear heating by allowing for greater clearance between the screw shaft screw sections **20** and the housing bores **16**, while at the same time supporting screw shaft rotational speeds greater than approximately 800 rpm, the screw shafts **18** include respective conveying portions **24** rotatably cantilevered for self-journaled support within respective separate tubular conveying chambers **26** that are arranged generally parallel to one another downstream of the mixing chamber **14**. This cantilevered self-journaled support also minimizes shaft sag and, consequently, internal wear and tear associated with shaft sag. The basic structure of twin screw extruders having downstream conveying chambers and screw shaft conveying portions is disclosed in U.S. Pat. Nos. 3,195,868; 4,752,135; and 5,439,286; and PCT International Patent Application No. PCT/US2006/035855; all of which are incorporated herein by reference in their entirety.

**[0019]** The apparatus **10** can support rotation of the screw shafts **18** at rotational speeds in the range of approximately 200 to 1800 rpm. To accomplish this, the housing bores **16** and the screw sections **20** of the screw shafts **18** may be sized to have a mixing chamber screw-to-chamber wall clearance **19** in the range of approximately $D_{os}/64$ to $D_{os}/128$, where $D_{os}$=an outside diameter of the screw sections **20** as best shown in FIG. **3**. The cantilevered self-journaled support of the conveying portions **24** of the screw shafts **18** within their respective separate conveying chambers **26** accommodates this range of mixing chamber screw-to-chamber wall clearances **19**. $D_{os}/64$ has been determined, both through theoretical modeling and practical experience, to be the maximum allowable screw-to-chamber wall clearance that a compounding twin-screw extruder of this type can have at high rpm without encountering an unacceptably high shear rate that would be potentially detrimental to extrudate being produced.

**[0020]** To provide sufficient cantilevered self-journaled support of the screw shafts **18**, the conveying chambers **26** and the conveying portions **24** of the screw shafts **18** may be sized to have a conveying section screw-to-chamber wall clearance **27** of less than $D_{oc}/128$, where $D_{oc}$=an outside diameter of the conveying portions **24** of the screw shafts **18** as shown in FIG. **3**. In other embodiments the screw-to-chamber wall clearance in each of the conveying chambers **26** may be in the range of approximately $D_{oc}/128$ to $D_{oc}/150$. Because the conveying section screw-to-chamber wall clearance **27** is less than the mixing chamber screw-to-chamber wall clearance **19**, leakage flow losses between screw crests and chamber walls are reduced. The conveying portions **24** of the screw shafts **18** may be configured for pumping and not for melting so as to provide greater flow rate at higher RPM without the significant viscous dissipation effects.

**[0021]** To allow for the intermeshing of the screw sections **20** of the screw shafts **18** within intersecting housing bores **16** while, at the same time, allowing for the conveying portions **24** of the screw shafts **18** to be received in separate conveying chambers **26**, each screw shaft conveying portion **24** has an outer diameter smaller than an outer diameter of the screw section **20** of each screw shaft **18**. The conveying portions **24** of the screw shafts **18** include helical screw flights **28** shaped to convey mixed material axially downstream from the screw shaft screw sections **20** toward a mixing chamber outlet **30** disposed axially downstream from the conveying portions **24** of the screw shafts **18**.

**[0022]** In the present embodiment, the screw shaft screw sections **20** have a shaft center distance to screw diameter ratio of 0.775. Also, each screw shaft screw section **20** may have an outside diameter to inside diameter (OD-ID) ratio of approximately 1.78. However, in other embodiments, each screw shaft screw section **20** may have an OD-ID ratio anywhere in the range of approximately 1.4-1.8. In other embodiments, the point at which the OD-ID ratio falls within this range depends on the available torque density that a gearbox of the drive mechanism **22** provides as well as the configuration of the screw sections **20** of the screw shafts **18**. Variations in the OD/ID ratio for a given screw configuration alter screw shaft and gearbox power available for mixing. In general, a lower ratio, e.g., of 1.55, is associated with a larger diameter drive shaft and generally greater available power for mixing, but lower free volume inside the mixing chamber **14**. In general, a higher OD/ID ratio is associated with a slimmer drive shaft and less power capability, but higher free volume. In contrast, the conveying portions **24** of the screw shafts **18** may have an OD-ID ratio of 1.3.

**[0023]** The drive mechanism **22** and the screw shaft screw sections **20** of the present embodiment may operate at a torque density in excess of 11 $Nm/cm^3$. Depending on the application, the screw shaft screw sections **20** may be shaped and the drive mechanism **22** selected and/or set to develop, withstand, and operate at a torque density in the range of approximately 8.7 to 13.6 $Nm/cm^3$. As shown in FIGS. **5** and **6** the torque-carrying capability of the screw shafts **18** may be enhanced by including sinusoidally splined engagement sections **29** at the ends of the screw shafts **18** that engage the drive mechanism **22**. The sinusoidally splined engagement sections **29** may include a radially outwardly extending spline array that engages a complementary radially inwardly extending spline array of the drive mechanism **22**.

