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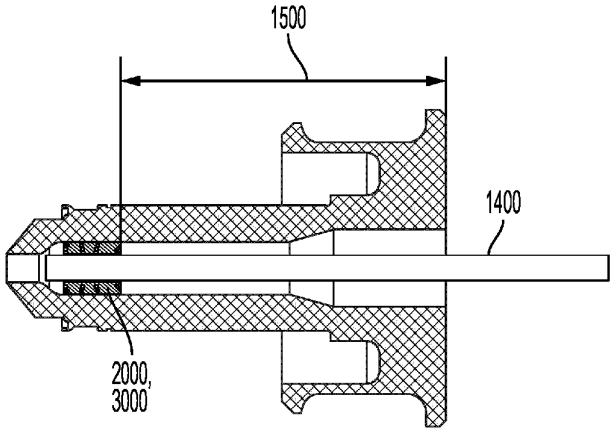


FIG. 4A

(57) Abstract: The invention is directed to a mixing device, a nozzle collar comprising a monolithically integrated mixing device, a system for mixing a composition and a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent. The present invention achieves superior mixing performances of the composition comprising a primary constituent and at least one auxiliary constituent through the application of predictable, mathematically governed mixing principles, exercised on discrete portions of the polymer melt, flowing through a plurality of open and isolated channels.

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[Continued on next page]

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INSERTS FOR IMPROVED MIXING AND METHODS OF USE

CROSS REFERENCES AND PRIORITIES

[0001] This application claims priority from United States Provisional Application No. 63/803,009 filed 9 May 2025, the teachings of which are incorporated in their entirety.

BACKGROUND

[0002] In polymer processing, neat polymers (referred to as a primary constituent or the primary constituent in this specification) often require the addition of auxiliary constituents, such as additives or other polymers, to enhance their mechanical, thermal, barrier or chemical properties. Even small amounts of these auxiliary constituents can significantly alter the final polymer composition properties compared to the neat polymer counterpart. A common method for combining these constituents is during the injection moulding process, where the polymer is typically melted in the screw of the injection moulding machine, to which the auxiliary constituents are added in a solid or liquid state, and subsequently mixed and injected into the mould. For avoidance of doubt, in this specification, and in accordance with to the present invention, the word “melt stream”, whether singular or plural is equivalent to a “composition comprising a primary constituent and at least one auxiliary constituent”.

[0003] A key challenge in the injection moulding process is ensuring and maintaining a good mix of the primary constituent and the at least one auxiliary constituent. The concentration of the at least one auxiliary constituent from one location inside the injection melt stream comprised of the primary constituent and at least one auxiliary constituent to another location is often variable. For example, if the at least one auxiliary constituent is a solid, like a color particle, or fluid like a liquid colorant, the at least one auxiliary constituent is to be dispersed to the extent possible within the primary constituent. However, this typically does not happen in laminar flow systems with low Reynolds numbers. Many of the color particles remain clumped together with each other, or the liquid, which is typically immiscible or less miscible with the primary constituent, are present as different sized droplets/phases within the primary constituent.

[0004] A good mix provides both good dispersion and good distribution of the auxiliary constituents within the primary constituent (polymer) matrix in the finished injection

moulded article. This is graphically shown in FIG. 1: the at least one auxiliary constituent moves from starting high concentration (upper left) to a good distribution and good dispersion in other words, inadequate mixing can lead to poor dispersion and distribution, with improper mixing causing the auxiliary constituents to re-agglomerate or coalesce after mixing and before demoulding. This results in inconsistent material properties in the macroscale and can negatively affect the performance of the final moulded product. Therefore, achieving effective mixing during injection moulding is important to ensure the uniformity of the desired properties and functionality in the final composition of the moulded article.

[0005] The effectiveness of mixing of polymer constituents in a polymer composition is largely influenced by the molecular compatibility between the primary polymer and the auxiliary constituents. A useful tool for understanding these interactions is the Hansen Solubility Parameters (HSP), which describe the intermolecular forces between materials based on three key components: dispersion (non-polar) forces, hydrogen bonding (polar) forces, and cohesive forces arising from dipole interactions. When the HSP values of the polymer and auxiliary constituent are similar, the materials are more likely to achieve a more homogenous mix due to favourable interactions.

[0006] However, even when the HSP values suggest compatibility, the mixing process in polymer compositions remains challenging. The high viscosity of the polymer significantly hinders spontaneous molecular diffusion driven by concentration gradients, thus limiting the ability of the auxiliary constituents to diffuse and achieve a homogeneous dispersion and distribution throughout the primary polymer matrix. Furthermore, the residence time in the injection moulding process further restricts the time available for spontaneous diffusion. These combined factors make it difficult for auxiliary constituents to mix effectively with the primary constituent, regardless of their molecular compatibility.

[0007] In cases where there are significant differences in the HSP values between the primary constituent and the auxiliary constituent, poor dispersion and less homogeneity are often observed. This incompatibility exacerbates the difficulty of achieving a uniform mixture.

[0008] In addition to the influence of HSP, the injection moulding process itself operates under conditions that limit the mixing effectiveness. The constituents are subjected to a laminar flow regime, characterized by low Reynolds numbers. While a

laminar flow regime may be advantageous for some aspects of processing, it typically lacks the turbulence necessary to achieve effective mixing which would enhance both the dispersion and the distribution of the constituents. This approach creates a gap where improvements in distribution and dispersion are needed.

[0009] To address these challenges, the prior art proposes using external mixers integrated with the injection moulding machine. These mixers are designed to redirect the flow by inducing a swirling movement of the polymer melt stream. By enhancing the flow dynamics, multiplying, diverting and recombining the flow, and effectively increasing the surface contact area for molecular exchange, the mixers statistically increase the likelihood of forming intermolecular and intramolecular bonds, between the primary and the auxiliary constituents. This improvement in mixing enhances the interaction and uniformity of the mixture.

[0010] However, even when the primary and the auxiliary constituents are well-mixed during the dynamic part of the injection moulding process, re-agglomeration, coalescence, and phase separation can still occur after the dynamic part of the injection cycle, such as during the static filling, the holding cycle and the cooling cycle. The static portion of the injection cycle can last longer than the dynamic portion, and under these conditions, immiscible or insoluble constituents are prone to re-agglomeration, coalescence, and phase separation, driven by material incompatibility. Thus, regardless of the initial mixing achieved during the dynamic part of the process, re-agglomeration, coalescence and phase separation remain important challenges during the static portion of the injection cycle. The static mixers disclosed in the prior art have partially addressed this issue by positioning the static mixers further down in the polymer flow path, including in the hot runner system.

[0011] A hot runner system, also referred to as a nozzle, is a heated assembly comprising an internal channel configured to transport molten polymer from an injection source to a mould gate. Within the hot runner system, the flow at the gate is regulated by a movable needle (valve pin) that mechanically opens and closes the mould gate to provide a precise shut-off. The system includes a nozzle collar - a high-conductivity, replaceable component threaded or seated at the hot runner nozzle end to precisely control gate temperature and seal the melt stream pathway against the mold. It acts as the final interface between the heated manifold and the cavity, ensuring a clean part separation while preventing pressurized plastic from leaking into the mold's plate pocket.

[0012] The hot runner architecture may utilize modular "extra parts" (e.g., detachable nozzle port) to optimize heat transfer and / or maintenance accessibility compared to integrated system logics. The channel of the hot runner system, due to the empty space, could accommodate "free parts," such as protection inserts to filter debris and integrated processing devices like static mixers to ensure melt stream homogeneity.

[0013] Providing design space in the hot runner system, the above mixing principles have been incorporated into various types of mixers in the prior art, such as mixers based on herringbone designs, helical channels and melt stream recombination.

[0014] U.S. Patent Publication 2010/0015275 published Jan.21, 2010, discloses an injection moulding nozzle having an axial passage aperture for a valve needle and contains integrated herringbone flow elements to swirl the polymer melt stream passing through the nozzle. The mixing principle based on herringbone structures, like that disclosed in U.S. Patent Publication 2010/0015275published Jan.21, 2010, has been abundantly described in the prior art. The pattern of the surface grooves, typically in a staggered configuration, induce transverse flows and create chaotic advection in the polymer flow, even at lower Reynolds numbers. However, mixers based on herringbone structures, like disclosed in U.S. Patent Publication 2010/0015275 published Jan.21, 2010, come with several inherent limitations tied to the way they generate flow. Because mixing is driven solely by surface-mounted features, which are only impacting the polymer which is closest to said surface-mounted features, thus its effectiveness drops sharply as channel dimensions increase; the central core of the flow can remain only weakly mixed. The sharp chevron corners that create the transverse vortices can also become trapping points, leading to dead zones, exposure to local high shear rates, melt stream accumulation, or uneven residence-time distribution. Although deeper or more complex grooves can enhance mixing performance, they do so at the cost of significantly higher-pressure losses, and excessive shear, pressure losses, and long-term mechanical stress which may be unacceptable in low-energy or pressure-sensitive systems. Finally, the steep, intricate geometry of the herringbone pattern makes the mixer more vulnerable to long-term cyclic pressure loads, reducing mechanical robustness over extended operation U.S. Patent Publication US 2001/0022321A1 published Sep. 20, 2001 discloses another principle of mixing, based on the presence of open or isolated channels introducing a spiral or helical movement to the polymer flow, herewith generating rotational flow and radial melt stream redistribution as

the polymer exists these channels. This mechanism improves flow uniformity downstream, with distributive mixing arising from rotational reorientation of the melt stream.

[0015] However, mixers based on the presence of spiraling or helical channels, like disclosed in U.S. Patent Publication 2001/0022321A15, published Sep. 20, 2001, face several inherent limitations due to the nature of the flow they generate. Because the swirling motion only weakly disrupts the polymer flow path, the polymer can remain at nearly constant radial positions, leading to segregated flow layers that never fully interpenetrate. Mixing depends on maintaining a continuous helical motion rather than on discrete reorientation events, which makes these designs less capable of breaking laminar stratification. Their efficiency drops further when viscosity increases or when flow rates are low, since the swirling motions after exiting the mixer become too weak to mix the polymer meaningfully. In designs where the channel geometry opens or closes along the helical path, the flow may follow the curvature without mixing unless the channels merge, limiting the creation of strong interfacial stretching. Moreover, because the helical architecture cannot generate sharp, localized disturbances or abrupt directional changes, it lacks the intense flow perturbations needed for rapid homogenization, resulting in slower and less complete mixing overall.

[0016] U.S. Patent Publication 4,027,857 published June 7, 1977, discloses a series of fixed internal elements, where the polymer melt stream is repeatedly divided, twisted and recombined to increase mixing performance. The prior art contains a myriad of executions based on the principle of melt stream recombination. However, mixers based on flow recombination, like disclosed in U.S. Patent Publication 4,027,857 published June 7, 1977, face several structural constraints. Although the channels meet in the center, they do not create any layer-stacking effect, and the flow remains governed by random collisions rather than controlled recombination. The flow patterns as disclosed in the prior art introduce a significant risk to create preferential flows at the wall of the mixer due to the memory effect driven by the laminar nature of the high viscosity polymer. As a result, individual flow paths do not allow radial displacement of the polymer, hence no flow inversion. There is no reliable way to predict how mixing efficiency scales with the mixer size. Furthermore, the flow patterns as disclosed in the prior art force the polymer into sharp turns, disrupting smooth melt stream and increasing the risk of instabilities or stagnation zones. These abrupt

geometric transitions also experience high mechanical loads, making the mixer less durable under long-term, cyclic pressure operations.

[0017] Regardless of the underlying execution to increase mixing performance, whether based on herringbone structures, helical channels or melt stream recombination, one of the most basic problems known with the static mixers disclosed in the prior art is that they do not provide the desired combination of effective mixing, with the required resiliency to withstand the substantial and cyclic operational pressures of a plastic injection moulding machine. In practice, the failure of a static mixer in an injection moulding machine has proven to be catastrophic, with mixer remnants flowing throughout the hot runner system, requiring a complete refurbishment of the tool and lost production, both at a significant financial cost. In accordance with the present invention, the present invention provides a solution to the underlying problem of achieving an acceptable longevity under industrial processing conditions.

[0018] Furthermore, many existing mixing systems require modifications to surrounding components, sealing rings, or special housing, creating operational burden for installation and overall increased operational costs.

