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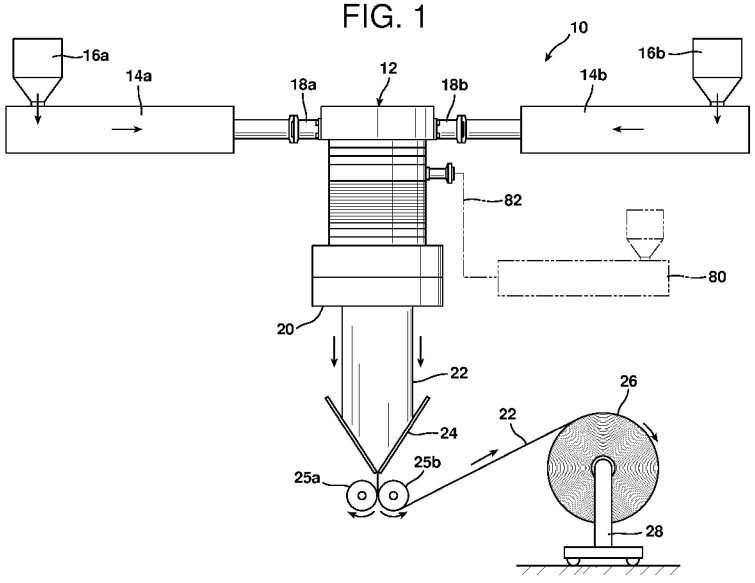
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(54) **Title**: DIES FOR COEXTRUDING A PLURALITY OF FLUID LAYERS

FIG. 1



(57) **Abstract**: A die (12, 12', 112) for coextruding a plurality of fluid layers includes one or more distribution plates (32, 132), for forming relatively thick layers, and a microlayer assembly (34, 134) for forming a plurality of microlayers. The die (12, 12', 112) includes internal fluid passages (42, 62, 142, 162) and/or forming surfaces (172) to allow the microlayers to assemble into a microlayered fluid mass prior to merging with the relatively thick layers from the distribution plates (32, 132).

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DIES FOR COEXTRUDING A PLURALITY OF FLUID LAYERS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-Part of U.S. Patent Application Ser. No. 12/284,510, filed September 23, 2008, the entire disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to a coextrusion die and, more particularly, to a coextrusion die containing both a microlayer assembly and one or more distribution plates to produce coextruded films having both microlayers and thicker, conventional film layers.

Coextrusion is a technique for producing a multilayer plastic (polymeric) film by bringing two or more molten polymers together in a die, in which the polymers are formed into a generally tubular or planar shape, juxtaposed in layered form, and then pushed out of an annular- or slot-shaped opening in the die. Once outside of the die, the still-molten multilayer film is exposed to an environment having a temperature that is maintained below the melting point of the component polymeric layers of the film, which causes the layers to melt-bond together as they cool and solidify.

Multilayer films typically have a thickness in the range of 50 – 200 mils upon emergence from the die, but the films are generally stretched prior to final solidification in order to expand their surface area and reduce their final thickness to a range of about 0.5 to about 50 mils. Conventional multilayer films generally have 3 – 10 layers; prior to stretching and thinning, i.e., while still in the die, each such layer generally ranges from about 20 – 100 mils in thickness.

Microlayer extrusion is a technique for increasing the total number of layers in a multilayer film for a given film thickness, by reducing the thickness of the component layers of the film. Thus, while conventional film layers generally range from 20 – 100 mils inside the die (i.e., prior to stretching and

thinning), microlayers generally have an 'in-die' thickness ranging from about 1-20 mils. In this manner, microlayered films may have far more than 10 layers, e.g., 20, 30, 40, 50, or more layers. Such microlayered films have been found to provide certain beneficial properties relative to conventional films composed of thicker layers that are fewer in number, e.g., improved mechanical properties such as superior flex cracking and puncture resistance.

For many applications, it is desirable to combine thicker, conventional layers with microlayers. Such thicker layers are often superior to microlayers for functions such as heat-sealing and abuse-resistance.

Unfortunately, it has proven to be difficult to combine the flow of thin layers, such as microlayers, with relatively thick layers in such a way that the physical integrity and independent properties of the thin layers are maintained. This is primarily the result of interfacial flow instabilities, which are encountered when microlayers are merged together with thicker layers in a die. Such interfacial flow instabilities are caused by the more powerful sheer forces of the thicker layers flowing against the microlayers, which result from the higher mass flow rate of the thicker layers relative to the microlayers. The resultant loss of the integrity and independent characteristics of the microlayers diminishes or even eradicates the beneficial properties thereof.

Accordingly, there is a need in the art for an improved die that permits microlayers to be combined with conventional, thicker layers in such a way that the integrity and independent properties of the microlayers are maintained.

SUMMARY OF THE INVENTION

That need is met by the present invention, which, in one aspect, provides a die for coextruding a plurality of fluid layers, comprising:

a. a primary fluid passage;

b. one or more distribution plates, each of the plates having a fluid inlet and a fluid outlet, the fluid outlet from each of the plates being in fluid communication with the primary fluid passage and structured to deliver a layer of fluid to the primary fluid passage; and

c. a microlayer assembly, comprising

(1) a microlayer fluid passage, and

(2) a plurality of microlayer distribution plates, each of the microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of the microlayer plates being in fluid communication with the microlayer fluid passage and structured to deliver a microlayer of fluid to the microlayer fluid passage, the microlayer plates being arranged to provide a predetermined order in which the microlayers are delivered to the microlayer fluid passage to form a substantially unified, microlayered fluid mass in the microlayer fluid passage,

wherein, the microlayer fluid passage is in fluid communication with the primary fluid passage such that the microlayered fluid mass flows from the microlayer fluid passage and into the primary fluid passage.

Another aspect of the invention pertains to a die for coextruding a plurality of fluid layers, comprising:

a. an annular forming stem having an inner surface and an outer surface;

b. one or more distribution plates, each of the plates having a fluid inlet and a fluid outlet, the fluid outlet from at least one of the plates being in fluid communication with, and structured to deposit a layer of fluid onto, the outer surface of the forming stem; and

c. a microlayer assembly, comprising a plurality of microlayer distribution plates, each of the microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of the microlayer plates being in fluid communication with, and structured to deposit a microlayer of fluid onto, the inner surface of the forming stem, the microlayer plates being arranged to provide a predetermined order in which the microlayers are deposited onto the inner surface in order to form a substantially unified, microlayered fluid mass thereon,

wherein, the inner and outer surfaces of the forming stem are structured to cause the microlayered fluid mass to merge with the fluid from the distribution plates.

A further aspect of the invention is directed towards a die for coextruding a plurality of fluid layers, comprising:

a. a microlayer assembly, comprising

(1) a microlayer forming surface, and

(2) a plurality of microlayer distribution plates, each of the microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of the microlayer plates being in fluid communication with the microlayer forming surface and structured to deposit a microlayer of fluid onto the microlayer forming surface, the microlayer plates being arranged to provide a predetermined order in which the microlayers are deposited onto the microlayer forming stem to form a substantially unified, microlayered fluid mass on the microlayer forming surface; and

b. one or more distribution plates, each of the plates having a fluid inlet and a fluid outlet, the fluid outlet from at least one of the distribution plates being in fluid communication with the microlayer forming surface such that the microlayered fluid mass merges with fluid from the distribution plates.

These and other aspects and features of the invention may be better understood with reference to the following description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic view of a system 10 in accordance with the present invention for coextruding a plurality of fluid layers, including a die 12;

FIG. 2 is a cross-sectional view of the die 12 shown in FIG. 1;

FIG. 3 is a plan view one of the microlayer plates 48 in die 12;

FIG. 4 is a cross-sectional view of the microlayer plate 48 shown in FIG. 3; FIG. 5 is a magnified, cross-sectional view of die 12, showing the combined flows from the microlayer plates 48 and distribution plates 32;

FIG. 6 is a cross-sectional view of an alternative die in accordance with the present invention, which includes two microlayer assemblies;

FIG. 7 is a cross-sectional view of a further alternative die in accordance with the present invention;

FIG. 8 is a plan view of one of the microlayer plates 148 in the die shown in FIG. 7; and

FIG. 9 is a magnified, cross-sectional view of the die shown in FIG. 7, taken from the circled area in FIG. 7, showing the combined flows from the microlayer plates 148 and distribution plates 132.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 schematically illustrates a system 10 in accordance with the present invention for coextruding a plurality of fluid layers. System 10 generally includes a die 12 and one or more extruders 14a and 14b in fluid communication with the die 12 to supply one or more fluids to the die.

In a typical application, the fluid layers coextruded by die 12 may comprise one or more molten thermoplastic polymers. Examples of such polymers include polyolefins, polyesters (e.g., PET), polystyrenes, polyamide homopolymers and copolymers (e.g. PA6, PA12, PA6/12, etc.), polycarbonates, etc. Within the family of polyolefins, various polyethylene homopolymers and copolymers may be used, as well as polypropylene homopolymers and copolymers (e.g., propylene/ethylene copolymer). Polyethylene homopolymers may include low density polyethylene (LDPE) and high density polyethylene (HDPE). Suitable polyethylene copolymers may include a wide variety of polymers, such as, e.g., ionomers, ethylene/vinyl acetate (EVA), ethylene/vinyl alcohol (EVOH), and ethylene/alpha-olefins, including heterogeneous (Zeigler-Natta catalyzed) and homogeneous (metallocene, single-cite catalyzed) ethylene/alpha-olefin copolymers. Ethylene/alpha-olefin copolymers are copolymers of ethylene with one or more comonomers selected from C_3 to C_{20} alpha-olefins, such as 1-butene, 1-pentene, 1-hexene, 1-octene, methyl pentene and the like, including linear low density polyethylene (LLDPE), linear medium density polyethylene (LMDPE), very low density polyethylene (VLDPE), and ultra-low density polyethylene (ULDPE).

As is conventional, the polymeric materials may be supplied to the extruders 14a, b in the solid-state, e.g., in the form of pellets or flakes, via respective hoppers 16a, b. Extruders 14a, b are maintained at a temperature sufficient to convert the solid-state polymer to a molten state, and internal screws within the extruders (not shown) move the molten polymer into and through die 12 via respective pipes 18a, b. As will be explained in further detail below, within die 12, the molten polymer is converted into thin film layers, and each of the layers are superimposed, combined together, and expelled from the die at discharge end 20, i.e., “coextruded,” to form a tubular, multilayer film 22. Upon

emergence from the die 12 at discharge end 20, the tubular, multilayer film 22 is exposed to ambient air or a similar environment having a temperature sufficiently low to cause the molten polymer from which the film is formed to transition from a liquid state to a solid state. Additional cooling/quenching of the film may be achieved by providing a liquid quench bath (not shown), and then directing the film through such bath.

The solidified tubular film 22 is then collapsed by a convergence device 24, e.g., a V-shaped guide as shown, which may contain an array of rollers to facilitate the passage of film 22 therethrough. A pair of counter-rotating drive rollers 25a, b may be employed as shown to pull the film 22 through the convergence device 24. The resultant collapsed tubular film 22 may then be wound into a roll 26 by a film winding device 28 as shown. The film 22 on roll 26 may subsequently be unwound for use, e.g., for packaging, or for further processing, e.g., stretch-orientation, irradiation, or other conventional film-processing techniques, which are used to impart desired properties as necessary for the intended end-use applications for the film.

Referring now to FIG. 2, die 12 will be described in further detail. As noted above, die 12 is adapted to coextrude a plurality of fluid layers, and generally includes a primary forming stem 30, one or more distribution plates 32, and a microlayer assembly 34. In the presently illustrated die, five distribution plates 32 are included, as individually indicated by the reference numerals 32a-e. A greater or lesser number of distribution plates 32 may be included as desired. The number of distribution plates in die 12 may range, e.g., from one to twenty, or even more then twenty if desired.

Each of the distribution plates 32 has a fluid inlet 36 and a fluid outlet 38 (the fluid inlet is not shown in plate 32b). The fluid outlet 38 from each of the distribution plates 32 is in fluid communication with the primary forming stem 30, and also is structured to deposit a layer of fluid onto the primary forming stem. The distribution plates 32 may be constructed as described in U.S. Pat. No. 5,076,776, the entire disclosure of which is hereby incorporated herein by reference thereto. As described in the ‘776 patent, the distribution plates 32 may have one or more spiral-shaped fluid-flow channels 40 to direct fluid from the fluid inlet 36 and onto the primary forming stem 30 via the fluid outlet 38. As the

fluid proceeds along the channel 40, the channel becomes progressively shallower such that the fluid is forced to assume a progressively thinner profile. The fluid outlet 38 generally provides a relatively narrow fluid-flow passage such that the fluid flowing out of the plate has a final desired thickness corresponding to the thickness of the fluid outlet 38. Other channel configurations may also be employed, e.g., a toroid-shaped channel; an asymmetrical toroid, e.g., as disclosed in U.S. Pat. No. 4,832,589; a heart-shaped channel; a helical-shaped channel, e.g., on a conical-shaped plate as disclosed in U.S. Pat. No. 6,409,953, etc. The channel(s) may have a semi-circular or semi-oval cross-section as shown, or may have a fuller shape, such as an oval or circular cross-sectional shape.