**[0024]** The torque delivery capability of the drive mechanism **22** is limited primarily the useful life of gearbox bearings of the drive mechanism **22**. Operating at a torque density of approximately 8.7 $Nm/cm^3$ the gearbox bearings can be expected to last for approximately 40,000 hours. Operating at approximately 13.6 $Nm/cm^3$ of operation the bearings can be expected to last approximately 20,000 hours. In other embodiments drive mechanisms **22** and screw shaft screw sections **20** may be provided that develop and operate at any suitable torque density over a desired operating life.

**[0025]** What constitutes a suitable torque density is related to the OD/ID ratio of the screw shaft screw sections **20**. For shallow channel depth, e.g., OD/ID=1.5, a sufficient torque density will be approximately 11 $Nm/cm^3$. For deeper channel depth, e.g., OD/ID=1.8, a sufficient torque density will be approximately 8.7 $Nm/cm^3$. Accordingly, in embodiments having OD/ID ratios in the range of approximately 1.5 to 1.8, the torque density will generally be in the range of approximately 8-11 $Nm/cm^3$. Further information on this subject is available in a paper entitled "Deeper Screw Flights 28 Offer New Opportunities for Co-rotating Twin Screw Extruders" by Klaus Kapfer and Erwin Häring, Published in SPE Conference Proceedings, ANTEC 2002, San Francisco, Calif., and is incorporated herein by reference.

**[0026]** As shown in FIG. **1** the apparatus **10** includes a first or upstream inlet **32** that receives material into the mixing chamber **14** and may include additional downstream inlets **34** positioned to receive material into the mixing chamber **14** downstream from the upstream inlet **32** from side feeders **35** or, alternatively, to serve as degassing ports **36**. Each degassing port **36** may comprise a stuffing device **37** with degassing of the material in the mixing chamber **14** being accomplished by applying a staged incremental vacuum **39** to the stuffing device **37**.

**[0027]** The apparatus **10** may further comprise a profile die **40** supported downstream from the conveying portions **24** of the screw shafts **18**. The profile die **40** may be arranged to receive mixed material discharged from the conveying chambers **26** and to form an extrudate of a desired cross-sectional shape. In other embodiments, a pelletizer may be positioned downstream from the conveying portions **24** of the screw shafts **18** in place of a profile die **40**.

**[0028]** The apparatus **10** may further comprise a common discharge cavity **42** disposed downstream from the conveying chambers **26**, in advance of the profile die **40**, and in fluid communication with the conveying chambers **26**. Two screw tips **43** may be disposed within the common discharge cavity **42** and supported on respective downstream ends of the screw shafts **18** for coaxial rotation with the respective screw shafts **18**.

**[0029]** In practice, an extrudate may be formed at high screw rpm and without excessive shear heating by first fabricating a twin-screw extruder apparatus **10** that, as described above, includes a housing **12** comprising both a mixing chamber **14** comprising two parallel generally cylindrical intersecting housing bores **16**, and separate conveying chambers **26** arranged generally parallel to one another downstream of the mixing chamber **14**. The conveying chambers **26** and the conveying portions **24** of the screw shafts **18** may be formed to leave a conveying section screw-to-chamber wall clearance **27** in the range of approximately $D_{oc}/128$ to $D_{oc}/150$ between respective inner walls of the conveying chambers **26** and the conveying portions **24** of the screw shafts **18**. The screw sections **20** of the two screw shafts **18** are then supported for co-wiping intermeshing rotation within the respective housing bores **16** of the mixing chamber **14** while the conveying portions **24** of the screw shafts **18** are supported for rotation within the separate conveying chambers **26** of the housing **12**. The housing bores **16** and the screw sections **20** of the screw shafts **18** may be formed to leave a mixing chamber screw-to-chamber wall clearance **19** in the range of approximately $D_{oc}/64$-$D_{oc}/128$ between the inner wall of the mixing chamber **14** and the screw sections **20** of the screw shafts **18**. The screw sections **20** of the screw shafts **18** may be formed to have respective outside diameter to inside diameter (OD-ID) ratios in the range of approximately 1.4-1.8. The drive mechanism **22** may then be operably attached to the screw shafts **18**.