[0019] There is a clear need for a static mixing approach that overcomes the persistent shortcomings of existing herringbone structures, helical-channel, and uncontrolled melt-recombination devices. Current designs rely heavily on wall-induced perturbations, random collisions, or weak swirling flows after exiting the mixer, which fail to deliver predictable, full-cross-section mixing.

[0020] Existing mixers also struggle with scalability: their performance cannot be reliably predicted when dimensions change, and core regions often remain insufficiently mixed. This creates a need for a geometry whose behavior is mathematically defined, ensuring reproducibility and tunability across different sizes and operating conditions. Likewise, prior-art designs cannot selectively manipulate flow components or enforce controlled radial migration, making it desirable to achieve deliberate inward and outward movement of the polymer melt stream to eliminate unmixed cores and allow the polymer melt stream to fully interpenetrate.

[0021] In summary, the limitations of prior art create a strong need for a static mixer that delivers predictable, controllable, full-cross-section mixing while avoiding swirling or

wall-dependent mechanisms that ensures smooth, low-stress flow behavior while fitting seamlessly into the existing processing environment.

SUMMARY

[0022] This specification discloses a mixing device, a nozzle collar comprising a monolithically integrated mixing device, a system and a process for injection moulding a part comprising a primary constituent and at least one auxiliary constituent.

[0023] The present invention is directed to mixing device (2000) for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[0024] Also disclosed as a specific embodiment of the invention is a nozzle collar comprising a monolithically integrated mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels

(3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[0025] Also disclosed is a system for mixing a primary component and at least one auxiliary component, the system comprising an injection nozzle, having a nozzle outlet port (1200), a nozzle melt channel (1300) which houses a needle (1400) and at least one transformation element (3000) of a transformation device (2000) with the transformation device having a transformation device central void zone (2500) surrounding a transformation device central axis (2550) and the needle; wherein at least a portion of the transformation device central void zone lies between the transformation device central axis and the at least one transformation element; and wherein the at least one transformation element has a plurality of melt channels (3100) with at least one melt channel inlet (3200) and at least one melt channel outlet (3300), wherein each melt channel of the plurality of melt channels is fluidly connected with at least one other melt channel of the plurality of melt channels.

[0026] Also disclosed is a system for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element with the mixing device having a mixing device central void zone surrounding a mixing device central axis ; wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[0027] Also disclosed is a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element

with the mixing device having a mixing device central void zone surrounding a mixing device central axis ; wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels with at least one channel inlet and at least one channel outlet, wherein the plurality of channels has at least two isolated channels having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[0028] Also disclosed is a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a nozzle collar comprising a monolithically integrated mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element with the mixing device having a mixing device central void zone surrounding a mixing device central axis; wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels with at least one channel inlet and at least one channel outlet , wherein the plurality of channels has at least two isolated channels having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[0029] It is further disclosed that the primary constituent may be selected from the group consisting of rubbers and plastics which includes, without limitations, the group consisting of polyethylene terephthalate (PET) and its copolymers, polybutylene terephthalate (PBT) and its copolymers, polypropylene (PP) and its copolymers, high and low density polyethylenes (HDPE, LDPE) and their copolymers, nylons (PA), polyvinyl chloride (PVC), polycarbonate (PC), and acrylobutadiene styrene (ABS), natural rubber, silicones, ethylene propylene diene monomer based rubbers, fluorosilicone, nitrile rubber,

polychloroprene, styrene-butadiene, and isoprene and its copolymers. Especially preferred are virgin plastics, recycled plastics or a combination thereof.

[0030] The at least one auxiliary constituent can be selected from the group consisting of, without limitations, colorants, nucleants, clays and a material selected from the group consisting of, without limitations, polyethylene terephthalate (PET) and its copolymers, polybutylene terephthalate (PBT) and its copolymers, polypropylene (PP) and its copolymers, high and low density polyethylenes (HDPE, LDPE) and their copolymers, nylons (PA), polyvinyl chloride (PVC), polycarbonate (PC), and acrylobutadiene styrene (ABS), natural rubber, silicones, ethylene propylene diene monomer based rubbers, fluorosilicone, nitrile rubber, polychloroprene, styrene-butadiene, and isoprene and its copolymers. Especially preferred are virgin plastics, recycled plastics or a combination thereof. A percent volume of the at least one auxiliary constituent is less than or equal to a percent volume of the primary constituent when a volume percentage of all the constituents totals 100%.

BRIEF DESCRIPTION OF FIGURES

[0031] FIG. 1 depicts the distinctions between distribution and dispersion.

[0032] FIG. 2A depicts an embodiment of a prior art nozzle.

[0033] FIG. 2B depicts an embodiment of a prior art nozzle.

[0034] FIG. 3A depicts an embodiment of a prior art nozzle in a closed position.

[0035] FIG. 3B depicts an embodiment of a prior art nozzle in an open position.

[0036] FIG. 4A depicts an embodiment of an improved nozzle containing the mixing device.

[0037] FIG. 4B depicts an embodiment of an improved nozzle containing the mixing device.

[0038] FIG. 4C is an enlargement of FIG. 4A.

[0039] FIG. 4D is an enlargement of FIG. 4B.

[0040] FIG. 5A depicts an embodiment of an improved nozzle with a detachable nozzle port comprising a monolithically integrated mixing device.

[0041] FIG. 5B depicts an embodiment of an improved nozzle with a detachable nozzle collar comprising a monolithically integrated mixing device.

[0042] FIG. 5C depicts another embodiment of an improved nozzle with a detachable nozzle collar comprising a monolithically integrated mixing device.

[0043] FIG. 6A depicts a rear perspective view of an embodiment of a mixing device.

[0044] FIG. 6B depicts a front perspective view of an embodiment of a mixing device.

[0045] FIG. 6C depicts a cross section of a mixing element showing at least two isolated channels within the cross section.

[0046] FIG. 6D depicts the minimum reduced area for flow in a mixing element as compared to a larger area of flow in FIG. 6C.

[0047] FIG. 6E, 6F, 6G, 6H depict various embodiments of mixing elements whereby either isolated or the combination with open channels are present within the cross sections.

[0048] FIG. 7A depicts a rear perspective view of an embodiment of a mixing device monolithically integrated in the detachable nozzle port

[0049] FIG. 7B depicts a front perspective view of an embodiment of a mixing device monolithically integrated in the detachable nozzle port.

[0050] FIG. 8 depicts a numeric representation of the preforms with visually apparent colorant mixing issues produced without using the mixing device (labeled as transformation device) across indicated production time frames and colorant concentrations.

[0051] FIG. 9 depicts a numeric representation of the preforms with visually apparent colorant mixing issues produced using the mixing device (labeled as transformation device) across indicated production time frames and colorant concentrations.

[0052] FIG. 10 depicts an intracavity numeric representation of the preforms with visually apparent colorant mixing issues produced using mixing device (labeled as transformation device) across indicated production time frames and colorant concentrations.

[0053] FIG. 11 depicts a numeric representation of the bottles produced from the preforms injected without using the mixing device (labeled as transformation device) showing visually apparent colorant mixing issues across indicated production time frames and colorant concentrations.

[0054] FIG. 12 depicts a numeric representation of the bottles produced from the preforms injected using the mixing device (labeled as transformation device) showing

visually apparent colorant mixing issues across indicated production time frames and colorant concentrations.

[0055] FIG. 13 depicts an intracavity numeric representation of the bottles showing visually apparent colorant mixing issues produced from the preforms injected using the mixing device (labeled as transformation device) across indicated production time frames and colorant concentrations.

[0056] FIG. 14 depicts a plurality of channels of a plurality of mixing elements on the top and, on the bottom, a cross section of a mixing device showing the mixing elements with the plurality of channel structures.

[0057] FIG 15A depicts a mixing device comprising a mixing element displaying 6 channels within the mixing element.

[0058] FIG. 15B shows the mixing element consisting of channels outside of a mixing device.

[0059] FIG. 15C depicts the structure of the fluid connection of channels having 6 channel inlets and 6 channel outlets, highlighting where and how the isolated channels are fluidly connected to another channel.

[0060] FIG. 16B is the entrance view of the mixing device channels which are isolated from each other.

[0061] FIG. 16A is the cross section of a mixing device showing the mixing elements with the plurality of channel structures. Vertical lines marking the respective cross-sections that are depicted in the cascade of the FIGS. 16C - 16F.

[0062] FIG. 16C is a cross section showing the narrowing of the merged flow channel to about 50% of the cross-sectional flow area at the entry of the mixing element.

[0063] FIG. 16D is another cross section showing the narrowing of the merged flow channel to about 50% of the cross-sectional flow area at the entry of the mixing element. .

[0064] FIG. 16E depicts the cross-section showing the pattern of the isolated channels at the mixing element outlet.

[0065] FIG. 16F depicts the cross section of the transition zone.

[0066] FIG. 17 is a 2-dimensional depiction of how the melt stream is split and recombined as it passes through the channels of the mixing element.

[0067] FIG. 18A depicts the constituents in the channels immediately following the splitting of the stream after entering the mixing element, at position Z=0.

[0068] FIG. 18B depicts the constituents in the channels when they are in fluid contact and the constituents of two channels have merged into one, at position Z=1.

[0069] FIG. 18C depicts the channels when the channels cease to be fluidly connected and are split again, at position z=2.

[0070] FIG. 18D depicts how the constituents have been mixed as they exit the channels.

DETAILED DESCRIPTION

[0071] 1000 depicts a nozzle also referred to as a hot runner system.

[0072] 1100 depicts a nozzle inlet.

[0073] 1150 depicts a nozzle central axis.

[0074] 1200 depicts a nozzle outlet port.

[0075] 1250 depicts a nozzle proximal end.

[0076] 1260 depicts a nozzle distal end.

[0077] 1300 depicts a nozzle channel.

[0078] 1400 depicts a needle or pin.

[0079] 1450 depicts a needle central axis.

[0080] 1500 depicts a nozzle feed zone.

[0081] 1600 depicts a nozzle mixing zone.

[0082] 1650 depicts an optional nozzle transition zone.

[0083] 1700 depicts a nozzle attachment mechanism.

[0084] 1800 depicts a nozzle collar or nozzle tip.

[0085] 1900 depicts a detachable nozzle port.

[0086] 1950 depicts a nozzle body or nozzle housing.

[0087] 2000 depicts a mixing device.

[0088] 2200 depicts a mixing device outer diameter.

[0089] 2300 depicts a mixing device proximal end.

[0090] 2400 depicts a mixing device distal end.

[0091] 2500 depicts a mixing device central void zone.

[0092] 2525 is a mixing device central void zone diameter.

[0093] 2550 depicts a mixing device central axis.

[0094] 2700 depicts the attachment mechanism of the nozzle collar comprising a monolithically integrated mixing device.

[0095] 3000 depicts a mixing element.

[0096] 3100 depicts a mixing element isolated channel.

[0097] 3150 depicts a mixing element open channel.

[0098] 3200 depicts a mixing element channel inlet.

[0099] 3300 depicts a mixing element channel outlet.

[00100] 3500 depicts a mixing element central void zone.

[00101] 3550 depicts a mixing element central axis.

[00102] 4000 depicts an optional mixing device transition zone of a monolithic mixing device.

[00103] 4100 depicts an optional mixing device transition feature of a mixing device monolithically integrated with a nozzle collar, detachable nozzle port or the combination thereof.

[00104] 4200 depicts a mixing device outlet port.

[00105] As mentioned in the background section, there are significant defects for the prior art configurations for static mixers.

[00106] FIGS. 2A,2B, 3A and 3B are prior art systems. As shown in FIGS. 2A and 2B, the current injection moulding machinery has a nozzle (1000) with a nozzle central axis (1150). The melt stream being injected flows into the nozzle channel (1300) at the nozzle inlet (1100) and exits the nozzle via the nozzle outlet port (1200). The nozzle outlet port is located at the distal end of the nozzle (1260).

[00107] In many injection moulding machinery, the nozzle is of unitary construction (FIG. 2A and FIG. 3A). The nozzle can also be of varied constructions, included but not limited to FIG. 2B and FIG. 3B which show a nozzle body (1950) with a detachable nozzle port (1900). In the embodiment shown in FIG. 2B and FIG 3B, the detachable nozzle port is secured to the nozzle body using a nozzle collar (1800).

[00108] As shown in FIG 2B, the nozzle collar can be configured to be attached and tightened to the nozzle body via a nozzle attachment mechanism (1700) which in this case includes outer nozzle threads. However, this is not limiting as shown of FIG. 5C, of the improved nozzle with a detachable nozzle collar comprising a monolithically integrated mixing device, which depicts the nozzle body as having threads around the inside of the nozzle body with the nozzle collar screwing into the nozzle body internal threads.