In some embodiments, distribution plates 32 may have a generally annular shape such that the fluid outlet 38 forms a generally ring-like structure, which forces fluid flowing through the plate to assume a ring-like form. Such ring-like structure of fluid outlet 38, in combination with its proximity to the primary forming stem 30, causes the fluid flowing through the plate 32 to assume a cylindrical shape as the fluid is deposited onto the stem 30. Each flow of fluid from each of the distribution plates 32 thus forms a distinct cylindrical layer on the primary forming stem 30.

The fluid outlets 38 of the distribution plates 32 are spaced from the primary forming stem 30 to form an annular passage 42, which, for ease of reference, may be termed a 'primary fluid passage' (e.g., in order to provide a linguistic distinction from the annular passage 62 for microlayer assembly 34, as described below). The extent of such spacing is sufficient to accommodate the volume of the concentric fluid layers flowing along the forming stem 30.

The order in which the distribution plates 32 are arranged in die 12 determines the order in which the fluid layers are deposited onto the primary forming stem 30. For example, if all five distribution plates 32a-e are supplied with fluid, fluid from plate 32a will be the first to be deposited onto primary forming stem 30 such that such fluid will be in direct contact with the stem 30. The next layer to be deposited onto the forming stem would be from distribution plate 32b. This layer will be deposited onto the fluid layer from plate 32a. Next, fluid from plate 32c will be deposited on top of the fluid from plate 32b. If

microlayer assembly 34 were not present in the die, the next layer to be deposited would be from distribution plate 32d, which would be layered on top of the fluid layer from plate 32c. Finally, the last and, therefore, outermost layer to be deposited would be from plate 32e. In this example (again, ignoring the microlayer assembly 34), the resultant tubular film 22 that would emerge from the die would have five distinct layers, which would be arranged as five concentric cylinders bonded together.

Accordingly, it may be appreciated that the fluid layers from the distribution plates 32 are deposited onto the primary forming stem 30 either directly (first layer to be deposited, e.g., from distribution plate 32a) or indirectly (second and subsequent layers, e.g., from plates 32b-e).

As noted above, the tubular, multilayer film 22 emerges from die 12 at discharge end 20. The discharge end 20 may thus include an annular discharge opening 44 to allow the passage of the tubular film 22 out of the die. Such annular discharge opening is commonly referred to as a "die lip." As illustrated, the diameter of the annular discharge opening 44 may be greater than that of the annular, primary fluid passage 42, e.g., to increase the diameter of the tubular film 22 to a desired extent. This has the effect of decreasing the thickness of each of the concentric layers that make up the tubular film 22, i.e., relative to the thickness of such layers during their residence time within the annular passage 42. Alternatively, the diameter of the annular discharge opening 44 may be smaller than that of the annular passage 42.

Microlayer assembly 34 generally comprises a microlayer forming surface, e.g., a microlayer forming stem 46, and a plurality of microlayer distribution plates 48. In the presently illustrated embodiment, fifteen microlayer distribution plates 48a-o are shown. A greater or lesser number of microlayer distribution plates 48 may be included as desired. The number of microlayer distribution plates 48 in microlayer assembly 34 may range, e.g., from one to fifty, or even more then fifty if desired. In many embodiments of the present invention, the number of microlayer distribution plates 48 in microlayer assembly 34 will be at least about 5, e.g., 10, 15, 20, 25, 30, 35, 40, 45, 50, etc., or any number of plates in between the foregoing numbers.

Each of the microlayer plates 48 has a fluid inlet 50 and a fluid outlet 52.

The fluid outlet 52 from each of the microlayer plates 48 is in fluid communication with microlayer forming stem 46 or other such microlayer forming surface, and is structured to deposit a microlayer of fluid onto such forming surface, e.g., microlayer forming stem 46. Similar to the distribution plates 32, the microlayer plates 48 may also be constructed as described in the above-incorporated U.S. Pat. No. 5,076,776.

For example, as shown in FIG. 3, the microlayer plates 48 may have a spiral-shaped fluid-flow channel 54, which is supplied with fluid via fluid inlet 50. Alternatively, two more fluid-flow channels may be employed in plate 48, which may be fed from separate fluid inlets or a single fluid inlet. Other channel configurations may also be employed, e.g., a toroid-shaped channel; an asymmetrical toroid, e.g., as disclosed in U.S. Pat. No. 4,832,589; a heart-shaped channel; a helical-shaped channel, e.g., on a conical-shaped plate as disclosed in U.S. Pat. No. 6,409,953; etc. The channel(s) may have a semi-circular or semi-oval cross-section as shown, or may have a fuller shape, such as an oval or circular cross-sectional shape, e.g., as shown in FIG. 7 with respect to distribution plates 132.

Regardless of the particular configuration or pattern that is selected for the flow channel(s) 54, its function is to connect the fluid inlet(s) 50 with the fluid outlet 52 in such a manner that the flow of fluid through the microlayer assembly 34 is converted from a generally stream-like, axial flow to a generally film-like, convergent radial flow towards the microlayer forming stem 46. Microlayer plate 48 as shown in FIG. 3 may accomplish this in two ways. First, the channel 54 spirals inwards towards the center of the plate, and thus directs fluid from the fluid inlet 50, located near the periphery of the plate, towards the fluid outlet 52, which is located near the center of the plate. Secondly, the channel 54 may be fashioned with a progressively shallower depth as the channel approaches the fluid outlet 52. This has the effect of causing some of the fluid flowing through the channel 54 to overflow the channel and proceed radially-inward toward the fluid outlet 52 in a relatively flat, film-like flow. Such radial-inward flow may occur in overflow regions 53, which may be located between the spaced-apart spiral sections of channel 54. As shown in FIG. 4, the overflow regions 53 may be formed as recessed sections in plate 48, i.e., recessed relative to the thicker,

non-recessed region 55 at the periphery of the plate. As shown in FIG. 3, overflow regions 53 may begin at step-down 57 and, e.g., spiral inwards towards fluid outlet 52 between the spirals of channel 54. The non-recessed, peripheral region 55 abuts against the plate or other structure above the plate, e.g., as shown in FIGS. 2 and 5, and thus prevents fluid from flowing outside the periphery of the plate. In this manner, the non-recessed, peripheral region 55 forces fluid entering the plate to flow radially inward toward fluid outlet 52. Step-down 57 thus represents a line or zone of demarcation between the 'no-flow' peripheral region 55 and the 'flow' regions 53 and 54. The fluid that remains in the channel 54 and reaches the end 56 of the channel flows directly into the fluid outlet 52.

The fluid outlet 52 generally provides a relatively narrow fluid-flow passage and generally determines the thickness of the microlayer flowing out of the microlayer plate 48. The thickness of the fluid outlet 52, and therefore the thickness of the microlayer flowing therethrough, may be determined, e.g., by the spacing between the plate surface at outlet 52 and the bottom of the plate or other structure (e.g., manifold 76 or 78) immediately above the plate surface at outlet 52.

With continuing reference to FIGS. 2-3, each of the microlayer distribution plates 48 may have an orifice 58 extending through the plate. The orifice 58 may be located substantially in the center of each microlayer plate 48, with the fluid outlet 52 of each plate positioned adjacent to such orifice 58. In this manner, the microlayer forming stem 46 may extend through the orifice 58 of each of the microlayer distribution plates 48. With such a configuration, the microlayer distribution plates 48 may have a generally annular shape such that the fluid outlet 52 forms a generally ring-like structure, which forces fluid flowing through the plate to exit the plate in a radially-convergent, ring-like flow pattern. Such ring-like structure of fluid outlet 52, in combination with its proximity to the microlayer forming stem 46, causes the fluid exiting the microlayer plates 48 to assume a cylindrical shape as the fluid is deposited onto the microlayer stem 46. Each flow of fluid from each of the microlayer distribution plates 48 thus deposits a distinct cylindrical microlayer on the microlayer forming stem 46.

The microlayer plates 48 may be arranged to provide a predetermined order in which the microlayers are deposited onto the microlayer forming stem 46. For example, if all fifteen microlayer distribution plates 48a-o are supplied with fluid, a microlayer of fluid from plate 48a will be the first to be deposited onto microlayer forming stem 46 such that such microlayer will be in direct contact with the stem 46. The next microlayer to be deposited onto the forming stem would be from microlayer plate 48b. This microlayer will be deposited onto the microlayer from plate 48a. Next, fluid from microlayer plate 48c will be deposited on top of the microlayer from plate 48b, etc. The last and, therefore, outermost microlayer to be deposited is from plate 48o. In this manner, the microlayers are deposited onto the microlayer forming stem 46 in the form of a substantially unified, microlayered fluid mass 60 (see FIG. 5). In the present example, such microlayered fluid mass 60 would comprise up to fifteen distinct microlayers (at the downstream end of stem 46), arranged as fifteen concentric cylindrical microlayers bonded and flowing together in a predetermined order (based on the ordering of the microlayer plates 48a-o) on microlayer forming stem 46.

It may thus be appreciated that the fluid layers from the microlayer distribution plates 48 are deposited onto the microlayer forming stem 46 either directly (the first layer to be deposited, e.g., from microlayer plate 48a) or indirectly (the second and subsequent layers, e.g., from microlayer plates 48b-o). The orifices 58 in each of the microlayer plates 48 are preferably large enough in diameter to space the fluid outlets 52 of the microlayer plates 48 sufficiently from the microlayer forming stem 46 to form an annular passage 62 for the microlayers, which may thus be termed a 'microlayer fluid passage' (see FIG. 2). The extent of such spacing is preferably sufficient to accommodate the volume of the concentric microlayers flowing along the microlayer stem 46.

In accordance with the present invention, microlayer forming stem 46 is in fluid communication with primary forming stem 30 such that the microlayered fluid mass 60 flows from the microlayer forming stem 46 and onto the primary forming stem 30. This may be seen in FIG. 5, wherein microlayered fluid mass 60 from microlayer assembly 34 is shown flowing from microlayer forming stem 46 and onto primary forming stem 30. Fluid communication between the microlayer stem 46 and primary stem 30 may be achieved by including in die 12

an annular transfer gap 64 between the annular passage 62 for the microlayer stem 46 and the annular passage 42 for the primary stem 30 (see also FIG. 2). Such transfer gap 64 allows the microlayer fluid passage 62 to be in fluid communication with the primary fluid passage 42, and thereby allows the microlayered fluid mass 60 to flow out of the microlayer passage 62 and into the primary passage 42. In other words, the transfer gap 64 places the fluid outlets 38 of the distribution plates 32 in fluid communication with the microlayer forming surface provided by microlayer stem 46. In this manner, the microlayers from microlayer plates 48 are introduced as a unified mass into the generally larger volumetric flow of the thicker fluid layers from the distribution plates 32. As shown in FIG. 5, such merger of the microlayered fluid mass 60 and the fluids 65, 70 from the distribution plates 32 occurs in primary fluid passage 42.

The inventors have discovered that combining the flows of the microlayers with the thicker fluid layers in this fashion minimizes the deleterious effects of interfacial flow instabilities, which generally make it difficult to combine the flow of thin layers with relatively thick layers in such a way that the physical integrity and independent properties of the thin layers are maintained. The microlayer forming stem 46, or other suitable microlayer forming surface, allows the microlayers from the microlayer plates 48 to assemble into the microlayered fluid mass 60 in relative calm, i.e., without being subjected to the more powerful sheer forces of the thicker layers flowing from the distribution plates 32. As the microlayers assemble into the unified fluid mass 60 on stem 46, the interfacial flow instabilities created by the merger of each layer onto the fluid mass 60 are minimized because all the microlayers have a similar degree of thickness, i.e., relative to the larger degree of thickness of the fluid layers from distribution plates 32. When fully assembled, the microlayered fluid mass 60 enters the flow of the thicker layers from distribution plates 32 on primary stem 30 with a mass flow rate that more closely approximates that of such thicker layers, thereby increasing the ability of the microlayers in fluid mass 60 to retain their physical integrity and independent physical properties.