**[0030]** Material to be extruded may then be fed into the mixing chamber **14** and the drive mechanism **22** actuated to mixing or agitating the material by rotating the screw shafts **18** in the same direction and in the same sense at rotational speeds in the range of approximately 200 to 1800 rpm, depending on the composition of the material to be extruded. Where the material includes polymeric material fed into the mixing chamber **14** through an upstream inlet **32** and organic material fed into the mixing chamber **14** through a downstream inlet **34** disposed downstream from the upstream inlet **32**, the drive mechanism **22** is actuated to rotate the screw shafts **18** in the same direction and in the same sense at rotational speeds in the range of 600 to 1500 rpm, which has been found to be an acceptable speed range for polymer compounding, while developing a torque density in the range of approximately 8-11 $Nm/cm^3$. The polymeric material may be heated to a molten state before reaching the downstream inlet **34** and before minor components are mixed into it through the downstream inlet **34** as is described in PCT/US2006/035855, which is incorporated herein by reference.

**[0031]** Polymeric materials fed into the mixing chamber **14** may include thermoplastic resins such as high-density polyethylene, low-density polyethylene, linear low-density polyethylene, polyvinyl chloride, and/or polypropylene. Organic materials fed into the mixing chamber **14** may include wood flour, wood pellets, wood fibers, wastepaper, kenaf, flax, rice hulls, jute, sisal, coconut, and/or hemp. Inorganic materials such as glass fibers, carbon fibers, modifiers and fillers such as calcium carbonate, talc, wollastonite, carbon black, and other additives such as antioxidants, UV stabilizers, colorants, impact modifiers, and lubricants, may also be fed into the mixing chamber **14**.

**[0032]** The material continues to be mixed or agitated within the mixing chamber **14** as it is conveyed further downstream through the mixing chamber **14** and along the respective conveying chambers **26** by the rotation of the screw shafts **18**. As it is being conveyed further downstream through the mixing chamber **14** the material may be degassed or devolatilized through one ore more degassing vents downstream from the downstream inlet **34**. The material may then be conveyed and merged into the discharge cavity **42** provided additional mixing and propulsion by the rotation of the screw tips **43** within the discharge cavity **42**. The mixture may then be discharged axially from the discharge cavity **42** through one or more dies **40**, such as may be provided as disclosed in U.S. Pat. No. 5,516,472, which is incorporated herein by reference. The material or mixture may, alternatively, be axially discharged from the discharge cavity **42** through a pelletizer.

**[0033]** Through self-journaled support, a twin-screw extruder may thus be constructed in such a way as to reduce shear heating in the vicinity of the screw shaft screw sections **20** by allowing for a larger mixing chamber screw-to-chamber wall clearance **19** in the mixing chamber **14**.

**[0034]** This description, rather than describing limitations of an invention, only illustrates (an) embodiment(s) of the invention recited in the claims. The language of this description is therefore exclusively descriptive and is non-limiting. Obviously, it's possible to modify this invention from what the description teaches. Within the scope of the claims, one may practice the invention other than as described above.

What is claimed is:

**1**. An extrusion apparatus for forming an extrudate, the apparatus comprising:

a mixing chamber comprising two parallel intersecting housing bores;

two screw shafts supported for rotation about respective generally parallel axes and including:

respective screw sections positioned for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber; and

respective conveying portions rotatably cantilevered for self-journaled support within respective separate conveying chambers arranged generally parallel to one another downstream of the mixing chamber;

the apparatus being configured to support screw shaft rotational speeds greater than approximately 800 rpm.

**2**. An extrusion apparatus as defined in claim **1** in which:

the apparatus is configured to support rotation of the screw shafts at rotational speeds in the range of approximately 100 to 1800 rpm; and

the housing bores and the screw sections of the screw shafts are sized to have a screw-to-chamber wall clearance in the range of approximately $D_{os}/64$-$D_{os}/128$, where $D_{os}$=an outside diameter of the screw sections.

**3**. An extrusion apparatus as defined in claim **2** in which the conveying chambers and the conveying portions of the screw shafts are sized to have a screw-to-chamber wall clearance in the conveying chambers is less than $D_{oc}/128$, where $D_{oc}$=an outside diameter of the conveying portions of the screw shafts.

**4**. An extrusion apparatus as defined in claim **2** in which the screw-to-chamber wall clearance in each of the conveying chambers is in the range of approximately $D_{oc}/128$ to $D_{oc}/150$.

**5**. An extrusion apparatus as defined in claim **1** in which the screw sections of the screw shafts each have an outside diameter to inside diameter (OD-ID) ratio greater than 1.5.

6. An extrusion apparatus as defined in claim 5 in which screw sections of the screw shafts each have an outside diameter to inside diameter (OD-ID) ratio in the range of approximately 1.4-1.8.