[00109] FIG. 3A and FIG.3B show prior art FIGS.2A and 2B, with the needle (1400) or pin. The pin/needle can also be referred to as a rod, or rod-like body. The needle will have a needle central axis (1450). The needle central axis is typically co-located with the nozzle central axis. FIG. 2A shows the needle inserted into the nozzle outlet port shutting off the flow of the melt stream through the nozzle and out of the nozzle outlet port into the mould.

[00110] FIG. 3B shows the nozzle in an open position as the needle has been pulled back from the nozzle distal end (FIG. 2A) towards the nozzle proximal end (FIG. 2A, 1250) along

the needle central axis and out of the outlet port allowing the melt stream to flow out of the nozzle outlet port.

[00111] It is important to note that many needle tips and nozzle outlet port configurations exist. In some cases, the needle tip is rounded or conical with the nozzle outlet port configured to receive the needle tip.

[00112] The injection moulding cycle of the present invention relies upon a mixing device through which the composition comprises of a primary constituent and at least one auxiliary constituent before entering the mould.

[00113] The composition comprising of a primary constituent and at least one auxiliary constituent pass through and are acted upon by a mixing device (2000, FIGS. 4A – FIGS. 7B) at least a portion of which is in the nozzle. As illustrated in FIGS. 4A and 4B, the mixing device is configured to occupy the annular volume defined between the needle and the internal nozzle wall.

[00114] A mixing device is configured of mixing element(s), which role is to mix a polymer melt stream that is the composition comprising of a primary constituent and at least one auxiliary constituent by increasing the relative index of mixing as described later. The flow direction being from the mixing element inlet, which is the place where the composition comprising of the primary constituent and at least one auxiliary constituent are introduced into the (first) mixing element, to the mixing element outlet which is the place where the composition comprising of the primary constituent and at least one auxiliary constituent exit from the (last) mixing element.

[00115] FIG. 4B and shows the mixing device being partially fitted inside a detachable nozzle port with the nozzle collar holding the detachable nozzle port against the nozzle body. This detachable nozzle port can also be called the mixing device transition feature when the mixing element(s) (3000) and the mixing device transition feature are attached to one another in a monolithic execution. Since the detachable nozzle port (the mixing device transition feature) forms a transition zone after the mixing element, it is said that the mixing device may also comprise an optional mixing device transition feature.

[00116] As can be seen in FIGS. 4C and 4D the mixing device will have a mixing device central void zone (2500) with a mixing device central void zone central axis (2550), and the central void zone diameter (2525). Because the embodiment is tubular, the mixing device has a mixing device outer diameter (2200). The mixing device central void zone passes

through the mixing device and surrounds the mixing device central void zone central axis. As a void zone, a mixing device void zone is empty with nothing present that is in any way attached to the mixing device or a needle when in use. The mixing device central void zone may be physically separated from the channels of the mixing element with, for example, a wall between the two. In this case, the mixing device central void zone does not have any radial fluid contact with the channels of the mixing element because of the wall.

[00117] The mixing device central void zone is where the needle or pin resides and moves axially through the mixing device when the mixing device is installed in an injection moulding machine. Typically, the mixing device central axis will be co-located with the mixing element central axis (FIG. 4B, 3550), needle central axis and the nozzle central axis. Whereby in this case the mixing device and mixing element central void zone are the same.

[00118] In practice, the difference between the outer diameter of the needle and the mixing device central void zone diameter (2225) can be as little as 0.01mm. This difference is determined and configured so that there is no flow of the injection melt stream composition comprising of a primary constituent and at least one auxiliary constituent in the gap between the needle and the diameter of the mixing device central void zone towards the nozzle outlet.

[00119] FIG. 5A shows a further improved embodiment where the mixing device is attached to the detachable nozzle port (the mixing device transition feature (4100) having a mixing device outlet port (4200), with the nozzle collar being a separate component that is not attached to either. In this embodiment, the mixing device comprises the mixing element(s) and the mixing device transition feature. Because they are attached, they are monolithic (existing as one article).

[00120] FIG. 5B is a further improved embodiment where the mixing device, the optional mixing device transition feature and the nozzle collar are monolithic, or one piece. In this instance, the threads are called the mixing device nozzle attachment mechanism. In this manner, the mixing device can be removed from the nozzle body as the mixing device nozzle attachment mechanism of the monolithic mixing device is removed from the nozzle body. This embodiment has threads as the attachment mechanism, accordingly the mixing device can be rotated and removed from the nozzle as one piece. This also prevents introducing the mixing element in the reverse direction of flow (backwards in the nozzle).

[00121] FIG. 5C is an alternative embodiment to FIG. 5A. In FIG. 5A, the nozzle body is threaded on the outside (2700). In FIG. 5C, the nozzle body is threaded on the inside with the mixing device being monolithic with the mixing transition feature threaded on the outside and which is being attached to the nozzle body via the nozzle body's inner threads.

[00122] FIG. 6A and 6B are depictodiments of the mixing device, when being outside of the nozzle. FIG. 6A and FIG. 6B show the mixing device with the diameter of the mixing device central void zone (2250) and the mixing device central void zone central axis. While shown as a tube, the outer configuration of the mixing device does not necessarily need to be a tube or cylindrical as shown. No matter the configuration, it should be configured to fit into the nozzle leaving a small gap, or even no gap, such that there can be no flow of the melt stream composition comprising of a primary constituent and at least one auxiliary constituent between the nozzle and the mixing element.

[00123] FIG. 7A and 7B are depicting the embodiments of the detachable nozzle port comprising a monolithically integrated mixing device, when being outside of the nozzle. FIG. 7A and FIG. 7B are monolithic structures of the mixing transition feature with the mixing element(s) and show the mixing element feeding into a transition zone.

[00124] The mixing device proximal end (FIGS. 6A – FIGS. 7B, 2300) is the end where the needle enters the mixing device central void zone and the composition comprised of the primary constituent and at least one auxiliary constituent first contacts the mixing device. The mixing device distal end (FIGS. 6A – FIGS. 7B, 2400) is the end of the mixing device opposite the proximal end along the central axis.

[00125] The mixing devices shown in FIGS 6A and 6B as well as monolithically integrated mixing device within the nozzle collar shown in FIGS. 7A and 7B, consist of mixing element(s), which comprise a plurality of channels. Said plurality of channels will have at least two isolated channels (FIG. 6E, 3100) having a cross-section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[00126] In another embodiment, said plurality of channels will have at least three isolated channels (FIG. 6F) having a cross-section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[00127] In another embodiment, the mixing element may be configured that, in at least one cross-sectional area, isolated channels coexist with open channels (FIGS. 6G and 6H, 3150).

[00128] In a specific embodiment showing high-density configuration, the mixing device may comprise thirty-six such isolated channels, partitioned into an inner radial ring of eighteen isolated channels and an outer radial ring of eighteen isolated channels (FIG. 6C), or single ring of eighteen isolated channels (FIG. 6D).

[00129] In a typical embodiment there are the same number of mixing element channel outlets (FIG. 6A, 3300) as there are mixing element channel inlets (FIG. 6B, 3200). That is, the number of mixing element channel inlets equals the number of mixing element channel outlets. However, there does not necessarily need to be the same number of mixing element channel outlets as there are mixing element channel inlets. For example, two or more mixing element channels may merge into one mixing element channel with one mixing element channel outlet. In that case, that mixing element channel outlet will be associated with all the mixing element channel inlets which may have melt stream exiting that mixing element channel outlet. Alternatively, a mixing element channel inlet may split into two or more mixing element channel outlets. In that case, all the mixing element channel outlets are fluidly connected to the mixing element channel inlet channel are considered associated with that channel inlet.

[00130] Each of the at least two isolated channels are fluidly connected to at least one other channel inlet and at least one mixing element channel outlet of the plurality of channels before the exit of the at least one mixing element. Because the purpose of the mixing conducted by the mixing element of the mixing device is to further mix the primary constituent and the at least one auxiliary constituent, the mixing element channels must interact with each other which is done by the fluid connection to at least one other mixing element channel.

[00131] The flow direction (Z) is also the axial direction and the direction perpendicular to the flow direction/axial direction is the radial direction.

[00132] In accordance with the present invention, it has now been found that it is desirable to have smoother, gradual transitions that optimize mixing efficiency without compromising polymer stability or hardware durability.

[00133] In accordance with the present invention, the present invention provides for a mixer which integrates easily into standard hardware without important additional adaptations or maintenance demands.

[00134] In accordance with the present invention, it has surprisingly been found that it is desirable to subdivide the initial melt stream into smaller, discrete portions of the melt stream to mix the polymer melt stream in more manageable quantities rather than in a single, non-uniform bulk. Also, provided that the channels are geometrically balanced, that is the volume and cross sectional area at a given point are the similar if not the same for each channel s each polymer melt stream experiences the similar, if not the same, shear and thermal history, there are no hot spots, or high shear spots, that provide degradation greater in one spot, than the other. This effect of this similar if not the same shear and temperature exposure is significant as the degradation caused by temperature (and increased shear) exponentially increases as the temperature rises.

[00135] In accordance with the present invention, it has been found that it is desirable to achieve deliberate inward and outward movement of the polymer melt stream form the central axis to eliminate unmixed cores and allow the polymer melt stream to fully interpenetrate and provide a superior homogenization over the prior art.

[00136] In accordance with the present invention, it has been found that it is desirable to have a system that does not depend on surface features or swirling flow patterns, but instead the system should provide precise, controllable flow trajectories throughout the entire melt stream or discrete isolated portions of said melt stream.

[00137] The channels can be configured to mix the composition comprised of the primary constituent and the at least one auxiliary constituent according to various transformation principles.

[00138] Examples of these transformation principles are, without being limited, selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe), an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00139] The mixing element may be configured to act upon the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent according to a transformation principle selected from the group consisting of a Fractal geometry

Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00140] The superior homogenization achieved by using isolated channels and can be explained using an embodiment described in FIGS. 14 to 18.

[00141] FIG. 17 shows the 2D conceptual representation scheme of the mixing element based on a transformation principle selected from the group of transformation principles described in this specification and realized through the specific mechanical executions set forth in paragraph in this specification. This scheme represents a novel approach to melt stream processing, wherein the physical architecture of the mixing element is algorithmically defined according to predetermined mathematical formulae. This mathematical derivation ensures a deterministic redistribution of the melt streams, from the plurality of the channels at least two will be isolated channels at least one cross-sectional area, optimizing mixing within the nozzle channel.

[00142] Unlike prior art mixers, in the envisioned embodiment, the inlet to the mixing element is subdivided into a plurality of discrete, localized pockets of the melt stream, which is subsequently processed throughout the longitudinal extent of the mixing element according to the algorithmically guided geometry of the mixing element. By discretizing the flow at the inlet, the mixing element achieves a level of precision in constituent redistribution that is unattainable by non-partitioned mixing structures.

[00143] As further depicted in FIG. 17, the flow strategy is characterized by a multi-stage fluidic transition. Specifically, channels are configured to fluidly connect, in this embodiment, in pairs that converge at predetermined junction points. Subsequent to this convergence, the flow paths undergo a secondary splitting at the outlet at distinct spatial coordinates.

[00144] The resultant outlet positions of these channels are spatially offset within the transverse plane relative to the initial inlet area. This transformation principle facilitates a redirection of the melt stream, wherein the output coordinates are non-aligned with the input coordinates of the same mixing element, thereby achieving a specific spatial redistribution of the melt stream. Hence, the mixing element relies on intentional melt stream distribution, rather than on random collisions of melt stream, as described in the prior art.

[00145] The aforementioned transformation principle is integrated into a mixing element consisting of a plurality of three-dimensional (3D) channels architecture, as illustrated in FIG. 15B. These 3D channels of the mixing element incorporate the identical functional features as described prior 2D scheme. Specifically, as schematically represented in FIG. 15C the architecture comprises:

- An initial split at the entrance of the mixing element into at least two of the isolated channels inlets;
- A subsequent fluid connection wherein isolated channels merge into a singular isolated channel, resulting in the formation of three discrete isolated channels in this specific embodiment; and
- A secondary split at the outlet of the mixing element, resulting in the plurality outlets of the isolated channels characterized by a predetermined transverse offset.