As shown in FIG. 2, primary forming stem 30 and microlayer forming stem 46 may be substantially coaxially aligned with one another in die 12, e.g., with the microlayer forming stem 46 being external to the primary forming stem

30. This construction provides a relatively compact configuration for die 12, which can be highly advantageous in view of the stringent space constraints that exist in the operating environment of many commercial coextrusion systems.

For example, the coaxial alignment of the primary forming stem 30 with the microlayer forming stem 46 allows the distribution plates 32 and the microlayer assembly 34 to be axially positioned along the primary forming stem, as shown in FIG. 2. This reduces the width of die 12, and also allows the fluids from both the distribution plates 32 and the microlayer assembly 34 to flow in an axial direction, e.g., in parallel paths along primary forming stem 30 and microlayer forming stem 46, then together along the primary stem 30 downstream of transfer gap 64, at which the microlayered fluid mass 60 flows from the microlayer stem 46 and onto the primary stem 30 to merge with the fluid layers from the distribution plates 32.

Such construction also allows die 12 to be set up in a variety of different configurations to produce a coextruded film having a desired combination of thick layers and microlayers. For example, one or more distribution plates 32 may be located upstream of the microlayer assembly 34. In this embodiment, fluid layers from such upstream distribution plates are deposited onto primary forming stem 30 prior to the deposition of the microlayered fluid mass 60 onto the primary stem 30. With reference to FIG. 2, it may be seen that distribution plates 32a-c are located upstream of microlayer assembly 34 in die 12. Fluid layers 65 from such upstream distribution plates 32a-c are thus interposed between the microlayered fluid mass 60 and the primary forming stem 30 (see FIG. 5).

Alternatively, the microlayer assembly 34 may be located upstream of the distribution plates 32, i.e., the distribution plates may be located downstream of the microlayer assembly 34 in this alternative embodiment. Thus, the microlayers from the microlayer assembly 34, i.e., the microlayered fluid mass 60, will be deposited onto primary forming stem 30 prior to the deposition thereon of the fluid layers from the downstream distribution plates 32. With reference to FIG. 2, it may be seen that microlayer assembly 34 is located upstream of distribution plates 32d-e in die 12. As shown in FIG. 5, the

microlayered fluid mass 60 is thus interposed between the fluid layer(s) 70 from such distribution plates 32d-e and the primary forming stem 30.

As illustrated in FIG. 2, the microlayer assembly 34 may also be positioned between one or more upstream distribution plates, e.g., plates 32a-c, and one or more downstream distribution plates, e.g., plates 32d-e. In this embodiment, fluid(s) from upstream plates 32a-c are deposited first onto primary stem 30, followed by the microlayered fluid mass 60 from the microlayer assembly 34, and then further followed by fluid(s) from downstream plates 32d-e. In the resultant multilayered film, the microlayers from microlayer assembly 34 are sandwiched between thicker layers from both the upstream plates 32a-c and the downstream plates 32d-e.

As a further variation, die 12 may include one or more additional microlayer assemblies, which may be the same as microlayer assembly 34 or may have a different configuration, e.g., a different number of microlayer plates. In this embodiment, any such additional microlayer assemblies may be coaxially aligned with the primary forming stem 30, and may be positioned upstream and/or downstream of the microlayer assembly 34 shown in FIG. 2. Such additional microlayer assemblies may be used in place of or in addition to the distribution plates 32. Thus, additional microlayer assemblies may be positioned adjacent to the microlayer assembly 34, or may be spaced from such assembly 34 by one or more distribution plates 32. If two or more microlayer assemblies are included in die 12, such assemblies may also be sandwiched between upstream and downstream distribution plates, e.g., between the upstream plates 32a-c and downstream plates 32d-e shown in FIG. 2. Such an alternative die is illustrated in FIG. 6 and described below.

In many embodiments of the invention, most or all of the microlayer plates 48 have a thickness that is less than that of the distribution plates 32. Thus, for example, the distribution plates 32 may have a thickness T_1 (see FIG. 5) ranging from about 0.5 to about 2 inches, e.g., greater than 0.5 inch, such as 0.501 or more, 0.502 or more, 0.503 or more, etc., or less than 2, e.g., 1.999 or less, 1.998 or less, etc., such as from about 0.501 to 1.999 inches, 0.502 to 1.998 inches, etc. The microlayer distribution plates 48 may have a thickness T_2 ranging from about 0.1 to about 0.5 inch, e.g., greater than 0.1, such as 0.101 or

more, 0.102 or more, etc., or less than 0.5, e.g., 0.499 or less, 0.498 or less, etc., such as from about 0.101 to 0.499 inch, 0.102 to 0.498 inch, etc. Such thickness ranges are not intended to be limiting in any way, but only to illustrate typical examples. All distribution plates 32 will not necessarily have the same thickness, nor will all of the microlayer plates 48. For example, microlayer plate 48o, the most downstream of the microlayer plates in the assembly 34, may be thicker than the other microlayer plates to accommodate a sloped contact surface 66, which may be employed to facilitate the transfer of microlayered fluid mass 60 through the annular gap 64 and onto the primary forming stem 30.

As also shown in FIG. 5, each of the microlayers flowing out of the plates 48 has a thickness "M" corresponding to the thickness of the fluid outlet 52 from which each microlayer emerges. The microlayers flowing from the microlayer plates 48 are schematically represented in FIG. 5 by the phantom arrows 68.

Similarly, each of the relatively thick fluid layers flowing out of the plates 32 has a thickness "D" corresponding to the thickness of the fluid outlet 38 from which each such layer emerges (see FIG. 5). The relatively thick fluid layers flowing from the distribution plates 32 are schematically represented in FIG. 5 by the phantom arrows 70.

Generally, the thickness M of the microlayers will be less than the thickness D of the fluid layers from the distribution plates 32. The thinner that such microlayers are relative to the fluid layers from the distribution plates 32, the more of such microlayers that can be included in a multilayer film, for a given overall film thickness. Microlayer thickness M from each microlayer plate 48 will generally range from about 1-20 mils (1 mil = 0.001 inch), e.g., greater than 1 mil, greater than 2 mils, greater than 3 mils, etc., less than 20 mils, less than 19 mils, less than 18 mils, etc., such as between 2 to 19 mils, 3 to 18 mils, 4 to 17 mils, etc. Thickness D from each distribution plate 32 will generally range from about 20-100 mils, e.g., greater than 20 mils, greater than 21 mils, greater than 22 mils, etc., less than 100 mils, less than 90 mils, less than 80 mils, less than 70 mils, less than 60 mils, etc., such as between 20 to 50 mils, 21 to 49 mils, 22 to 48 mils, 23 to 47 mils, etc. The foregoing thicknesses are not intended to be limiting of the scope of the present invention in any way, and are provided solely for illustration purposes.

The ratio of M:D may range from about 1:1 to about 1:8, e.g., greater than 1:1, greater than 1:1.1, greater than 1:1.2, greater than 1:2, greater than 1:3, etc., less than 1:8, less than 1:7.9, less than 1:7.8, less than 1:7, less than 1:6, etc., such as between 1:1.1 – 1:7.9; 1:1.2 – 1:7.8, 1:2 – 1:7, 1:3 – 1:6, 1:4 – 1:5, etc.

Thickness M may be the same or different among the microlayers 68 flowing from microlayer plates 48 to achieve a desired distribution of layer thicknesses in the microlayer section of the resultant film. Similarly, thickness D may be the same or different among the thicker layers 70 flowing from the distribution plates 32 to achieve a desired distribution of layer thicknesses in the 'thick-layer section(s)' of the resultant film. The layer thicknesses M and D will typically change as the fluid flows downstream through the die, e.g., if the melt tube is expanded at annular discharge opening 44 as shown in FIG. 2, and/or upon further downstream processing of the tubular film, e.g., by stretching, orienting, or otherwise expanding the tube to achieve a final desired film thickness and/or to impart desired properties into the film. Such downstream processing techniques are well known in the art. The flow rate of fluids through the plates will also have an effect on the final downstream thicknesses of the corresponding film layers.

With reference back to FIGS. 1-2, it may be appreciated that a method of coextruding a plurality of fluid layers in accordance with the present invention comprises the steps of:

a. directing one or more fluids through one or more distribution plates 32 and onto primary forming stem 30 in die 12;

b. forming a substantially unified, microlayered fluid mass 60 on microlayer forming stem 46 by directing at least one additional fluid through microlayer assembly 34; and

c. directing the microlayered fluid mass 60 from the microlayer forming stem 46 and onto the primary forming stem 30 to merge the microlayered fluid mass 60 with the fluid layer(s) from the distribution plate(s) 32.

As described above, the distribution plates 32 and microlayer plates 48 preferably have an annular configuration, such that primary forming stem 30 and microlayer stem 46 pass through the center of the plates to receive fluid that is

directed into the plates. The fluid may be supplied from extruders, such as extruders 14a, b. The fluid may be directed into the die 12 via vertical supply passages 72, which receive fluid from feed pipes 18, and direct such fluid into the die plates 32 and 48. For this purpose, the plates may have one or more through-holes 74, e.g., near the periphery of the plate as shown in FIG. 3, which may be aligned to provide the vertical passages 72 through which fluid may be directed to one or more downstream plates.

Although three through-holes 74 are shown in FIG. 3, a greater or lesser number may be employed as necessary, e.g., depending upon the number of extruders that are employed. In general, one supply passage 72 may be used for each extruder 14 that supplies fluid to die 12. The extruders 14 may be arrayed around the circumference of the die, e.g., like the spokes of a wheel feeding into a hub, wherein the die is located at the hub position.

With reference to FIG. 1, die 12 may include a primary manifold 76 to receive the flow of fluid from the extruders 14 via feed pipes 18, and then direct such fluid into a designated vertical supply passage 72, in order to deliver the fluid to the intended distribution plate(s) 32 and/or microlayer plate(s) 48. The microlayer assembly 34 may optionally include a microlayer manifold 78 to receive fluid directly from one or more additional extruders 80 via feed pipe 82 (shown in phantom in FIG. 1).

In the example illustrated in FIGS. 1-2, extruder 14b delivers a fluid, e.g., a first molten polymer, directly to the fluid inlet 36 of distribution plate 32a via pipe 18b and primary manifold 76. In the presently illustrated embodiment, distribution plate 32a receives all of the output from extruder 14b, i.e., such that the remaining plates and microlayer plates in the die 12 are supplied, if at all, from other extruders. Alternatively, the fluid inlet 36 of distribution plate 32a may be configured to contain an outlet port to allow a portion of the supplied fluid to pass through to one or more additional plates, e.g., distribution plates 32 and/or microlayer plates 48, positioned downstream of distribution plate 32a.

For example, as shown in FIGS. 3-4 with respect to the illustrated microlayer plate 48, an outlet port 84 may be formed in the base of the fluid inlet 50 of the plate. Such outlet port 84 allows the flow of fluid delivered to plate 48 to be split: some of the fluid flows into channel 54 while the remainder passes

through the plate for delivery to one or more additional downstream plates 48 and/or 32. A similar outlet port can be included in the base of the fluid inlet 36 of a distribution plate 32. Delivery of fluid passing through the outlet port 84 (or through a similar outlet port in a distribution plate 32) may be effected via a through-hole 74 in an adjacent plate (see FIG. 5), or via other means, e.g., a lateral-flow supply plate, to direct the fluid in an axial, radial, and/or tangential direction through die 12 as necessary to reach its intended destination.

Distribution plates 32b-c are being supplied with fluid via extruder(s) and supply pipe(s) and/or through-holes that are not shown in FIG. 2. The fluid flow along primary forming stem 30 from distribution plates 32a-c is shown in FIG. 5, as indicated by reference numeral 65.

As shown in FIGS. 1-2, microlayer assembly 34 is being supplied with fluid by extruders 14a and 80. Specifically, microlayer plates 48a, c, e, g, i, k, m, and o are supplied by extruder 14a via supply pipe 18a and vertical pipe and/or passage 72. Microlayer plates 48b, d, f, h, j, l, and n are supplied with fluid by extruder 80 via feed pipe 82 and a vertical supply passage 86. In the illustrated embodiment, vertical passage 86 originates in microlayer manifold 78 and delivers fluid only within the microlayer assembly 34. In contrast, vertical passage 72 originates in manifold 76, extends through distribution plates 32a-c (via aligned through-holes 74 in such plates), then further extends through manifold 78 via manifold passage 79 before finally arriving at microlayer plate 48a.