7. An extrusion apparatus as defined in claim 6 in which the screw sections of the screw shafts each have an outside diameter to inside diameter ratio of approximately 1.78.

8. An extrusion apparatus as defined in claim 6 in which the screw sections of the screw shafts are configured to develop a torque density in excess of approximately 11 $Nm/cm^3$.

9. An extrusion apparatus as defined in claim 8 in which the screw sections of the screw shafts are configured to develop a torque density in the range of approximately 8.7-13.6 $Nm/cm^3$.

10. An extrusion apparatus as defined in claim 9 in which the screw shafts include engagement sections having sinusoidal spline configurations configured to engage complementary receptacles of a drive mechanism.

11. An extrusion apparatus as defined in claim 1 and further including:

a first inlet configured and positioned to receive material into the mixing chamber; and

a second inlet positioned to receive material into the mixing chamber downstream from the first inlet.

12. An extrusion apparatus as defined in claim 11 and further including a degassing port disposed downstream from the second inlet.

13. An extrusion apparatus as defined in claim 1 and further including a common discharge cavity disposed downstream from the conveying chambers, the discharge cavity being in fluid communication with the conveying chambers.

14. An extrusion apparatus as defined in claim 1 and further comprising two screw tips carried by the respective screw shafts for coaxial rotation with the respective screw shafts, the screw tips being disposed within a common discharge cavity

15. A method for rapid formation of an extrudate, the method including the steps of:

providing a housing including a mixing chamber comprising two parallel intersecting housing bores and including separate conveying chambers arranged generally parallel to one another downstream of the mixing chamber;

supporting screw sections of two screw shafts for co-wiping intermeshing rotation within the respective housing bores of the mixing chamber and conveying portions of the screw shafts for rotation within the separate conveying chambers of the housing;

feeding material into the mixing chamber; and

mixing the material within the mixing chamber and conveying the mixture downstream through the mixing chamber and along the respective conveying chambers by rotating the screw shafts in the same sense at a rotational speed in the range of 800 to 1800 rpm.

16. The method of claim 15 in which:

the step of providing a housing includes providing a discharge cavity downstream from and in fluid communication with the conveying chambers;

the step of supporting screw sections includes supporting screw tips on the respective screw shafts within the discharge cavity for coaxial rotation with the respective screw shafts; and

including the additional steps of:

conveying and merging the mixture into the discharge cavities from the mixing chamber; and

providing additional mixing and propulsion to the mixture through rotation of screw tips within the discharge cavity.

17. The method of claim 15 in which the steps of providing a housing and supporting screw sections include forming the conveying chambers and conveying portions of the screw shafts to leave a screw-to-chamber wall clearance in the range of approximately $D_{oc}/128$ to $D_{oc}/150$ between respective inner walls of the conveying chambers and the conveying portions of the screw shafts where $D_{oc}$=an outside diameter of the conveying portions of the screw shafts.

18. The method of claim 15 in which the steps of providing a housing and supporting screw sections include forming the housing bores and the screw sections of the screw shafts to leave a screw-to-chamber wall clearance in the range of approximately $D_{os}/64$-$D_{os}/128$ between an inner wall of the mixing chamber and screw sections of the screw shafts where $D_{os}$=an outside diameter of each of the screw sections.

19. The method of claim 15 in which the step of supporting screw sections within the separate conveying chambers of the housing includes providing screw sections that each have an outside diameter to inside diameter (OD-ID) ratio in the range of approximately 1.4-1.8.

20. The method of claim 15 in which the step of feeding material into the mixing chamber includes:

feeding polymeric material into the mixing chamber through an upstream inlet of the mixing apparatus; and

feeding organic material into the mixing chamber through a downstream inlet of the mixing apparatus disposed downstream from the upstream inlet;

and in which the step of mixing the material includes rotating the screw shafts at rotational speeds in the range of 600-1500 rpm.

21. The method of claim 20 including the additional step of heating the polymeric material to a molten state before mixing it with the organic material.

22. The method of claim 20 in which the step of feeding polymeric material includes feeding one or more of the thermoplastic resins selected from the group of thermoplastic resins consisting of high density polyethylene, low density polyethylene, linear low density polyethylene, polyvinyl chloride, and polypropylene.

23. The method of claim 20 in which the step of feeding organic material includes feeding one or more organic materials selected from the group consisting of wood flour, wood pellets, wood fibers, wastepaper, kenaf, flax, rice hulls, jute, sisal, coconut, and hemp.

24. The method of claim 15 in which the step of mixing the material and conveying the mixture downstream through the mixing chamber and along the respective conveying chambers includes developing a torque density in the range of approximately 8-11 $NM/cm^3$.

* * * * *