[00146] In this 3D embodiment, the channels of the mixing element are disposed circumferentially within the radial constraints of the nozzle channel (of the hot runner system), as depicted in FIG. 15A. To maintain operational integrity, the channels of the mixing element are arranged with the available annular nozzle channel while preserving the volume for needle functionality in the form of mixing element central void zone (3500), which in this case corresponds to the mixing device central void zone.

[00147] Precisely, the mixing element central void zone is specifically dimensioned to accommodate a reciprocating valve needle ensuring that the mixing device, consisting of multiple mixing elements, does not interfere with the mechanical needle functionality. It was surprisingly found that the use of metal additive manufacturing methods enabled to make the shift from a 2D conceptual layout to a 3D annular execution.

[00148] The transition from a two-dimensional (2D) conceptual model to a 3D annular execution represents a significant difference from conventional mixing architectures. In accordance with the present invention, it has been surprisingly found that the complex, non-linear trajectories of the fluidly connected channels of the mixing element within an annular constraint provide an unexpected technical advantage in the mixing of the composition comprised of the primary constituent and the at least one auxiliary constituent. Due to the high degree of geometric complexity required to maintain these channels around a central void zone, the mixing device consisting of mixing elements is preferably fabricated using additive manufacturing (AM) techniques. The use of AM allows

for the realization of internal channel geometries that can be open or isolated and smooth fluidic transitions that are hard to obtain or unattainable via subtractive manufacturing or traditional machining processes, thereby enabling the precise execution of the mathematically derived transformation principles.

[00149] The channel structure of the mixing device, consisting of multiple mixing elements, is shown in FIG. 14. FIG. 14 (top) illustrates a perspective view of the radial and axial populations of the plurality of mixing elements, consisting of the channels disposed around a mixing element central void zone. To accomplish this, each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to the immediately preceding mixing element so that at least one channel inlet of the immediately successive mixing element is completely or partially aligned with a channel outlet of the immediately preceding mixing element.

[00150] The channels are configured to transport a melt stream consisting of the primary constituent and at least one auxiliary constituent. The flow direction is oriented from the upstream interface (left) to the downstream interface (right) along the Z-axis, which corresponds to the forward flow direction. The channels are the only paths for the melt stream to travel from the entrance of the mixing element on the left to the exit of the mixing element at the right. The channel exits are shown on the right side.

[00151] It is worth noting that the flow inside the channels at any given location may be axial, radial, or have a component which is axial flow and a component which is radial flow. Because the radial flow is not parallel with any central axis, radial flow can be any direction that is not parallel to any of the coincident central axes listed previously (1150, 1450, 2550, 3550).

[00152] The particular embodiment of FIG 14 (top) consists of 6 mixing elements in succession, of which two are shown by the vertical lines. In this particular embodiment, subsequent mixing elements outlets are completely aligned with the mixing elements inlets of the immediately following mixing element, providing flexibility for the axial stacking of the mixing elements.

[00153] FIG. 14 (bottom) shows the cross section of the mixing device comprising the mixing elements containing the plurality of the channels. The isolated channels could be achieved in one embodiment through the architecture whereby an inner radial wall circumferentially surrounding the mixing element central void zone separating at least two

channels of the mixing element. This inner radial wall serves as a fluidic barrier, providing control over melt stream transport and effectively preventing any radial flow of melt stream from the channels into the central void zone. As radial flow to or from an element's respective central axis, one alternative description is that there is no radial flow out of the mixing element. Radial flow out of the mixing element means flow radially into the mixing element central void zone.

[00154] As can be seen in FIG. 14, bottom figure, and in FIG. 16B, the open or isolated channels move towards and away from the mixing element's central axis and become fluidly connected to a corresponding channel. This is evidenced by the word merge in FIG. 15C which shows a single channel formed fluid connection of two channels.

[00155] The cross-section view of the channels as the melt stream passes through the channels of the mixing device, FIG. 16A, can be seen in FIG. series 16.

[00156] FIG. 16B shows the inlets of the plurality of channels which split the melt stream, in this case, into 36 channels (18 in the outer ring and 18 in the inner ring).

[00157] In some embodiments of the invention, the transformation principles perform a compression or squeezing step upon the melt stream comprised of a primary constituent and at least one auxiliary constituent flowing through the mixing element. This squeezing is done by reducing the cross-sectional area flow perpendicular to the axial direction. This causes the local linear volumetric flow rate of the melt stream comprised of the primary constituent and the at least one auxiliary constituent to increase when the volumetric flow is constant. One way to describe this is as a ratio of the minimum cross sectional flow area in the mixing element to the maximum cross sectional flow area in the mixing element. The cross-sectional flow area is the sum of the flow areas of the plurality of channels in the cross section. This ratio of the minimum cross sectional flow area in the mixing element to the maximum cross sectional flow area in the mixing element is preferably less than 0.9, more preferably less than 0.75 and most preferably less than 0.5. FIG. 16C and FIG. 16D are cross sections showing the narrowing of the merged flow channel to about 50% of the cross-sectional flow area at the entry of the mixing element.

[00158] The maximum cross section flow area is typically at the mixing element inlet (FIG. 16B) and the mixing element outlet (FIG. 16E).

[00159] FIG. 16F shows transition feature at the outlet from the mixing device, which is in this embodiment monolithically integrated in the detachable nozzle port.

[00160] FIG. 18A through 18D provides a visual representation of how the composition comprised of the primary constituent and the at least one auxiliary constituent is shifted and redirected between the discrete channels of the mixing elements, effectively validating the functional performance of the mixing device. The progression along the Z-axis illustrates the evolution of the distribution of the composition comprised of the primary constituent and the at least one auxiliary constituent based on Computational Fluid Dynamics (CFD) flowline analysis. For clarity, each discrete inlet within the mixing element is assigned a distinct color-coding to track the trajectory of individual melt streams. In the initial state at plane Z=0, the circumferential arrangement comprises six repeating sets of six distinct visual identifiers.

[00161] As previously disclosed, in this embodiment, the channels are configured for pairwise fluid connection (merge). As depicted in FIG. 18B, an inner-ring channel and an outer-ring channel fluidly connect (merge) to form a single isolated channel. This connection results in a visual appreciation of the bi-colour stratified flow within the merged channel, representing the initial stage of constituent juxtaposition.

[00162] Following this fluid connection (merge), the composition comprises the primary constituent and the at least one auxiliary constituent undergoes a secondary split as it approaches the mixing element outlet. As illustrated in FIG. 18C and 18D, the merged melt streams are re-separated into individual channels with a predetermined transverse offset. Notably, the flow logic is configured such that the specific constituent pair is redirected to every third exit location in the outer ring, as indicated by the directional arrows. This confirms a deterministic circumferential displacement of the composition comprised of the primary constituent and the at least one auxiliary constituent relative to their initial radial coordinates.

[00163] The overlay of CFD-calculated flowlines demonstrates that the forced mechanical shift of the composition comprised of the primary constituent and the at least one auxiliary constituent achieves a specific spatial redistribution. While a singular pass through the mixing element initiates redistribution, the mixing element is configured for modular scalability. Consequently, a plurality of mixing elements may be arranged in axial succession to achieve a progressively higher degree of constituent mixing.

[00164] It has surprisingly been found that the unique combination of discrete inlet partitioning, isolated channels fluid connection (merge), followed by the offset split—as

validated by the illustrated flowline analysis—represents a non-obvious difference from conventional static mixing prior art.

[00165] As shown in FIG. 4C, after exiting the mixing zone (1600), and the last mixing element, the isolated melt streams converge and are combined in the space immediately after the last mixing element channel outlets, which is the nozzle transition zone (1650). As shown in FIGS. 5A-5C the mixing device monolithically integrated into the detachable nozzle port or nozzle collar may have an integrated mixing device transition zone (4000) where the melt streams are combined before flowing into the mould cavity.

[00166] To summarize, the mixing device of the present invention, comprising mixing elements, allows us to exercise the selected mathematical transformation principles on the discrete portions of melt stream, while moving it towards or away from the central axis, thus homogenizing the at least one auxiliary constituent into the primary constituent.

[00167] The mixing element(s) break the single feed melt stream into multiple melt streams and shuffle these melt streams to break up the agglomerated or clumped together droplets/phases of the at least one auxiliary constituent and increase the degree of mixing of the at least one auxiliary constituent into the primary constituent. This is also referred to as the relative index of mixing, which will be further referred to. This action further mixes the concentration of the at least one auxiliary constituent into the primary constituent. When applied to colorants, this improved mixing, also known as increased homogenization, can reduce the visual defects in the final part as well as the amount of the at least one auxiliary constituent needed to achieve the specified color in the final part.

[00168] The same is true of nucleants, catalysts, reaction inhibitors, oxygen scavengers, clays and other types of the at least one auxiliary constituent to be mixed into the primary constituent.

[00169] Improved mixing is also desired when the at least one auxiliary constituent is a chemical variant of the primary constituent such as a recycled version of the primary constituent. It is well known that the heat histories experienced by the recycled version typically creates some degradation of various properties which lead to, for example, decreased performance, the presence of undesired colors, and an increased amount of degradation products.

[00170] Assume for example that at least one auxiliary constituent is uncolored recycled PET. When added to the primary constituent of virgin PET, the resulting mixture

may become yellowish with higher color variability because the recycled PET, which is more yellow due to its multiple heat histories, is localized and not evenly distributed through the final article. However, after improved mixing by the mixing element of the present invention, less overall yellowish color is expected. In this manner, more recycled PET can be incorporated into the primary constituent of virgin PET because of the superior mixing achieved by passing the primary constituent and the at least one auxiliary constituent through the mixing element or plurality of mixing elements.

[00171] Even miscible auxiliary constituents benefit from the use of the mixing element(s) with improved mixing being achieved. Although miscible, it takes time for the at least the one auxiliary constituent to mix into the phase of the primary constituent. Improved mixing greatly increases the amount of the at least one auxiliary constituent solubilized into the primary constituent in a given amount of time.

[00172] The mixing elements of the mixing device or the nozzle collar comprising a monolithically integrated mixing device can be configured to increase a relative index of mixing of an injection melt stream comprised of a primary constituent and at least one auxiliary constituent by at least 0.16 where the relative index of mixing is determined by 1 minus a Kullback-Leibler Divergence (KLD) value. The use of the KLD to determine the relative index of mixing or degree of disorder is known in the field of polymer mixing. While increasing the relative index of mixing by 0.16 is desirable, increasing it by at least 0.3 is more preferred, and increasing it by 0.5 most preferred.

[00173] In this case, it is determined at an outlet of the mixing element or an outlet of the last mixing element if there is a plurality of mixing elements. As mixing depends upon the primary constituent's viscosity, the viscosity at the surface of the mixing element structure can be estimated by using the Carreau Viscosity $\eta_{T,p}$ for a model primary constituent according to the equation

$$\eta_{T,p} = a_T a_p \eta_0 \left[1 + (\lambda \dot{\gamma} a_T)^2\right]^{(n-1)/2}$$

where the values of the model primary constituent are such that

$\dot{\gamma}$ is the local shear rate at the surface as the polymer melt stream changes flow normal to the flow direction and in the flow direction as the melt stream progresses through the mixing element.

η_0 is the zero-shear rate viscosity equal to 766.3 (Pa.s). This is fixed to always provide the same viscosity for use in the simulations.

λ is the onset of shear thinning and equal to 0.011 (s). Again, this is fixed to always provide the same viscosity for use in the simulations.

n is the degree of shear thinning and equal to 0.6307. Again, this is fixed to always provide the same viscosity for use in the simulations.

a_T is a factor indicating the temperature dependence of the viscosity and other material flow properties and is

$$a_T = exp\left[\frac{E}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$$

where the values of the model primary constituent are such that

E is an energy of activation equal to 55100 J/mol,

R is a gas constant equal to 8.3145 J/Kmol,

T is a processing temperature equal to 275°C, and

T_{ref} is a reference temperature equal to 275°C;

The value is therefore 1 as T and T_{ref} are equal.

and

a_P is a factor indicating the pressure dependence of the viscosity and other material flow properties

$$a_p = \frac{\eta_p}{\eta_{p0}} = exp^{(\beta p)}$$

where the values of the model primary constituent are such that,

β is the pressure dependency coefficient of viscosity and is equal to 5 GPa^(-1) at pressures below 100 MPa, and equal to 2 GPa^(-1) for pressures greater than or equal to 100MPa and less than or equal to 260 MPa), and

p is an absolute pressure which varies in the range of atmospheric pressure at the exit of the mixing device to as high as 260 MPa.