Fluid from extruder 14a and vertical passage 72 enters microlayer plate 48a at fluid inlet 50. Some of the fluid passes from inlet 50 and into channel 54 (for eventual deposition on microlayer stem 46 as the first microlayer to be deposited on stem 46), while the remainder of the fluid may pass through plate 48a via outlet port 84. Microlayer plate 48b may be oriented, i.e., rotated, such that a through-hole 74 is positioned beneath the outlet port 84 of microlayer plate 48a so that the fluid flowing out of the outlet port 84 flows through the microlayer plate 48b, and not into the channel 54 thereof. Microlayer plate 48c may be positioned such that the fluid inlet 50 thereof is in the same location as that of microlayer plate 48a so that fluid flowing out of through-hole 74 of microlayer plate 48b flows into the inlet 50 of plate 48c. Some of this fluid flows into the

channel 54 of plate 48c while some of the fluid passes through the plate via outlet port 84, passes through a through-hole 74 in the next plate 48d, and is received by fluid inlet 50 of the next microlayer plate 48e, where some of the fluid flows into channel 54 and some passes out of the plate via outlet port 84. Fluid from extruder 14a continues to be distributed to remaining plates 48g, i, k, and m in this manner, except for microlayer plate 48o, which has no outlet port 84 so that fluid does not pass through plate 48o, except via channel 54 and fluid outlet 52.

In a similar manner, fluid from extruder 80 and vertical passage 86 passes through microlayer plate 48a via a through-hole 74 and then enters microlayer plate 48b at fluid inlet 50 thereof. Some of this fluid flows through the channel 54 and exits the plate at outlet 52, to become the second microlayer to be deposited onto microlayer stem 46 (on top of the microlayer from plate 48a), while the remainder of the fluid passes through the plate via an outlet port 84. Such fluid may pass through microlayer plate 48c via a through-hole 74, and be delivered to plate 48d via appropriate alignment of its inlet 50 with the through-hole 74 of plate 48c, through which the fluid from extruder 80 passes. This fluid-distribution process may continue for plates 48f, h, j, and l, until the fluid reaches plate 48n, which has no outlet port 84 such that fluid does not pass through this plate except via its fluid outlet 52.

In this manner, a series of microlayers comprising alternating fluids from extruders 14a and 80 may be formed on microlayer stem 46. For example, if extruder 14a supplied EVOH and extruder 80 supplied PA6, the resultant microlayered fluid mass 60 would have the structure:

EVOH/PA6/EVOH/PA6/EVOH/PA6/EVOH/PA6/EVOH/PA6/EVOH/PA6/EVOH/PA6/EVOH

The fluids from extruders 14a and 80 may be the same or different such that the resultant microlayers in microlayered fluid mass 60 may have the same or a different composition. Only one extruder may be employed to supply fluid to the entire microlayer assembly 34, in which case all of the resultant microlayers will have the same composition. Alternatively, three or more extruders may be used to supply fluid to the microlayer assembly 34, e.g., with each supplying a

different fluid such that three different microlayer compositions are formed in microlayered fluid mass 60, in any desired order, e.g., abcabc; abbcabbc; abacabac; etc.

Similarly, the fluid(s) directed through the distribution plate(s) 32 may be substantially the same as the fluid(s) directed through the microlayer assembly 34. Alternatively, the fluid(s) directed through the distribution plate(s) 32 may be different from the fluid(s) directed through the microlayer assembly. The resultant tubular film may have thick layers and microlayers that have substantially the same composition. Alternatively, some of the thick layers from distribution plates 32 may be the same as some or all of the microlayers from microlayer plates 48, while other thick layers may be different from some or all of the microlayers.

In the illustrated example, the extruders and supply passages for distribution plates 32d-e are not shown. One or both of such plates may be supplied from extruder 14a, 14b, and/or 80 by appropriate arrangement of vertical supply passages 72, 86, through-holes 74, and/or outlet ports 84 of the upstream distribution plates 32 and/or microlayer plates 48. Alternatively, one or both distribution plates 32d-e may not be supplied at all, or may be supplied from a separate extruder, such as an extruder in fluid communication with primary manifold 76 and a vertical supply passage 72 that extends through distribution plates 32a-c and microlayer assembly 34, e.g., via appropriate alignment of the through-holes 74 of plates 32a-c and microlayer assembly 34 to create a fluid transport passage through die 12, leading to fluid inlet 50 of distribution plate 32d and/or 32e.

If desired, one or more of the distribution plates 32 and/or microlayer plates 48 may be supplied with fluid directly from one or more extruders, i.e., by directing fluid directly into the fluid inlet of the plate, e.g., from the side of the plate, without the fluid being first routed through one of manifolds 76 or 78 and/or without using a vertical supply passage 72, 86. Such direct feed of one or more plates 32 and/or 48 may be employed as an alternative or in addition to the use of manifolds and vertical supply passages as shown in FIG. 2.

As noted above, in accordance with the present invention, die 12 may include one or more additional microlayer assemblies, which may be the same

as microlayer assembly 34 or may have a different configuration, e.g., a different number of microlayer plates. Such a variation is illustrated in FIG. 6, wherein alternative die 12' includes both microlayer assembly 34 as described above, and a second microlayer assembly 34'. In the illustrated embodiment, second microlayer assembly 34' is essentially the same as microlayer assembly 34, e.g., with fifteen microlayer plates 48, but it should be understood that the second microlayer assembly 34' (and/or additional microlayer assemblies) may have a different configuration, e.g., a different number of microlayer plates, from microlayer assembly 34. Also in the illustrated embodiment, second microlayer assembly 34' is coaxially aligned with the primary forming stem 30, and is positioned downstream of microlayer assembly 34. The microlayer assemblies 34, 34' are sandwiched between upstream and downstream distribution plates, e.g., between upstream distribution plates 32a, b and downstream distribution plates 32e, f. Microlayer assemblies 34, 34' are spaced apart by intermediate distribution plates 32c, d.

In the illustrated configuration, distribution plates 32a, b are both supplied with fluid via feed pipe 18b. Microlayer assembly 34 is supplied with fluids from both feed pipes 18a and 82 such that the resultant microlayers will have an alternating arrangement, e.g., a/b/a/b/a/b…, wherein layers "a" are formed from fluid supplied by feed pipe 18a and layers "b" are formed from fluid supplied via feed pipe 82, with layers "a" and "b" having the same composition or a different composition, depending on the composition of the fluids supplied by respective extruders 14a and 80.

As also illustrated, vertical supply passage 86 is extended below microlayer assembly 34, with the extension designated 86', in order to supply fluid to microlayer assembly 34'. Thus, the same fluid source that supplies every other microlayer plate 48 in microlayer assembly 34, e.g., extruder 80 via feed pipe 18b, may also supply some or all of the microlayer plates 48' in microlayer assembly 34', e.g., every other plate 48' as illustrated. In this manner, at least some of the microlayers produced from microlayer assembly 34 will have the same composition as at least some of the microlayers produced from microlayer assembly 34'. This is just an example, however, and is not intended to be limiting in any way, as numerous other configurations are possible, e.g., with a

completely different fluid source supplying fluid to microlayer assembly 34' via a separate feed pipe and supply passage.

The remaining microlayer plates 48' in microlayer assembly 34' may be supplied by a separate fluid source, e.g., a fourth extruder (not shown), in order to supply a fourth type of fluid to die 12', e.g., alternating every other layer with fluid supplied via feed pipe 18b/supply extension 86' in microlayer assembly 34'. Such microlayer plates 48' may be supplied via fourth feed pipe 88 and vertical passage 90 as shown.

Supply sources for distribution plates 32c-f are not shown. If all plates shown, including distribution plates 32c-f, are supplied with fluid, it may be appreciated that relatively thick layers from distribution plates 32a, b would be delivered first to primary fluid passage 42, for deposition on primary forming stem 30. Next, a microlayered fluid mass 60 from microlayer assembly 34 would be delivered from microlayer fluid passage 62 and deposited onto the layers from distribution plates 32a, b in primary fluid passage 42 via transfer gap 64. Relatively thick layers from the intermediately-positioned distribution plates 32c, d would then be deposited atop the microlayered fluid mass 60 from microlayer assembly 34, followed by a second microlayered fluid mass from the second microlayer assembly 34'. Finally, relatively thick layers from distribution plates 32e, f would be delivered into the primary fluid passage 42 for deposition on the microlayered fluid mass from second microlayer assembly 34'. The resultant tubular, multilayer film would thus feature two distinct microlayer sections sandwiched between inner, intermediate, and outer thick layer sections, i.e., with the thick layers from distribution plates 32a, b forming the innermost layers of the tube, with the microlayers from microlayer assembly 34 sandwiched between such innermost thick layers and the intermediate thick layers from distribution plates 32c, d, and the microlayers from microlayer assembly 34' sandwiched between the intermediate thick layers and the thick, outermost layers of the tube formed from distribution plates 32e, f.

Referring now to FIGS. 7-9, a further alternative die in accordance with the present invention will be described. Like die 12, alternative die 112 includes an annular, primary fluid passage 142, one or more distribution plates 132, and a microlayer assembly 134. Also like die 12, microlayer assembly 134 includes an

annular, microlayer fluid passage 162 and a plurality of microlayer distribution plates 148.

As shown in FIGS. 7 and 9, each of the distribution plates 132 has a fluid inlet 136 and a fluid outlet 138, wherein the fluid outlet from each of plates 132 is in fluid communication with the primary fluid passage 142 and structured to deliver a layer 170 of fluid to the primary fluid passage 142. Distribution plates 132a-c are similar in structure and function to distribution plates 32a-c as described above. In both of plates 132a-c and 32a-c, fluid is received at fluid inlet 136/36, positioned near the outer periphery of the plate, and directed inwards towards the fluid outlet 138/38, e.g., along spiral-shaped fluid-flow channels 140/40. However, instead of the semi-circular or semi-oval cross-sectional channel shapes depicted for channels 40 in plates 32 (see FIG. 2), the channels 140 in plates 132 are illustrated with a fuller shape, i.e., an oval/circular cross-sectional shape (FIG. 7).

Each of the microlayer plates 148 has a fluid inlet 150 and a fluid outlet 152, wherein the fluid outlet 152 from each of the microlayer plates 148 is in fluid communication with microlayer fluid passage 162 and structured to deliver a microlayer 168 of fluid to the microlayer fluid passage 162 (FIG. 9). The fluid inlet 150, in turn, fluidly communicates with fluid outlet 152 via spiral-shaped fluid-flow channel 154. Microlayer plates 148 thus perform the same function as microlayer plates 48 as described above, i.e., connecting the fluid inlet 150/50 with the fluid outlet 152/52 in such a manner that the flow of fluid through the microlayer assembly 134/34 is converted from a generally stream-like, axial flow to a generally film-like flow towards and into the microlayer fluid passage 162. However, unlike microlayer plates 48, in which the fluid is directed in a convergent radial flow towards the center 58 of the plate, microlayer plates 148 are configured such that the fluid flows outwards towards the periphery 151 of the microlayer plates 148, at which fluid outlet 152 is located (FIG. 8).

Thus, as shown collectively in FIGS. 7-9, fluid may enter each of the microlayer plates 148 at fluid inlet 150, from which it is directed spirally outwards along fluid-flow channel 154, and exits each plate at fluid outlet 152, located at periphery 151. As with microlayer plates 48, channel 154 in microlayer plates 148 may be fashioned with a progressively shallower depth as the channel

approaches the fluid outlet 152. This has the effect of causing some of the fluid flowing through the channel 154 to overflow the channel and proceed radially-outward toward the fluid outlet 152 in a relatively flat, film-like flow. Such radial-outward flow may occur in overflow regions 153, which may be located between the spaced-apart spiral sections of channel 154. The overflow regions 153 may be formed as recessed sections in plate 148, i.e., recessed relative to the thicker, non-recessed region 155 located inside of the channel 154 and surrounding the central orifice 158 at the center of the plate. Central orifices 158 in plates 148 may be used to align the plates in microlayer assembly 134, e.g., with an alignment pin or the like (not shown).

Like plates 48, overflow regions 153 in microlayer plates 148 may begin at step-down 157 and, unlike plates 48, spiral outwards (instead of inwards in plates 48) towards fluid outlet 152 between the spirals of channel 154. The non-recessed, central region 155 abuts against the plate or other structure above the plate, e.g., as shown in FIG. 7, and thus prevents fluid from flowing towards the center of the plate such that the fluid must flow outwards towards the periphery 151 of the plate, so that it exists the plate at fluid outlet 152. Similar to the step-down 57 in microlayer plates 48, step-down 157 in plates 148 represents a line or zone of demarcation between the 'no-flow' central region 155 and the peripheral 'flow' regions 153 and 154.

Accordingly, it may be appreciated that microlayer plates 48 and 148 both shape the fluid flowing through the plates into a ring-like flow pattern, for delivery into the microlayer fluid passage 62/162 as a cylindrical microlayer 68/168. The primary difference between the two plates is that the microlayered fluid ring 68 from each plate 48 is delivered to microlayer fluid passage 62 in a convergent fashion, from an outer position on the plate to an inner position at the center 58 of the plate where fluid outlet 52 is located, whereas the microlayered fluid ring 168 from each plate 148 is delivered to microlayer fluid passage 162 in a divergent fashion, from an inner position on the plate to an outer position at the periphery 151 of the plate where fluid outlet 152 is located.

Similar to microlayer plates 148, distribution plates 132d-e receive fluid at fluid inlet 136, which is positioned within the distribution plates 132d-e, and direct it divergently out of the plate at an outwardly directed fluid outlet 138. As may be

appreciated, with the configuration illustrated in FIG. 7, this arrangement allows the microlayers 168 from microlayer assembly 134 to be encapsulated on the outside by thicker layers from upstream distribution plates 136a-c, and on the inside by thicker layers from downstream distribution plates 136d-e. If desired, the fluid outlet 138 for distribution plate 132d may be arranged, e.g., angled upwards, so that the fluid from plate 132d will merge with the microlayered fluid mass 160 substantially simultaneously with the transfer of the microlayered fluid mass from the microlayer fluid passage 162 and into the primary fluid passage 142.

With reference to FIGS. 7 and 9, die 112 may include an annular forming stem 146 having an inner surface 172 and an outer surface 173. As shown, the annular forming stem 146 may be configured within the die such that the fluid outlet 138 from distribution plates 132a-c is in fluid communication with, and structured to deposit a layer of fluid onto, the outer surface 173 of forming stem 146. On the inside of the annular forming stem 146, the fluid outlet 152 from each of the microlayer plates 148 is in fluid communication with, and structured to deposit a microlayer of fluid onto, the inner surface 172 of the forming stem. Depending on the number of distribution plates 132 and/or microlayer plates 148, the forming stem 146 may have the shape of an annular cylinder, e.g., as shown in FIG. 7, with sufficient inner and outer surface lengths 172, 173 to accommodate such plates.

Accordingly, it may appreciated that in die 112, primary fluid passage 142 extends along the outer surface 173 of annular forming stem 146, while microlayer fluid passage 162 extends along the inner surface 172 of the forming stem. In comparison, while microlayer forming stem 46 in die 12 is also annular, the primary fluid passage 42 of die 12 extends along the inner surface of the forming stem 46, while the microlayer fluid passage 62 extends along the outer surface of the forming stem 46 (see FIG. 2). In die 112, the microlayer fluid passage 162 is in the shape of an annular cylinder, which is formed by a gap between the periphery 151 of the microlayer plates 148 and the inner surface 172 of annular forming stem 146. In die 12, the microlayer fluid passage 62 is also in the shape of an annular cylinder, which is formed by a gap between the

orifices 58 of the microlayer plates 48 and the outer surface of the annular, microlayer forming stem 46.

Nevertheless, dies 12 and 112 accomplish the same goal – they both allow the microlayers 68/168 to form into a unified fluid mass 60/160 in the microlayer fluid passage 62/162 prior to merging with the relatively thick layers 70/170 from the distribution plates 32/132, thereby preserving the physical integrity and independent properties of the microlayers. As with die 12, therefore, the microlayer fluid passage 162 of die 112 is in fluid communication with the primary fluid passage 142 such that the microlayered fluid mass 160 flows from the microlayer fluid passage 162 and into the primary fluid passage 142, as shown in FIG. 9. Fluid communication between the primary fluid passage 142 and the microlayered fluid passage 162 may be achieved by structuring the inner and outer surfaces 172, 173 of annular forming stem 146 such that the microlayered fluid mass 160 merges with the fluid(s) 170 from the distribution plates 132a-c, e.g., by providing an annular transfer gap 164, as a junction at which the inner and outer surfaces 172, 173 join together. As shown in FIG. 9, the annular transfer gap 164 is also the junction at which the microlayered fluid passage 162 merges with the primary fluid passage 142, just as the annular transfer gap 64 in die 12 is the junction at which the microlayered fluid passage 62 merges with the primary fluid passage 42. The microlayered fluid mass 60/160 and the fluid(s) 70/170 from the distribution plates 132a-c thus merge together in the primary fluid passage 42/142, in which the combined flows of the microlayers 68/168 and thick layers 70/170 continue their journey through die 12/112.

With continuing reference to FIG. 7 and 9, it may be seen that the microlayer plates 148 are arranged to provide a predetermined order in which the microlayers 168 are delivered to microlayer fluid passage 162 to form a substantially unified, microlayered fluid mass 160 in the microlayer fluid passage 162. Delivery of the microlayers to the fluid passage 162 such that the microlayers join and form microlayered fluid mass 160 is facilitated in die 112 by including a microlayer forming surface, i.e., the inner surface 172 of the annular forming stem 146, onto which the microlayers may be deposited. A microlayer forming surface is also provided in die 12, i.e., the outer surface of the annular,

microlayer forming stem 46, onto which the microlayers are deposited to facilitate their assembly into microlayered fluid mass 60 in microlayer fluid passage 62.

In the illustrated die 112, fifteen microlayer plates 148 are again depicted (as in dies 12 and 12' above), although a greater or lesser number of microlayer plates could, of course, also be employed in die 112. If all fifteen microlayer distribution plates 148a-o are supplied with fluid, a microlayer 168 of fluid from plate 148a will be the first to be delivered into microlayer fluid passage 162 such that such microlayer will be in direct contact with the inner surface 172 of annular forming stem 146. The next microlayer to be delivered into fluid passage 162 would be from microlayer plate 148b. This microlayer will be deposited onto the microlayer from plate 148a. Next, fluid from microlayer plate 148c will be deposited on top of the microlayer from plate 148b, etc. The last and, therefore, outermost microlayer to be deposited is from plate 148o. In this manner, the microlayers 148 are delivered to the microlayer fluid passage 162 in the form of a substantially unified, microlayered fluid mass 160 (see FIG. 9). In the present example, such microlayered fluid mass 160 comprises fifteen distinct microlayers (at the downstream end of microlayer fluid passage 162), arranged as fifteen concentric cylindrical microlayers bonded and flowing together in a predetermined order, based on the ordering of the microlayer plates 148a-o in microlayer assembly 134. The extent of the gap between the periphery 151 of the microlayer plates 148 and the inner surface 172 of annular forming stem 146, which forms the microlayer fluid passage 162, is preferably sufficient to accommodate the volume of the concentric microlayers 148 flowing in such fluid passage 162.

In die 112, as in die 12, fluids 170 from distribution plates 132 and fluids 168 from microlayer assembly 134 flow along primary fluid passage 142 and out of die 112 at discharge end 120, wherein annular discharge opening 144 is located. As shown in FIG. 7, at least some of the distribution plates 132, e.g., distribution plates 132a-c, may be located upstream of the microlayer assembly 134 along primary fluid passage 142, i.e., the fluid outlets 138 of such plates 132a-c may be located upstream of transfer gap 164 along primary fluid passage 142. Alternatively or in addition, at least some of the distribution plates, e.g.,

distribution plates 132d-e, may be located downstream of the microlayer assembly 134 along the primary fluid passage 142, i.e., the fluid outlets 138 of such plates 132d-e may be located downstream of transfer gap 164 along primary fluid passage 142. As a further alternative, which is illustrated in FIG. 7, microlayer assembly 134 may be positioned between one or more upstream distribution plates, e.g., plates 132a-c, and one or more downstream distribution plates, e.g., 132d-e.

Prior to the merger of the microlayers 168 with the thick layers 170 from upstream distribution plates 132a-c at transfer gap 164, such layers may flow separately in an axial direction through die 112 along essentially parallel paths, e.g., along the inner and outer surfaces 172, 173 of annular forming stem 146, with the microlayers 168 flowing in microlayer fluid passage 162 and the thick layers 170 flowing in the primary fluid passage 142. Following the microlayer/thick layer merger at transfer gap 164, all fluid layers, including any additional thick layers 170 as supplied by downstream distribution plates 132d-e, flow together in primary fluid passage 142, until their collective exit from the die at discharge opening 144.

Fluid(s) may be supplied to die 112 generally as described above, e.g., with extruders and feed pipes (not shown in FIG. 7). With the configuration of die 112 as shown in FIG. 7, all of the distribution plates and microlayer plates shown may be supplied with fluid, i.e., via the various feed ports and feed passages illustrated. Thus, upstream distribution plates 132a-c may each be supplied with fluid via respective feed ports 176a-c and associated feed passages 178a-c. Each feed port 176 may be coupled to a feed pipe (not shown), which may be connected at the other end to an extruder (not shown) to supply, e.g., molten polymer to die 112. Downstream distribution plates 132d-e may similarly be supplied with fluid via respective feed ports 176d-e and associated feed passages 178d-e. As shown in FIG. 7, a portion of the feed passages 178d-e extends through microlayer assembly 134. Microlayer distribution plates 148 may thus include passage holes 179 to facilitate such extension of the feed passages 178d-e through the assembly 134 (FIG. 8). Microlayer plates 148 may also include bolt holes 184 (FIG. 8), to facilitate the assembly of die 112, e.g., via bolts 186 (FIG. 7).

Microlayer assembly 134 may be supplied with fluids via feed ports 180a-b and respective feed passages 182a-b. In the illustrated configuration, microlayer plates 148a, c, e, g, i, k, m, and o are in fluid communication with, and therefore may be supplied via, feed port 180a/feed passage 182a. Microlayer plates 48b, d, f, h, j, l, and n are in fluid communication with, and therefore may be supplied via, feed port 180b/feed passage 182b.

The fluids supplied to microlayer assembly 134 may be distributed through the assembly in the same manner as described above. Thus, fluid entering microlayer plate 148a at fluid inlet 150 may be split, with some of the fluid entering channel 154 (for delivery into microlayer fluid passage 162 as the first microlayer 168 to be so delivered), while the remainder of the fluid may pass through microlayer plate 148a via an outlet port (not shown), e.g., as shown at 84 in FIGS. 3-4. Microlayer plate 148b may be oriented, i.e., rotated, such that through-hole 174 (FIG. 8) is positioned beneath the outlet port of microlayer plate 148a so that the fluid flowing out of the outlet port flows through the microlayer plate 148b, and not into the channel 154 thereof. Microlayer plate 148c may be positioned such that the fluid inlet 150 thereof is in the same location as that of microlayer plate 148a so that fluid flowing out of through-hole 174 of microlayer plate 148b flows into the inlet 150 of plate 148c. This arrangement may continue throughout the rest of the microlayer assembly 134 such that microlayer plates 148a, c, e, g, i, k, m, and o in fluid communication with feed port 180a/feed passage 182a are supplied with fluid, which is converted by each microlayer plate into microlayers and delivered into microlayer fluid passage 162. By a similar arrangement, microlayer plates 48b, d, f, h, j, l, and n are in fluid communication with feed port 180b/feed passage 182b may also be supplied with fluid, e.g., the same or a different fluid, for conversion thereof into microlayers and delivery into fluid passage 162. The end result will be a microlayered fluid mass 160 having fifteen microlayers alternating in composition between those formed by microlayer plates 148a, c, e, g, i, k, m, and o and those formed by microlayer plates 48b, d, f, h, j, l, and n.

The foregoing description of preferred embodiments of the invention has been presented for purposes of illustration and description. It is not

intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention.

WHAT IS CLAIMED IS:

1. A die for coextruding a plurality of fluid layers, comprising:

a. a primary fluid passage;

b. one or more distribution plates, each of said plates having a fluid inlet and a fluid outlet, the fluid outlet from each of said plates being in fluid communication with said primary fluid passage and structured to deliver a layer of fluid to said primary fluid passage; and

c. a microlayer assembly, comprising

(1) a microlayer fluid passage, and

(2) a plurality of microlayer distribution plates, each of said microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of said microlayer plates being in fluid communication with said microlayer fluid passage and structured to deliver a microlayer of fluid to said microlayer fluid passage, said microlayer plates being arranged to provide a predetermined order in which the microlayers are delivered to said microlayer fluid passage to form a substantially unified, microlayered fluid mass in said microlayer fluid passage,

wherein, said microlayer fluid passage is in fluid communication with said primary fluid passage such that said microlayered fluid mass flows from said microlayer fluid passage and into said primary fluid passage.