[00174] Once the Carreau Viscosity for the model primary constituent is determined, the KLD number of an injection melt stream comprised of the primary constituent and the at least one auxiliary constituent can be determined as described in the literature using a CFD model with the relative index of mixing, the degree of disorder, determined as 1 minus the KLD number. The KLD number ranges from 0 (complete mixing, maximum increase in

the amount of mixing) to 1, which would be no homogenization or no increase in the relative index of mixing, also called degree of disorder, or also called entropy. Consequently, 1 minus the KLD describes the opposite: the value of 0 means no increase in entropy whereas the value of 1 means a perfect entropy.

[00175] This increase in the relative index of mixing (disorder) is theoretically the increase in the randomness of the incoming injection melt stream comprised of the primary constituent and the at least one auxiliary constituent. For example, by splitting the melt streams, recombining the melt streams, and splitting and then recombining multiple times.

[00176] In the CFD computations, the fluid domain, which in this case is melt streams of the mixing element, is divided into smaller control volumes through meshing. The smaller control volumes (or mesh cells) form a computational grid. The governing equations of fluid flow are then solved locally within each control volume. To capture the overall behavior of the fluid (primary component), the solutions in adjacent cells are coupled through their shared boundaries. This localized approach means that the solution is computed in a piecewise manner and then assembled to represent the entire domain. In the analysis, ý varies locally within each domain. Each mesh cell may use its own local coordinate system. In each mesh the local shear rate is derived from the velocity gradient tensor. For instance, in cylindrical coordinates, the magnitude of the shear rate (ý) is calculated as:

$$|\dot{\gamma}| \sqrt{\left(\frac{\partial V_z}{\partial r}\right)^2 + \left(\frac{\partial V_r}{\partial Z}\right)^2}$$

Here, r and z are components of the coordinate system, while v_r and v_z represent the corresponding local velocities. In case of symmetry, the component in the angular (θ) direction is assumed to be zero.

[00177] The mixing device or the nozzle collar comprising a monolithically integrated mixing device described in this specification can be used as taught below in the injection cycle of an injection moulding process to mould an injection moulded article from an injection melt stream comprised of the primary constituent and the at least one auxiliary constituent.

[00178] The injection cycle begins by withdrawing the needle away from or out of the nozzle outlet port to open the nozzle. The nozzle has a nozzle channel passing along the nozzle central axis from a nozzle proximal end to the nozzle distal end. The nozzle proximal end corresponds to the nozzle feed zone. The nozzle channel encompasses, or houses, the needle and at least a portion of a mixing device within the nozzle channel.

[00179] It should be noted that there is an injection melt stream comprised of the primary constituent and the at least one auxiliary constituent remaining in the nozzle from the previous injection cycle or shot. When the nozzle port is opened the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent which is in the nozzle flows out from the nozzle outlet port and into the injection mould which is shaped to hold the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent in the desired shape as the injected melt stream is cooled.

[00180] The amount of the primary constituent and the at least one auxiliary constituent required to fill the injection mould typically occupies more volume than the amount of the primary constituent and the at least one auxiliary constituent in the nozzle. As a result, additional amounts of the primary constituent and the at least one auxiliary constituent will enter the nozzle at the nozzle feed zone (FIG. 4C, 1500). The force causing the flow is a pressure differential between the nozzle outlet port and the nozzle feed zone. Further upstream from the nozzle feed zone is an extruder or other pressure building device that pushes the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent into the nozzle and out the nozzle outlet port.

[00181] An exemplary flow sequence through the nozzle is also shown in FIG. 4C. The melt stream passing through the nozzle passes first through the nozzle feed zone, then through the mixing element which, in this embodiment, corresponds to the length of the mixing device.

[00182] After being acted upon by the mixing element(s), the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent passes into the optional nozzle transition zone which ends at the nozzle outlet port when the injection melt stream comprised of the primary constituent and the at least one auxiliary constituent exits the nozzle and enters the mould.

[00183] Once the mould is completely filled, the needle is advanced along its needle central axis and closes the outlet port, leaving the primary constituent and the at least one auxiliary constituent in the nozzle to be part of the next subsequent injection cycle.

[00184] Practitioners seek to minimize the amount of the primary constituent (typically a polymer) that is held within the nozzle between injection cycles. In practicing the claimed process, it is desirable to minimize the amount of the primary constituent and the at least one auxiliary constituent after the mixing element. This is done by minimizing or eliminating the volume of the optional transition zone when the nozzle is closed. This is true whether the optional transition zone is the nozzle transition zone or the mixing device transition feature. Some designs may have no volume in the transition zone, thus making the transition zone an optional feature based on the specific design of the mould and nozzle. The minimization of the transition zone minimizes the dwell time after the last mixing element so the mixed injection melt stream re- agglomeration or decrease in relative index of mixing that occurs during the transition to the nozzle outlet and into the injection mould, or in-between consecutive injection cycles when remaining stagnant in the transition zone is minimized or eliminated.

[00185] In accordance to the present invention there is a process for injection moulding a part. Injection moulding is a well-known process in which a molten or plasticized polymer injection melt stream is pushed into a mould and is allowed to solidify by internal or external cooling or curing or a combination thereof.

[00186] In some embodiments the injection moulded part can be constructed of a composition comprised of a primary constituent and at least one auxiliary constituent. Examples of the primary constituent are polymers and rubbers and thermoset systems which cure upon mixing. The primary constituent is the constituent with the largest percent volume in the melt stream. All other constituents are auxiliary constituents. In the case when two or more constituents have the same volume percentages, such as a 50/50 mixture, one constituent is considered the primary constituent and the other constituent the auxiliary constituent. It is noted that the volume percentage of all the constituents totals 100%.

[00187] This primary constituent and the at least one auxiliary constituent may be polymers, oligomers, monomers, molecules, particles that are derived from natural sources which include synthetic fossil based, synthetic natural based (non-fossil-based), and native

chemically unprocessed sources (for example – extracted and isolated without further chemical processing).

[00188] While the general names are used, this primary constituent and the at least one auxiliary constituent can exist in all variants of chemical classification, such as but not limited to homopolymer, co-polymer, ter-polymer, and include such forms as -co-, -stat-, -ran, -alt-, -per, block-, -graft.

[00189] The primary constituent and the at least one auxiliary constituent may have at least one of the conformations selected from the group of linear, oriented chain, coil, zigzag, lamellar, helical, and cyclic.

[00190] The topology includes but is not limited to dispersed chain, branched, comb, star, tree-like, ladder, cross-linked, rotaxane, and catena.

[00191] The primary constituent and the at least one auxiliary constituent can be in special forms like telechelic polymers/oligomers.

[00192] The primary constituent and the at least one auxiliary constituent can be amphiphilic, polar, and non-polar, with a broad molecular weight range.

[00193] The at least one auxiliary constituent may be complemented with organic or inorganic molecules introduced in solid/masterbatch and/or liquid/fluid/gas form that serve the purpose of one or a combination of chemical reagents, catalyst, reaction initiator, reaction accelerator, reaction inhibitor, peroxides, cross-linkers.

[00194] The at least one auxiliary constituent may also be complemented by process facilitators such as a lubricant, a plasticizer, a thixotropic additive, a thickening agent, a rheology modifier, and an emulsifier.

[00195] The at least one auxiliary constituent may also contain performance additives such as fillers, carriers, foaming agents, U.V.-blockers, U.V-absorbers, U.V. stabilizers, oxygen scavenger, antioxidants, air/CO_2/O_2/hydro-barrier, flame retardants, nucleating agents, thermal stabilizers, antistatic agents, odor absorbers, odor neutralizers, anti-fogging agents, desiccants, dispersing agents, colorants and pigments, surface modifiers (e.g. for hydrophobic surfaces), adhesion promoters, and corrosion inhibitors.

[00196] The at least one auxiliary constituent may also contain active substances such as antimicrobial agents, antifungal agents, biocides, and chelating agents.

[00197] Common polymers for use as either the primary constituent or the at least one auxiliary constituent are polyethylene terephthalate (PET) and its copolymers, polylactic

acid (PLA) and its copolymers, polybutylene terephthalate (PBT) and its copolymers, polypropylene (PP) and its copolymers, high and low density polyethylenes (HDPE, LDPE) and its copolymers, nylons (PA), polyvinyl chloride (PVC), polycarbonate (PC), and acrylobutadiene styrene (ABS), are examples of polymers suitable for injection moulding processes.

[00198] Rubbers and elastomers are suitable, examples of which are natural rubber, silicones, ethylene propylene diene monomer-based rubbers, fluorosilicone, nitrile rubber, polychloroprene, styrene-butadiene, and isoprene and its copolymers.

[00199] Polyurethane is an example of a curable thermoset.

[00200] The at least one auxiliary constituent can also be selected from the group of polymers, rubbers, glass, nucleants, clays, colorants- both liquid and solid, and gasses. The at least one auxiliary constituent typically has a lower chemical affinity with the primary constituent at the processing temperatures and pressures.

[00201] Also contemplated are those composition in which the at least one auxiliary constituent catalyzes a reaction or reacts with the primary constituent.

[00202] The object of the injection cycle is to pass the composition comprising the primary constituent and the at least one auxiliary constituent through a nozzle and into a mould that is in a shape of the part, and to simultaneously apply this cycle across the different part cavitations which are present inside the mould.

[00203] Based on the details described in the specification, an injection cycle of injection moulding process can be contemplated whereby the injection moulding cycle is executed utilizing either the mixing device or the nozzle collar comprising a monolithically integrated mixing device to injection mould an article made from the composition comprising of the primary constituent and the at least one auxiliary constituent.

[00204] It should be clear from the descriptions in the specification that any and all of the embodiments directed to either the mixing device or the nozzle collar comprising a monolithically integrated mixing device can be utilized in the execution of the injection moulding cycle to injection mould an article made from the composition comprising of the primary constituent and the at least one auxiliary constituent.

[00205] Based on the description provided in the specification, it should be clear to a person skilled in the art, that the specific embodiments disclosed in the descriptions and

the drawings of the specification, shall not in any way be considered as a limitative or exhaustive list of embodiments for the present invention.

[00206] The present invention is directed to the totality of embodiments, which could be contemplated for the present invention, directed to either the mixing device, or the nozzle collar comprising a monolithically integrated mixing device, or the system for mixing a composition and a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent, integrating any and all of the embodiments directed to mixing device or the nozzle collar comprising a monolithically integrated mixing device.

[00207] In a main embodiment (A), the present invention is directed to a mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element with the mixing device having a mixing device central void zone surrounding a mixing device central axis; wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels with at least one channel inlet and at least one channel outlet, wherein the plurality of channels has at least two isolated channels having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[00208] According to another embodiment (A1), the main embodiment (A) referred to above is further characterized in that at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00209] According to another embodiment (A2), the main embodiment (A) is further characterized in that each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one channel inlet of an immediately successive mixing element is partially or completely aligned with a channel outlet of the immediately preceding mixing element.

[00210] According to another embodiment (A3), the main embodiment (A1) is further characterized in that at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis and each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one channel inlet of an immediately successive mixing element is partially or completely aligned with a channel outlet of the immediately preceding mixing element.

[00211] According to another embodiment (A4), the embodiment (A1) referred to above is further characterized in that a portion of each channel, whether open or isolated, of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00212] According to a series of embodiments (A5), the embodiment (A2) or (A3) referred to above is further characterized in that a portion of each channel, whether open or isolated, of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00213] According to another embodiment (A6), the main embodiment (A) referred to above is further characterized in that the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale mixing (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00214] According to another embodiment (A7), the embodiment (A1) referred to above is further characterized in that the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale mixing (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00215] According to a series of embodiments (A8), the main embodiment (A2) or (A3) is further characterized in that the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a

Baker Transformation, a Smale mixing (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00216] According to a series of embodiments (A9), the main embodiment (A4) or (A5) is further characterized in that the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale mixing (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00217] According to a series of embodiments (A10), the main embodiment (A6) or (A7) or (A8) or (A9) is further characterized in the mixing device comprises a Xemex mixer/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer.