2. The die of claim 1, wherein the fluids from said distribution plates and said microlayer assembly flow along said primary fluid passage and out of said die at a discharge end.

3. The die of claim 2, wherein said distribution plates are located upstream of said microlayer assembly along said primary fluid passage.

4. The die of claim 2, wherein said distribution plates are located downstream of said microlayer assembly along said primary fluid passage.

5. The die of claim 2, wherein said microlayer assembly is positioned between one or more upstream distribution plates and one or more downstream distribution plates.

6. The die of claim 1, further including one or more additional microlayer assemblies.

7. A die for coextruding a plurality of fluid layers, comprising:

a. an annular forming stem having an inner surface and an outer surface;

b. one or more distribution plates, each of said plates having a fluid inlet and a fluid outlet, the fluid outlet from at least one of said plates being in fluid communication with, and structured to deposit a layer of fluid onto, the outer surface of said forming stem; and

c. a microlayer assembly, comprising a plurality of microlayer distribution plates, each of said microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of said microlayer plates being in fluid communication with, and structured to deposit a microlayer of fluid onto, the inner surface of said forming stem, said microlayer plates being arranged to provide a predetermined order in which the microlayers are deposited onto said inner surface in order to form a substantially unified, microlayered fluid mass thereon,

wherein, said inner and outer surfaces of said forming stem are structured to cause said microlayered fluid mass to merge with the fluid from said distribution plates.

8. The die of claim 7, wherein said microlayered fluid mass and the fluid from said distribution plates merge together in a primary fluid passage.

9. The die of claim 8, wherein said primary fluid passage extends along said outer surface of said forming stem such that the fluid outlet from each of said distribution plates fluidly communicates with said primary fluid passage.

10. The die of claim 9, wherein a microlayer fluid passage extends along said inner surface of said forming stem such that the fluid outlet from each of said microlayer plates fluidly communicates with said microlayer fluid passage.

11. The die of claim 10, wherein said microlayer fluid passage is in fluid communication with said primary fluid passage such that said microlayered fluid mass flows from said microlayer fluid passage and into said primary fluid passage.

12. The die of claim 11, wherein the fluids from said distribution plates and said microlayer assembly flow along said primary fluid passage and out of said die at a discharge end.

13. The die of claim 12, wherein said distribution plates are located upstream of said microlayer assembly along said primary fluid passage.

14. The die of claim 12, wherein said die includes one or more additional distribution plates, which are located downstream of said microlayer assembly along said primary fluid passage.

15. The die of claim 12, wherein said microlayer assembly is positioned between one or more upstream distribution plates and one or more downstream distribution plates.

16. The die of claim 7, further including one or more additional microlayer assemblies.

17. A die for coextruding a plurality of fluid layers, comprising:

a. a microlayer assembly, comprising

(1) a microlayer forming surface, and

(2) a plurality of microlayer distribution plates, each of said microlayer plates having a fluid inlet and a fluid outlet, the fluid outlet from each of said microlayer plates being in fluid communication with said microlayer

forming surface and structured to deposit a microlayer of fluid onto said microlayer forming surface, said microlayer plates being arranged to provide a predetermined order in which the microlayers are deposited onto said microlayer forming stem to form a substantially unified, microlayered fluid mass on said microlayer forming surface; and

b. one or more distribution plates, each of said plates having a fluid inlet and a fluid outlet, the fluid outlet from at least one of said distribution plates being in fluid communication with said microlayer forming surface such that said microlayered fluid mass merges with fluid from said distribution plates.

FIG. 1

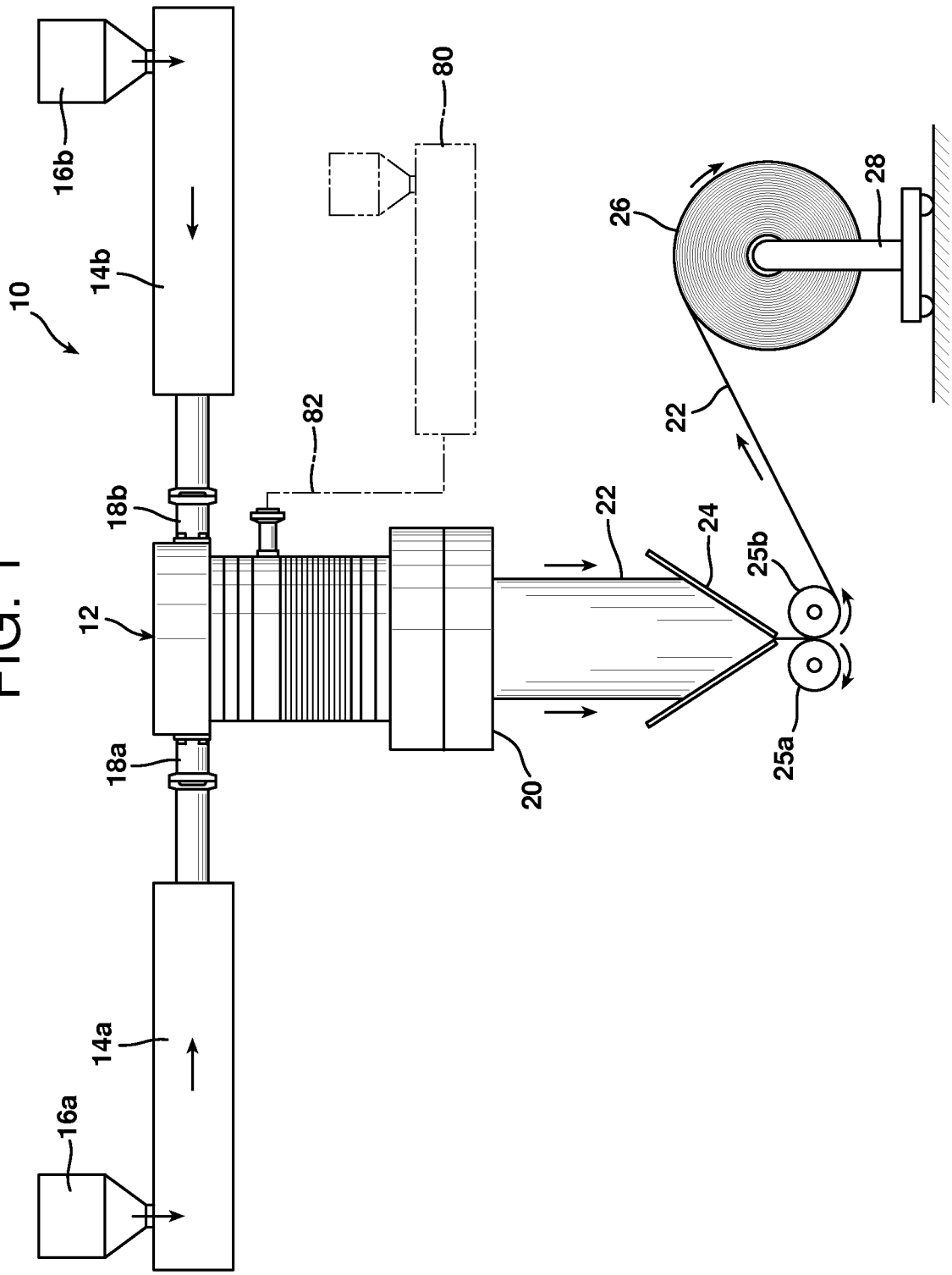


FIG. 2

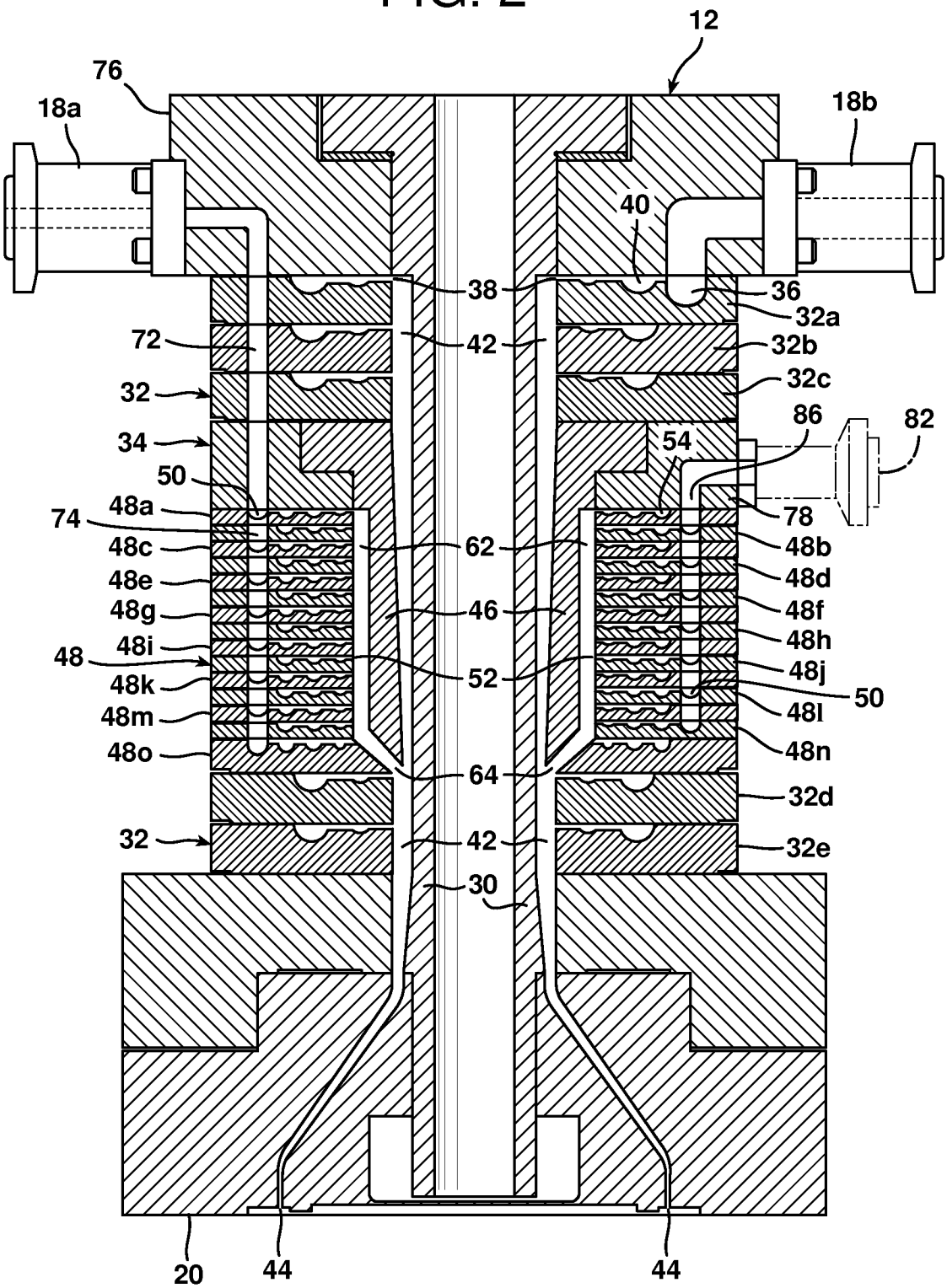

12
76
18a
18b
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38
36
32a
72
42
32b
32
32c
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86
82
54
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48a
74
78
48c
62
48b
48e
48d
48g
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48f
48i
48h
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48j
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32d
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32e
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FIG. 3