[00218] According to another embodiment (A11), the main embodiment (A) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00219] According to another embodiment (A12), the main embodiment (A1) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00220] According to a series of embodiments (A13), the main embodiment (A2) or (A3) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00221] According to a series of embodiments (A14), the main embodiment (A4) or (A5) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00222] According to a series of embodiments (A15), the main embodiment (A6) or (A7)or (A8) or (A9) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or

plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00223] According to another embodiment (A16), the main embodiment (A10) is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00224] According to another embodiment (A17), the main embodiment (A) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00225] According to another embodiment (A18), the main embodiment (A1) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00226] According to a series of embodiments (A19), the main embodiment (A2) or (A3) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00227] According to a series of embodiments (A20), the main embodiment (A4) or (A5) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00228] According to a series of embodiments (A21), the main embodiment (A6) or (A7) or (A8) or (A9) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00229] According to another embodiment (A22), the main embodiment (A10) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00230] According to a series of embodiments (A23), the main embodiment (A11) or (A12) or (A13) or (A14) or (A15) or (A16) is further characterized in that a ratio of a minimum

cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00231] According to a series of embodiments (A24), the main embodiment (A17) or (A18) or (A19) or (A20) or (A21) or (A22) or (A23) is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.

[00232] According to another embodiment (A25), the main embodiment (A) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00233] According to another embodiment (A26), the main embodiment (A1) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00234] According to a series of embodiments (A27), the main embodiment (A2) or (A3) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00235] According to a series of embodiments (A28), the main embodiment(A4) or (A5) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00236] According to a series of embodiments (A29), the main embodiment(A6) or (A7) or (A8) or (A9) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00237] According to another embodiment (A30), the main embodiment(A10) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00238] According to a series of embodiments (A31), the main embodiment (A11) or (A12) or (A13) or (A14) or (A15) or (A16) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00239] According to a series of embodiments (A32), the main embodiment (A17) or (A18) or (A19) or (A20) or (A21) or (A22) or (A23) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00240] According to another embodiment (A33), the main embodiment (A24) is further characterized in that the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.

[00241] According to another embodiment (A34), the main embodiment (A) is further characterized in that the mixing device is monolithic.

[00242] According to another embodiment (A35), the main embodiment (A1) is further characterized in that the mixing device is monolithic.

[00243] According to a series of embodiments (A36), the main embodiment (A2) or (A3) is further characterized in that the mixing device is monolithic.

[00244] According to a series of embodiments (A37), the main embodiment (A4) or (A5) is further characterized in that the mixing device is monolithic.

[00245] According to a series of embodiments (A38), the main embodiment(A6) or (A7) or (A8) or (A9) is further characterized in that the mixing device is monolithic.

[00246] According to another embodiment (A39), the main embodiment A (10) is further characterized in that the mixing device is monolithic.

[00247] According to a series of embodiments (A40), the main embodiment (A11) or (A12) or (A13) or (A14) or (A15) or (A16) is further characterized in that the mixing device is monolithic.

[00248] According to a series of embodiments (A41), the main embodiment (A17) or (A18) or (A19) or (A20) or (A21) or (A22) or (A23) is further characterized in that the mixing device is monolithic.

[00249] According to another embodiment (A42), the main embodiment (A24) is further characterized in that the mixing device is monolithic.

[00250] According to a series of embodiments (A43), the main embodiment (A25) or (A26) or (A27) or (A28) or (A29) or (A30) or (A31) or (A32) or (A33) is further characterized in that the mixing device is monolithic.

[00251] In another main embodiment (B), the present invention is directed to a nozzle collar comprising a monolithically integrated mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element with the mixing device having a mixing device central void zone surrounding a mixing device central axis ; wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least

one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels with at least one channel inlet and at least one channel outlet, wherein the plurality of channels has at least two isolated channels having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[00252] In another embodiment (B1), the main embodiment (B) referred to above is further characterized in that each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[00253] According to another embodiment (B2), the main embodiment (B) referred to above is further characterized in that at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00254] According to another embodiment (B3), the embodiment (B2) referred to above is further characterized in that at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00255] According to another embodiment (B4), the main embodiment (B) referred to above is further characterized in that each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one melt channel inlet of an immediately successive mixing element is partially or completely aligned with a melt channel outlet of the immediately preceding mixing element.

[00256] According to another embodiment (B5), the embodiment (B1) referred to above is further characterized in that each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one melt channel inlet of an immediately successive mixing element is partially or completely aligned with a melt channel outlet of the immediately preceding mixing element.

[00257] According to a series of embodiments (B6), the embodiment (B2) or (B3) referred to above is further characterized in that each successive mixing element of the

plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one melt channel inlet of an immediately successive mixing element is partially or completely aligned with a melt channel outlet of the immediately preceding mixing element.

[00258] According to another embodiment (B7), the embodiment (B1) referred to above is further characterized in that a portion of each channel, whether open or isolated, of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00259] According to a series of embodiments (B8), the embodiment (B2) or (B3) referred to above is further characterized in that a portion of each channel, whether open or isolated, of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00260] According to a series of embodiments (B9), the embodiment (B4) or (B5) or (B6) referred to above is further characterized in that a portion of each channel, whether open or isolated, of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

[00261] According to another embodiment (B10), the main embodiment (B) referred to above is further characterized in that the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00262] According to another embodiment (B11), the embodiment (B1) referred to above is further characterized in that the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00263] According to a series of embodiments (B12), the embodiment (B2) or (B3) referred to above is further characterized in that the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal

geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00264] According to a series of embodiments (B13), the embodiment (B4) or (B5) or (B6) referred to above is further characterized in that the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00265] According to a series of embodiments (B14), the embodiment (B7) or (B8) or (B9) referred to above is further characterized in that the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

[00266] According to a series of embodiments (B15), the embodiment (B10) or (B11) or (B12) or (B13) or (B14) referred to above is further characterized in that the mixing device comprises a Xemex mixer,/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer,

[00267] According to another embodiment (B16), the main embodiment (B) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00268] According to another embodiment (B17), the embodiment (B1) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00269] According to a series of embodiments (B18), the embodiment (B2) or (B3) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00270] According to a series of embodiments (B19), the embodiment (B4) or (B5) or (B6) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00271] According to a series of embodiments (B20), the embodiment (B7) or (B8) or (B9) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00272] According to a series of embodiments (B21), the embodiment (B10) or (B11) or (B12) or (B13) or (B14) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00273] According to another embodiment (B22), the embodiment (B15) referred to above is further characterized in that the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

[00274] According to another embodiment (B23), the main embodiment (B) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00275] According to another embodiment (B24), the embodiment (B1) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a

mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00276] According to a series of embodiments (B25), the embodiment (B2) or (B3) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00277] According to a series of embodiments (B26), the embodiment (B4) or (B5) or (B6) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00278] According to a series of embodiments (B27), the embodiment (B7) or (B8) or (B9) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00279] According to a series of embodiments (B28), the embodiment (B10) or (B11) or (B12) or (B13) or (B14) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00280] According to another embodiment (B29), the embodiment (B15) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00281] According to a series of embodiments (B30), the embodiment (B16) or (B17) or (B18) or (B19) or (B20) or (B21) or (B22) referred to above is further characterized in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

[00282] According to a series of embodiments (B31), the embodiment (B23) or (B24) or (B25) or (B26) or (B27) or (B28) or (B29) or B(30) referred to above is further characterized

in that a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.

[00283] In another main embodiment (C), the present invention is directed to a system for mixing a primary component and at least one auxiliary component, the system comprising an injection nozzle, having a nozzle outlet port , a nozzle melt channel which houses a needle and at least one transformation element of a transformation device with the transformation device having a transformation device central void zone surrounding a transformation device central axis and the needle; wherein at least a portion of the transformation device central void zone lies between the transformation device central axis and the at least one transformation element; and wherein the at least one transformation element has a plurality of melt channels with at least one melt channel inlet and at least one melt channel outlet , wherein each melt channel of the plurality of melt channels is fluidly connected with at least one other melt channel of the plurality of melt channels, wherein the plurality of channels has at least two isolated channels having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

[00284] According to another embodiment (C1), the main embodiment (C) referred to above is further characterized in that each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

[00285] According to a series of embodiments (D), the present invention is directed to a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a mixing device characterized by embodiments (A) to (A43).

[00286] According to a series of embodiments (E), the present invention is directed to a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a nozzle collar comprising a monolithically integrated mixing device characterized by embodiments (B) to (B31).

[00287] According to a series of embodiments (F), the present invention is directed to a process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a system characterized by embodiments (C) and (C1).

EXPERIMENTAL

[00288] The teachings of the above specification were used to create a mixing device and injection moulding process used in the following experiments.

[00289] The following methodology was used.

[00290] Materials Used:

[00291] Commercially available semi-crystallizable virgin PET polymer having an intrinsic viscosity (I.V.) in the range of 0.75 to 0.90 dl/g. RamaPET N180 supplied by Indorama is one such PET.

[00292] Commercially available grade of a semi-crystallizable recycled PET polymer, having an intrinsic viscosity (I.V.) in the range of 0.75 to 0.90 dl/g. Ecolor supplied by Lorraine Plast Recycling LPR is an example. This PET was the primary constituent used in the experiments.

[00293] A commercially available colorant capable of absorbing visible light across the UV-Visual spectrum. The colorant may be in various forms, including but not limited to liquid ink, pigment, or masterbatch. The masterbatch typically consists of a PET carrier with the colorant dispersed within, and the PET should also fall within the IV range of 0.75 to 0.90 dl/g. In these experiments the at least one auxiliary constituent was PennColor 66S11281., supplied by Penn Color Inc.

[00294] The polymer material and blends can be processed in combination with the colorant in a standard injection moulding machine. Suitable injection moulding machines include, but are not limited to, those made by Netstal Maschinen AG, Nafels, Switzerland; Husky IMS International, Bolton Ontario, Canada and S.I.P.A. S.p.A. Societa di Industrializzone Progettazione e Automazione, Veneto, Italy and equipped with various multi-cavity mould designs.

[00295] Typical process settings to operate the injection moulding machine are:

- Extruder Barrel: 270 - 295 °C

- Nozzle: 270 - 295 °C
- Manifold: 275 - 295 °C
- Gates: 280 - 300 °C
- Mould Coolant Water: 5 - 15 °C
- Cycle Time 10 - 60 seconds

[00296] Each of these injection machines operates with moulds which are connected to a hot runner system. The hot runners split the molten or plasticized injection melt stream that leaves the extruder into various channels each terminating at the injection nozzle.

[00297] The control examples of the various materials and blends were made with the use of a conventional hot runner system utilized for preform injection production, including but not limited to hot runner systems like Husky IMS mentioned earlier, MHT Mould and Hot Runner Technology AG, Hochheim am Main, Germany Mould-Masters Georgetown, Ontario, Canada. The injection melt stream comprised of the primary constituent and the at least one auxiliary constituent was injected into a preform as described below.

[00298] The working examples of the various material blends were made in the same manner except for the addition of a mixing device based on the teachings of this patent and integrated into the hot runner system as described. This integration involved inserting the mixing device into the hot runner nozzle housing and securing it with the hot runner nozzle tip applying the prescribed torque. Applicable systems include but are not limited to, those from Husky, MHT or Mould Masters. This integration procedure is repeated for each nozzle of each separate cavity within the multi-cavity injection mould.

[00299] The mixing device was not monolithic with 4 mixing elements in sequential series. There was also a nozzle transition zone in a detachable nozzle port. Each mixing element was configured to perform a single Baker transformation with a 0.5 compression step, meaning that the minimum cross sectional flow area in the series or plurality of mixing elements to the maximum cross sectional flow area in the series or plurality of mixing elements was 0.5. The initial mixing element split the melt stream into 36 mixing element channels or melt streams as shown in FIGS. 6A and 6B. Each element was rotated about the central axis with the melt outlet stream completely aligned with the melt inlet stream of the successive mixing element.

[00300] Preform Injection. The materials and equipment described were used to inject commercially available preforms of varying weights, suitable for producing injection stretch-blow moulded bottles of selected volumes and bottom configurations (e.g., round or oval bottles).

[00301] The same injection process settings are applied for both the control injection process, without the presence of any mixing devices and the working example injection process including the presence of such mixing devices in the nozzle.

[00302] The injection cycle is described for one preform cavity but is understood as being equivalent and simultaneous for each of the preform cavities present inside the multi-cavitation injection mould. The injection cycle began by opening a nozzle outlet port by moving a needle along a needle central axis to withdraw the needle from blocking the nozzle outlet port located at the nozzle tip at the nozzle's distal end. The nozzle had a nozzle channel passing from the nozzle's proximal end to the nozzle's distal end. This nozzle channel encompassed the needle and at least a portion of the mixing device. The nozzle channel had a nozzle feed zone preceding the mixing device, a nozzle mixing zone containing the mixing device and an optional nozzle transition zone between the end of a nozzle mixing zone and the end of the nozzle outlet port.

[00303] The mixing device had a mixing device central void zone surrounding a mixing device central axis and 4 consecutively positioned, alternatively known as successively positioned mixing elements consisting of isolated channels.

[00304] A portion of the mixing device central void zone was between the mixing device central axis and the mixing elements.

[00305] Each mixing element had a plurality of 36 mixing element isolated channels with each mixing element channel having a channel inlet and a mixing element channel outlet. In these mixing elements, each mixing element channel was fluidly connected with at least one other mixing element channel.

[00306] In these experiments, the mixing device was inserted into the nozzle of the injection moulding machine with the mixing device central void zone surrounding the needle of the nozzle. In this experiment, the mixing device central axis, the nozzle central axis and the needle central axis were on the same line. The mixing device was not attached to the needle so that the needle could move back and forth through the mixing device central void zone. The nozzle contained the injection melt stream comprised of the PET and

the colorant before the needle was opened. In this example, the mixing element was 3-D printed.

[00307] Other examples of configurations are when mixing element could be positioned in the different places in the flow path (for example behind the screw, at the end of the hot runner). The location at the end of the hot runner, immediately prior to the injection step was selected to provide

1) less demixing in the static and cooling stage

2) processing smaller portions of the material

3) easy installation

4) possibility to integrate with hot runner parts as depicted in the monolithic mixing device.

[00308] Upon opening the nozzle outlet, the injection melt stream comprised of the PET and the colorant referenced above which were already contained in the nozzle mixing zone and the optional nozzle transition zone passed through the nozzle outlet port into the mould. Simultaneously, and continuously, additional amounts of the injection melt stream comprised of the PET and colorant referenced above were passed into the nozzle feed zone, through the nozzle mixing zone, the optional nozzle transition zone, and through the nozzle outlet port into the mould until the mould was full.

[00309] After the mould was full, the nozzle outlet port was closed by advancing the needle through the mixing device central void zone towards the nozzle outlet port to close the nozzle outlet port while leaving an amount of the injection melt stream comprised of the PET and colorant referenced above in the nozzle feed zone, the nozzle mixing zone and the optional nozzle transition zone making it ready for the next injection cycle.

[00310] The preforms were subjected to routine quality control to ensure compliance with critical specifications like, but not limited to, injected polymer mass, fully injected shape, absence of gas entrapment and a completely formed injection tip.

[00311] Working and Control example preforms were manufactured with:

(i) 100% of the specified colorant concentration and

(ii) an arbitrary reduction to 85% of the specified colorant concentration.

[00312] All preforms were reheated on a conventional blow moulding machine, like Sidel of the Tetra Laval Group, Le Havre, France or KHS group, Germany, utilizing a conventional preform reheat temperature range of 90 to 115 °C.

[00313] Save for reheat time, the selected settings of the preform reheating process are kept identical across all preform types manufactured under this position. As one of ordinary skill knows that the reheat time is what is required to reach a certain preform temperature before blowing the bottle. One of ordinary skill also knows that the time is related to the absorption of heat which varies by composition. Proper time adjustments were made for the two different colorant loadings.

[00314] It should be noted that the bottle manufacturing is not limited to the two-stage reheat blow process but also works on one step blow processes of Aoki and Nissei, both of Japan, which machinery injects the preform, cools the preform to the blowing temperature and blows the preform into the bottle shape in one uninterrupted cycle.

[00315] The reheated preforms were blown with the use of a conventional blow moulding machine, like Sidel or KHS, suitable for stretch blow moulding of bottles of the selected size with the selected settings of the blow moulding process being kept identical across all preform of the working and control examples.

[00316] The preforms were evaluated for colour mixing according to the following protocols.

[00317] The preforms were produced over a 4-hour duration using an 8-cavity mould with an injection cycle time of 30 seconds, resulting in approximately 1,000 preforms per hour. Samples were collected during the first 15 minutes of production within the initial hour, generating a batch of approximately 250 preforms. This procedure was repeated after 4 hours, yielding a total of approximately 500 preforms for each sample set (see Table 1):

Table 1. *Sample collection matrix.*

	Colorant concentration	
	100 % of specified	85% of specified
Injection process without the use of mixing device	500	500
Injection process with the use of the mixing device	500	500

[00318] The collected preforms were separated per preform cavity number (allowing intra-cavity analysis) and per the production timeframe (1st hour versus 4th hour).

[00319] The effectiveness of the use of the mixing device as per the teachings of this patent on the colorant mixing inside the preforms was evaluated through a detailed surface analysis conducted under contrast lighting by two independent observers to enhance statistical reliability.

[00320] The visual observations were that for both colour concentrations and production timeframes, the control preforms manufactured according to the conventional process without the use of the mixing device displayed severe defects in colorant mixing, including but not limited to the presence of clearly discernible flowlines, marbling effects, colour streaks and colorant concentration spots.

[00321] Across all preforms visually examined, 100% showed such defects in mixing, regardless of the colorant concentration or production timeframe (FIG. 8).

[00322] In sharp contrast thereto, the working example preforms manufactured with the use of the mixing device demonstrated significantly lower amount of colorant mixing issues, about 25–30% of all the examined preforms, regardless of the colorant concentration or production timeframe (FIG. 9). Furthermore, the severity or expression level of the observed mixing issues, if present, was noticeably lower in preforms produced using the mixing device.

[00323] The results of the visual assessment clearly demonstrate the efficiency of the use of the mixing device on the presence of mixing related visual defects in the injected preforms.

[00324] The intra-cavity analysis revealed that the occurrence of the visually lower expressed mixing defects on the preforms produced with the use of the mixing device was evenly distributed across all eight cavities (FIG. 10). This demonstrated that the use of the mixing device yields uniform mixing improvements across all the preform mould cavities, regardless of the colorant concentration and production timeframe. This result highlights the precision and reliability of the colorant mixing in preforms manufactured with the use of the mixing device.

[00325] Consistency Over Time: The analysis of the data over the production timeframe demonstrated that the colorant mixing improvement inside the preforms manufactured with the use of the mixing device was stable over the 4-hour production period.

[00326] Bottles were visually evaluated as well. Bottles were separated per preform cavity (via intra-cavity sorting) and preforms production timeframe (1st hour vs. 4th hour). The effectiveness of the use of the mixing device as per the teachings of this patent on the colorant mixing inside the bottles was evaluated through a detailed surface analysis conducted under contrast lighting by two independent observers to enhance statistical reliability.

[00327] Colorant Mixing: Across all bottles visually examined, more than 98% of the control bottles produced from preforms manufactured without the use of the mixing device displayed severe defects in colorant mixing, including but not limited to the presence of clearly discernible flowlines, uncontrolled marbling effects, colour streaks and colorant concentration spots (FIG. 11). The severity or expression level of the observed mixing issues was more pronounced in bottles produced from preforms manufactured without the use of the mixing device and at 85% of the specified colorant concentration.

[00328] In sharp contrast thereto, bottles produced from preforms manufactured with the use of the mixing device demonstrated significantly lower amount of colorant mixing issues, with fewer than 30% exhibiting said mixing related issues (FIG. 12). Furthermore, the severity or expression level of the observed mixing issues, if present, was notably reduced in bottles produced with preforms manufactured with the use of the mixing device.

[00329] The use of the mixing device allowed for the (arbitrary) reduction to 85% of the specified colorant concentration whilst maintaining the improvement in colorant mixing.

[00330] Consistency Across Cavities: The intracavity analysis revealed that the occurrence of the visually lower expressed mixing defects on the bottle produced from preforms manufactured with the use of the mixing device was evenly distributed across all eight cavities (FIG. 13).

[00331] Consistency Over Time: The analysis of the data over the production timeframe demonstrated that the colorant mixing improvement inside the working example preforms manufactured with the use of the mixing device was stable over the 4-hour production period.

[00332] Bottles produced from preforms manufactured without the use of the mixing device showed persistent mixing defects over time and across cavities. In sharp contrast thereto, bottles produced from preforms manufactured with the use of the mixing device

consistently displayed substantially fewer mixing defects, irrespective of production time or preform cavity.

[00333] Relative Index of Mixing: The increase in the relative index of mixing provided by the mixing elements configuration was ascertained using the Carreau viscosity according to the parameters of the model material referred to earlier. The reason for this work is because the model material is the PET polymer used in the experiments. The melt streams passing through the mixing elements were analyzed using a computational fluid dynamics model to evaluate the Kullback-Leibler Divergence value after passing through the transition elements. This value was subtracted from 1 to determine the increase in the relative index of mixing. In this case, the mixing element configurations yielded an increase in the relative index of mixing of 0.40.

Claims

1. A mixing device (2000) for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.
2. The mixing device of claim 1, wherein at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.
3. The mixing device of any of claims 1 or 2, wherein each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one channel inlet of an immediately successive mixing element is partially or completely aligned with a channel outlet of the immediately preceding mixing element.
4. The mixing device of any of claims 2 or 3, wherein a portion of each channel whether open (3150) or isolated (3100) of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.
5. The mixing device of any of claims 1 to 4, wherein the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale mixing (Horseshoe)

, an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

6. The mixing device of claim 5, wherein the mixing device comprises a Xemex mixer/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer.
7. The mixing device of any of claims 1 to 6, wherein the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.
8. The mixing device of any of claims 1 to 7, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.
9. The mixing device of claims 8, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.
10. The mixing device of any of claims 1 to 9, wherein the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.
11. The mixing device of any of claims 1 to 10, wherein the mixing device is monolithic.
12. A nozzle collar comprising a monolithically integrated mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.

13. The nozzle collar of claim 12, wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

14. The nozzle collar of any of claim 12 or 13, wherein at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.af

15. The nozzle collar of any of claims 12 to 14, wherein each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one melt channel inlet of an immediately successive mixing element is partially or completely aligned with a melt channel outlet of the immediately preceding mixing element.

16. The nozzle collar of any of claims 13 to 15, wherein a portion of each channel whether open (3150) or isolated (3100) of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

17. The nozzle collar of any of claims 12 to 16, wherein the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

18. The nozzle collar of claim 17, wherein the mixing device comprises a Xemex mixer,/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer.

19. The nozzle collar of any of claims 12 to 18, wherein the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

20. The nozzle collar of any of claim 12 to 19, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

21. The nozzle collar of claim 20, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.

22. A system for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

23. The system of claim 22, wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

24. A process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a mixing device (2000) for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least

two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element, and wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.

25. The process of claim 24, wherein at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.

26. The process of any of claims 24 or 25, wherein each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one channel inlet of an immediately successive mixing element is partially or completely aligned with a channel outlet of the immediately preceding mixing element.

27. The process of any of claims 25 or 26, wherein a portion of each channel whether open (3150) or isolated (3100) of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

28. The process of any of claims 24 to 27, wherein the mixing device is configured to mix a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale mixing (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

29. The process of claim 28, wherein the mixing device comprises a Xemex mixer/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer.

30. The process of any of claims 24 to 29, wherein the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

31. The process of any of claims 24 to 30, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

32. The process of claims 31, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.
33. The process of any of claims 24 to 32, wherein the mixing device is configured to be attached to a detachable nozzle port or a nozzle collar.
34. The process of any of claims 24 to 33, wherein the mixing device is monolithic.
35. A process to injection mould a part comprised of a primary constituent and at least one auxiliary constituent in which said process comprises an injection cycle to pass the primary constituent and the at least one auxiliary constituent through a nozzle collar comprising a monolithically integrated mixing device for mixing a composition comprising a primary constituent and at least one auxiliary constituent, said mixing device comprising at least one mixing element (3000) with the mixing device having a mixing device central void zone (2500) surrounding a mixing device central axis (2550); wherein at least a portion of the mixing device central void zone lies between the mixing device central axis and the at least one mixing element which has at least one entrance at a first end and at least one exit at a second end opposite the first end; and wherein the at least one mixing element has a plurality of channels (3100, 3150) with at least one channel inlet (3200) and at least one channel outlet (3300), wherein the plurality of channels has at least two isolated channels (3100) having a cross section perimeter within at least one cross sectional area of the mixing element located between the entrance and the exit of the at least one mixing element.
36. The process of claim 35, wherein each of the at least two isolated channels is fluidly connected to at least one other channel of the plurality of channels before the exit of the at least one mixing element.
37. The process of any of claim 35 or 36, wherein at least a portion of a flow direction of at least one of the at least two isolated channels is directed towards either the mixing device central axis or away from the mixing device central axis.
38. The process of any of claims 35 or 37, wherein each successive mixing element of the plurality of mixing elements is rotated around the mixing device central axis relative to an immediately preceding mixing element so that at least one melt channel inlet of an immediately successive mixing element is partially or completely aligned with a melt channel outlet of the immediately preceding mixing element.