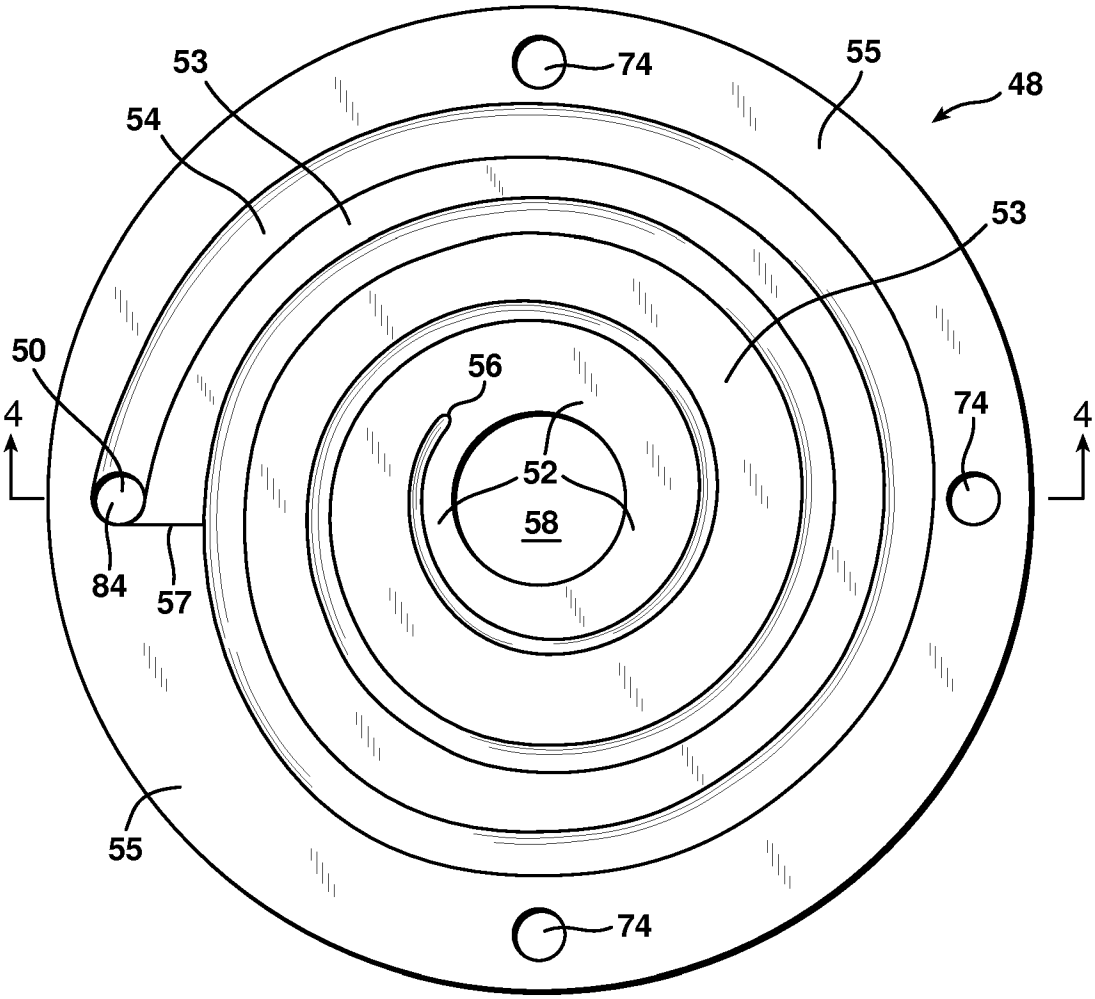
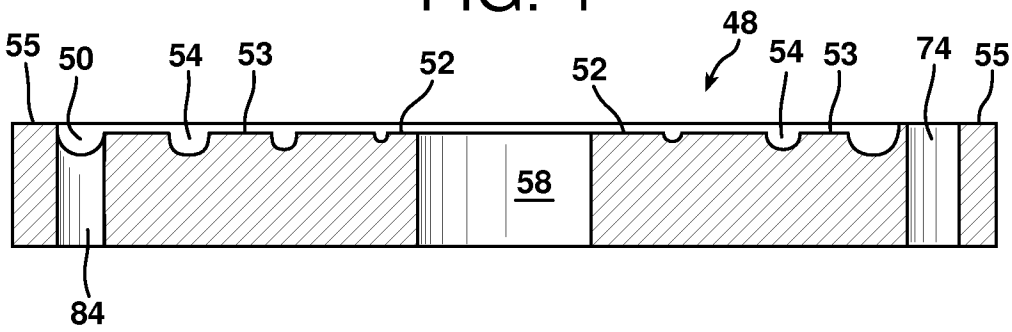

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FIG. 4


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74
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58
84

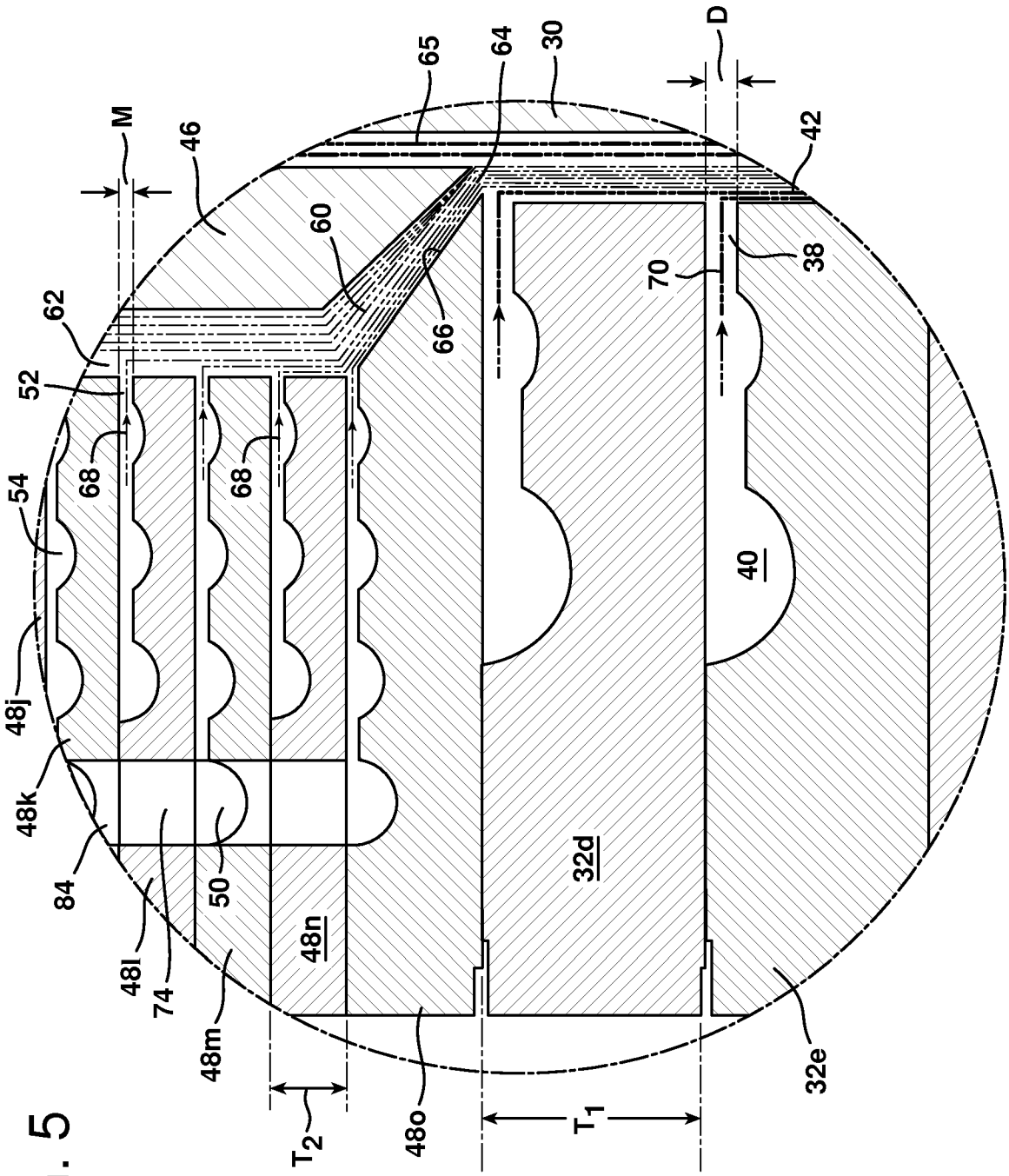
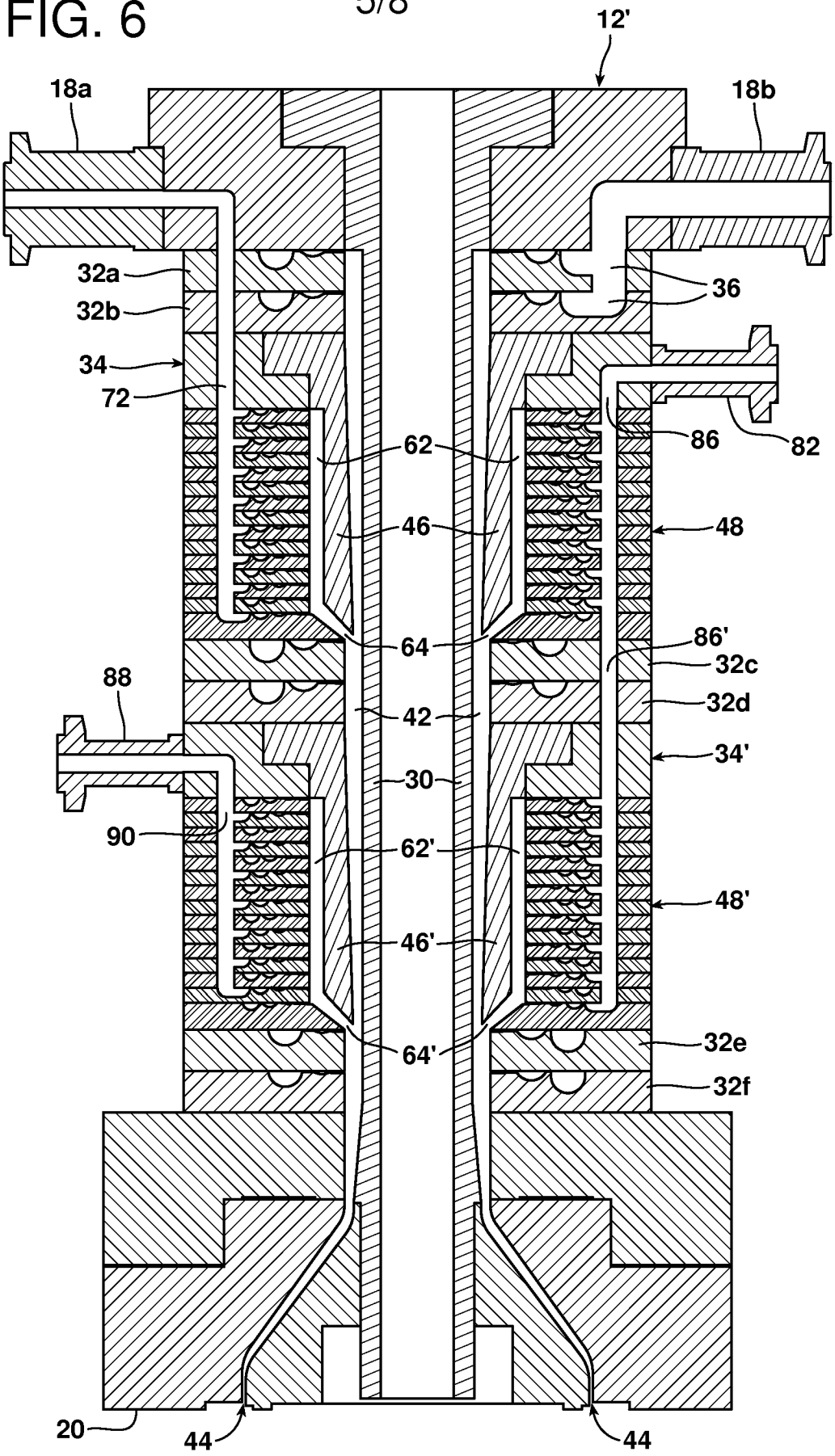

M
46
65
64
30
D
42
60
66
62
52
54
68
68
70
38
40
48j
48k
84
50
48l
74
48m
48n
32d
48o
32e
T_2
T_1

FIG. 5

FIG. 6


12'
18a
18b
32a
32b
34
72
36
86
82
62
46
48
64
86'
32c
88
42
32d
34'
30
90
62'
48'
46'
64'
32e
32f
20
44
44

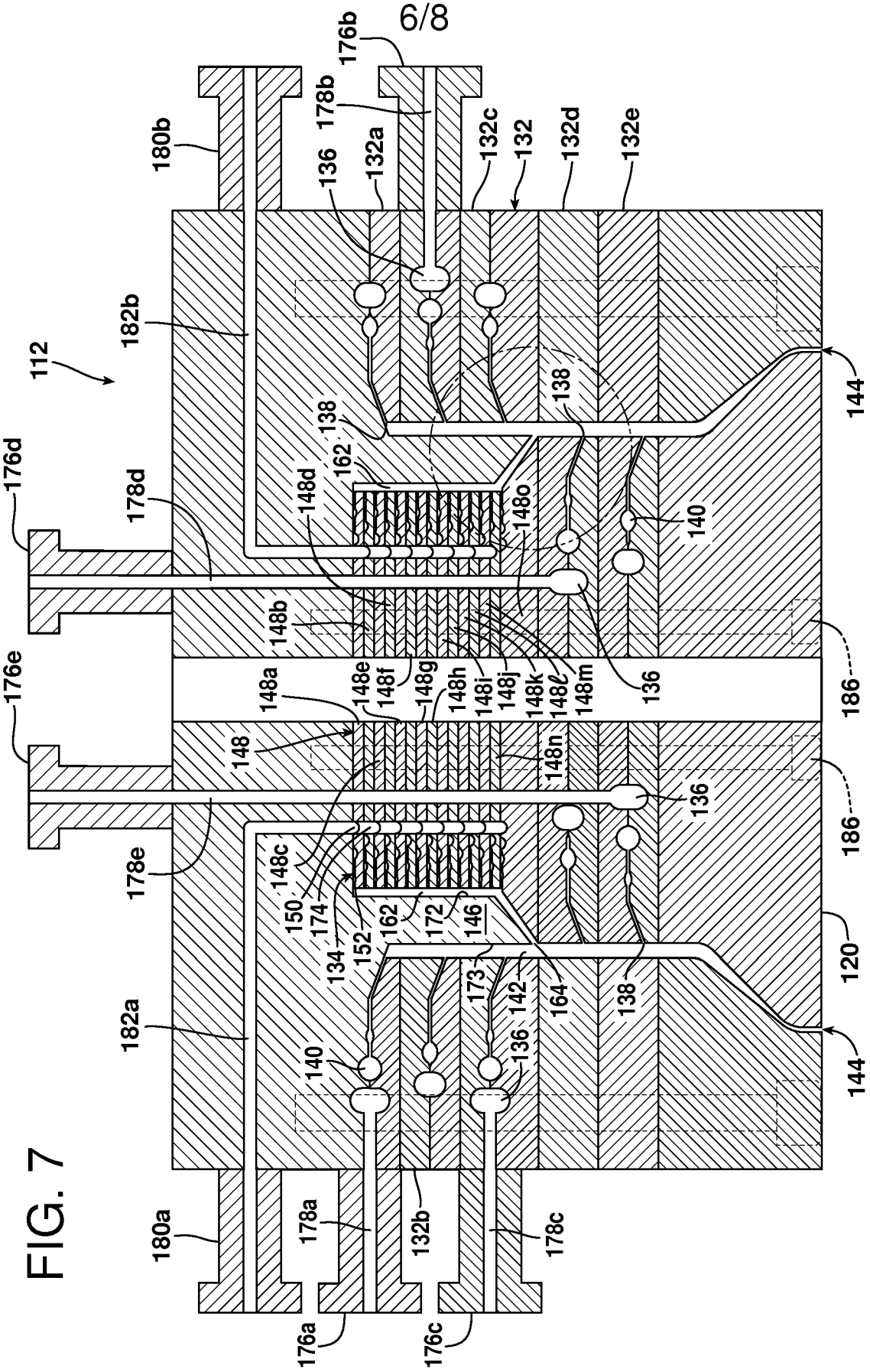

176b
178b
180b
136
132a
132c
132
132d
132e
182b
112
138
144
176d
178d
162
148d
148o
140
148b
148a
148e
148f
148g
148h
148i
148j
148k
148l
148m
136
186
176e
148
148n
178e
148c
150
174
162
172
146
152
134
173
142
164
120
182a
140
180a
178a
132b
178c
176a
176c

FIG. 7

FIG. 8

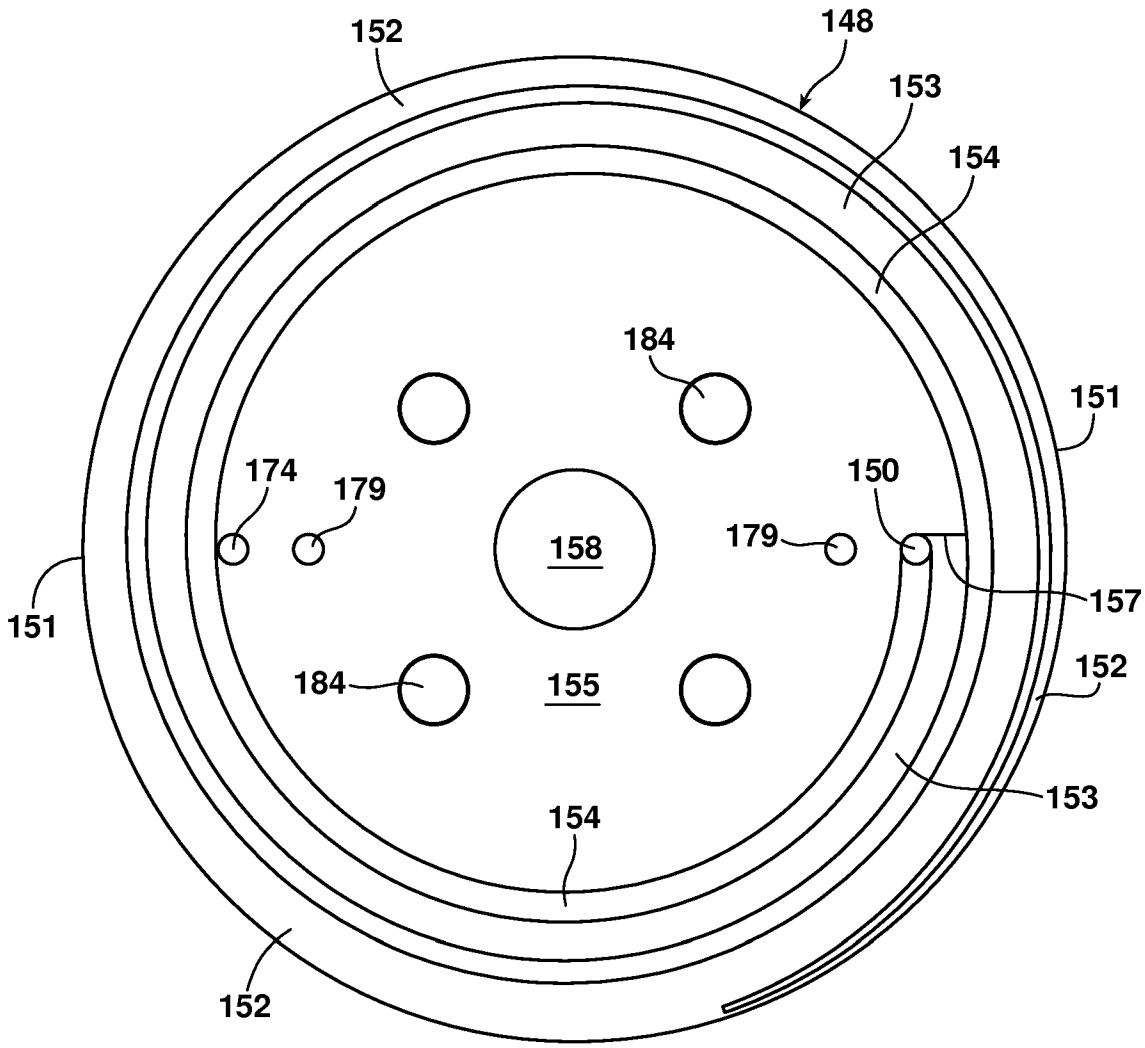
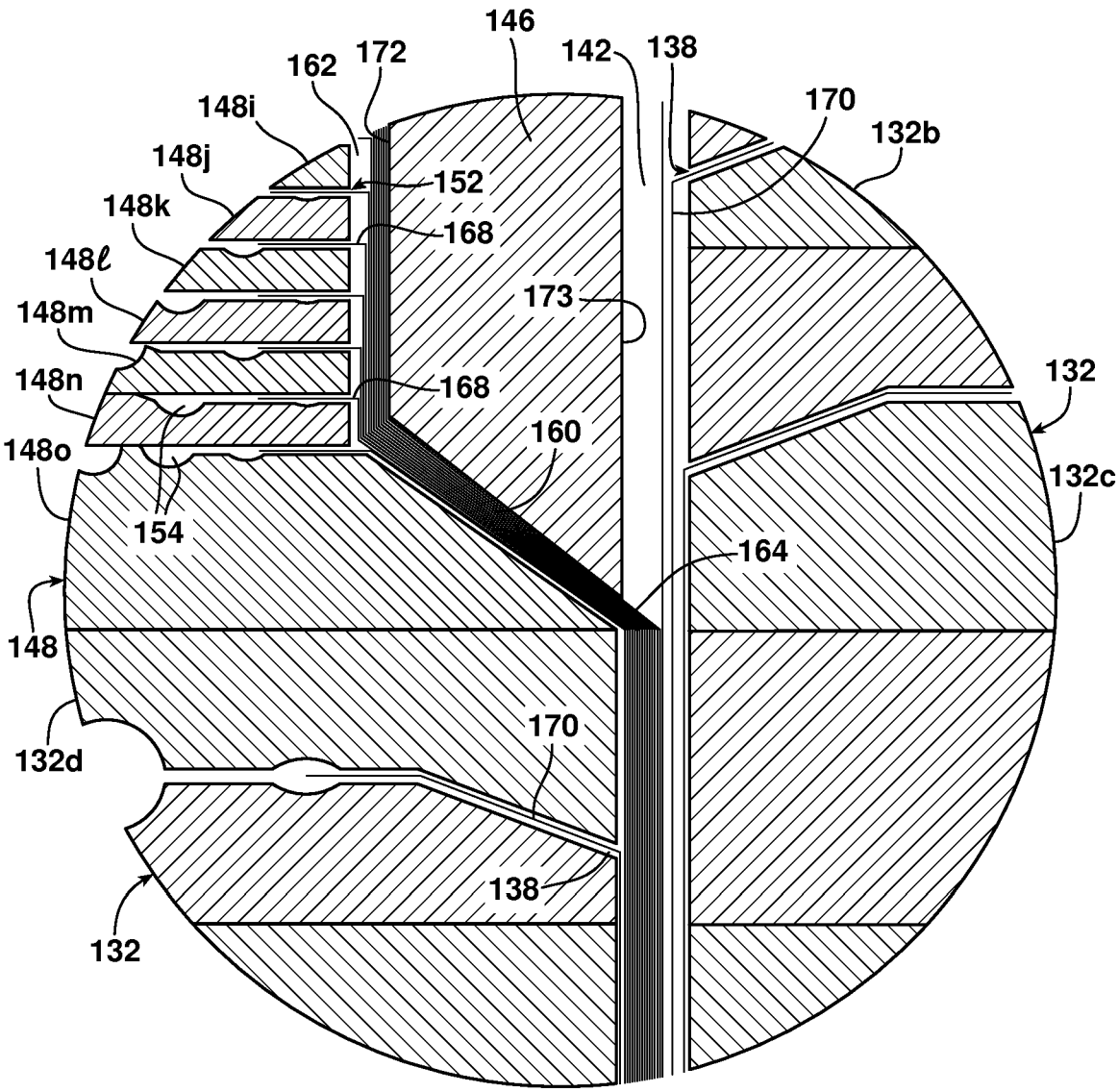

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148
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184
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184
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154
152

FIG. 9


146
142
138
162
172
148i
170
132b
148j
152
148k
168
148ℓ
173
148m
132
148n
168
160
148o
132c
154
164
148
170
132d
138
132

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/028018

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C47/06
ADD.

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

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 practical, search terms used)
EPO-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	US 2003/020204 A1 (DAVIDSON RANDOLPH L [US] ET AL) 30 January 2003 (2003-01-30) paragraphs [0024] - [0030], [0040], [0045], [0049] - [0058]; figures 1-3,5,6	1,2,4,6, 17

☐ 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 document 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	Date of mailing of the international search report
27 April 2011	29/07/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Baran, Norbert

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/028018

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1, 2, 4, 6, 17

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1, 2, 4, 6, 17

   A die for coextruding a plurality of fluid layers.

   ---

2. claims: 1-3

   A die for coextruding a plurality of fluid layers, wherein distribution plates are located upstream of a microlayer assembly along a primary fluid passage.

   ---

3. claims: 1, 2, 5

   A die for coextruding a plurality of fluid layers, wherein a microlayer assembly is positioned between one or more upstream distribution plates and one or more downstream distribution plates.

   ---

4. claims: 7-16

   A die for coextruding a plurality of fluid layers comprising an annular forming stem having an inner surface and an outer surface.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2011/028018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003020204 A1	30-01-2003	EP 1419043 A1	19-05-2004
		WO 03011565 A1	13-02-2003