39. The process of any of claims 36 to 38, wherein a portion of each channel whether open (3150) or isolated (3100) of the plurality of channels is directed towards either the mixing device central axis or away from the mixing device central axis.

40. The process of any of claims 36 to 39, wherein the mixing device is configured to transform a melt stream comprising a primary constituent and at least one auxiliary constituent according to a transformation selected from the group consisting of a Fractal geometry Transformation, a Baker Transformation, a Smale Transformation (Horseshoe) , an Arnold's Cat Map transformation, a Lyapunov exponent transformation and combinations thereof.

41. The process of claim 40, wherein the mixing device comprises a Xemex mixer,/ Transformation opposite chiralities, a Mobius band mixer, a Tesla structure with a Coandă effect, a Serpentine Laminating Structure, a Self-vortical mixer,

42. The process of any of claims 36 to 41, wherein the portion of the mixing device central void zone that lies between the mixing device central axis and the mixing element or plurality of mixing elements does not have any fluid contact with any channel of the plurality of channels.

43. The process of any of claim 36 to 42, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.9.

44. The process of claim 43, wherein a ratio of a minimum cross sectional flow area of a mixing element or the plurality of mixing elements to a maximum cross sectional flow area of the mixing element or the plurality of mixing elements is less than 0.75.

45. The process of any of claims 24 to 35, wherein the primary constituent is selected from the group consisting of rubbers and plastics, whether virgin, recycled or a combination thereof.

46. The process of any of claims 35 to 44, wherein the primary constituent is selected from the group consisting of rubbers and plastics, whether virgin, recycled or a combination thereof.

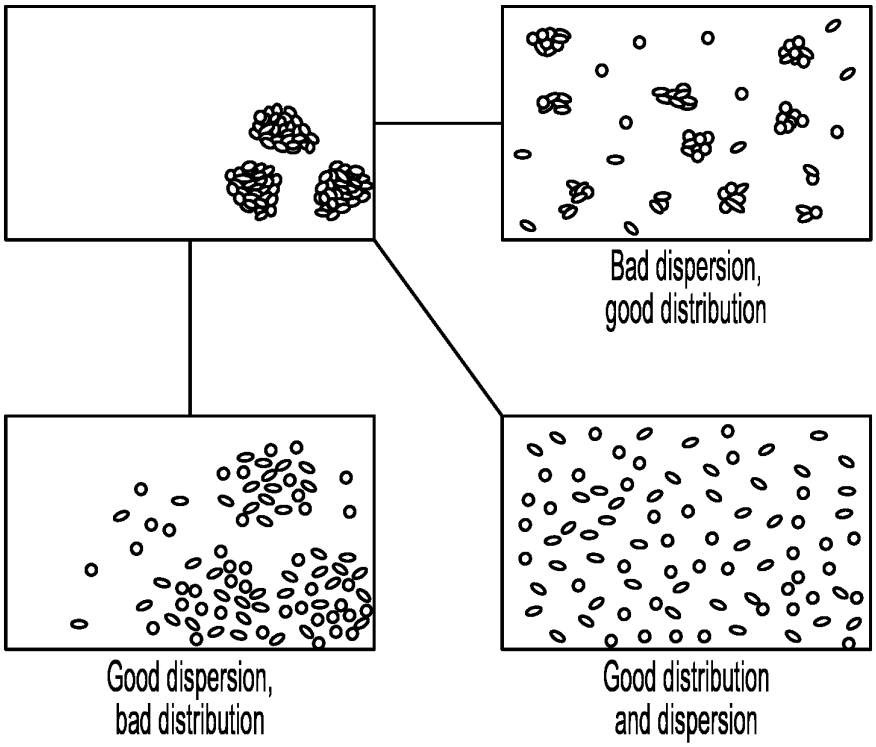

Bad dispersion,
good distribution
Good dispersion,
bad distribution
Good distribution
and dispersion

FIG. 1

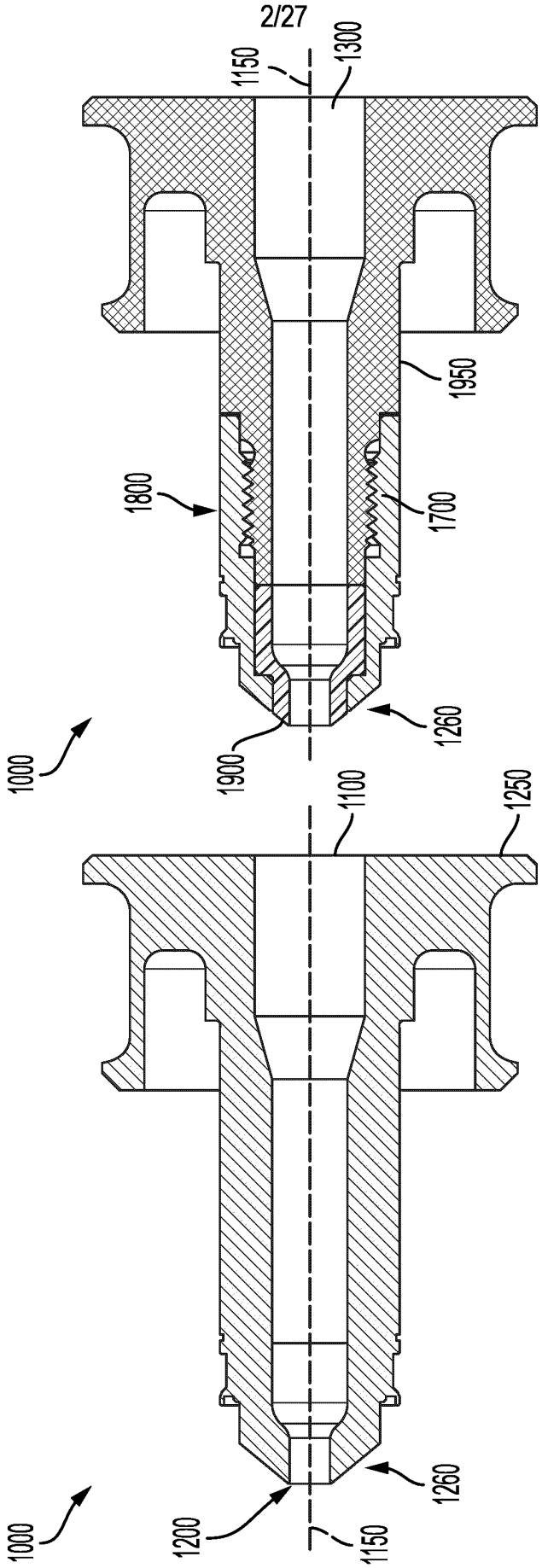


FIG. 2B
PRIOR ART

FIG. 2A
PRIOR ART

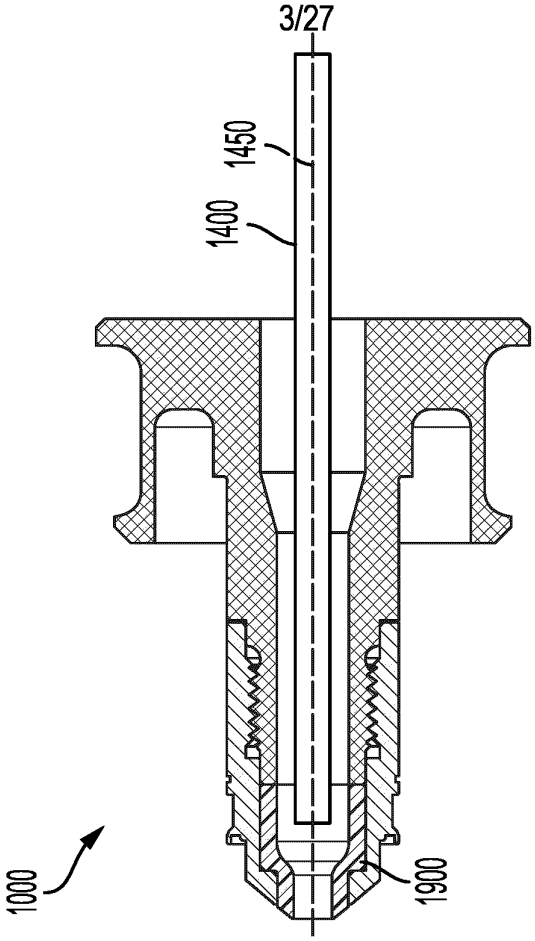


FIG. 3B
PRIOR ART

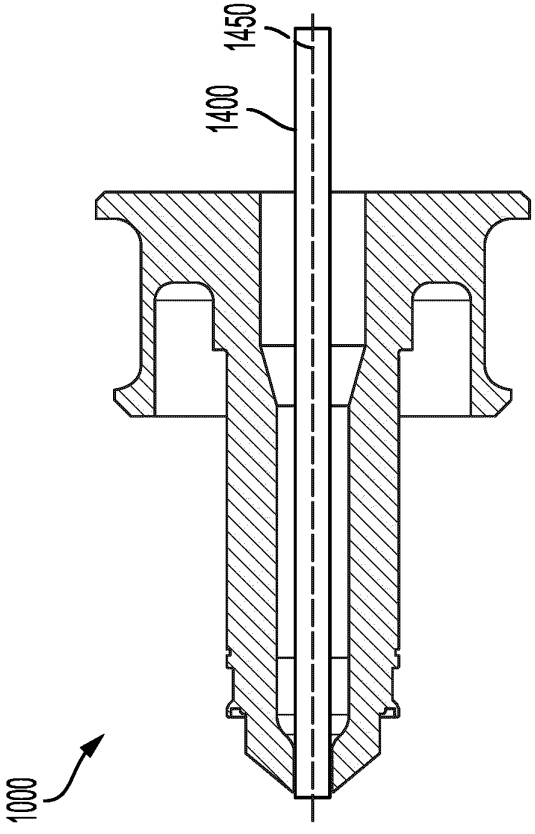


FIG. 3A
PRIOR ART

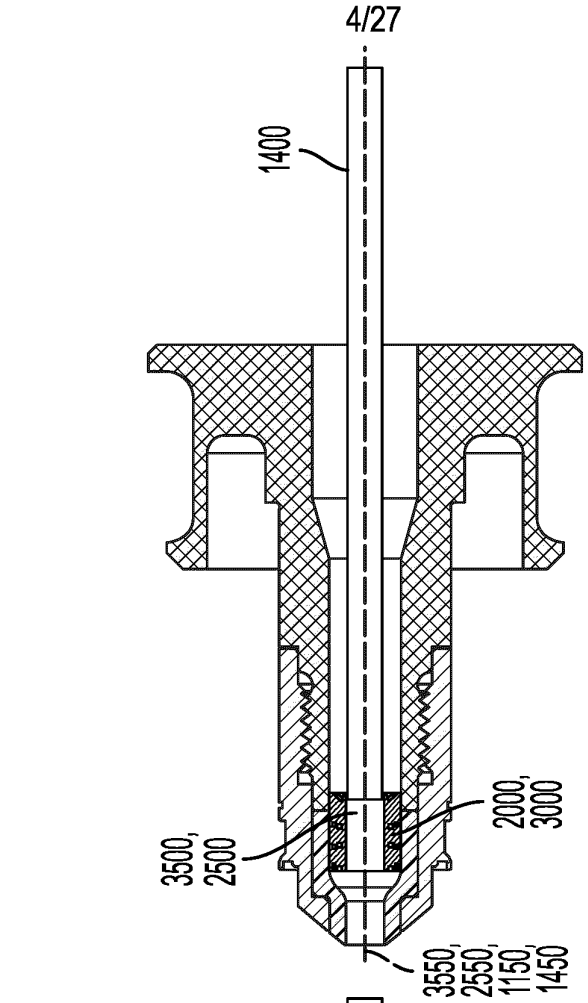

1400
3500,
2500
2000,
3000
3550,
2550,
1150,
1450

FIG. 4B

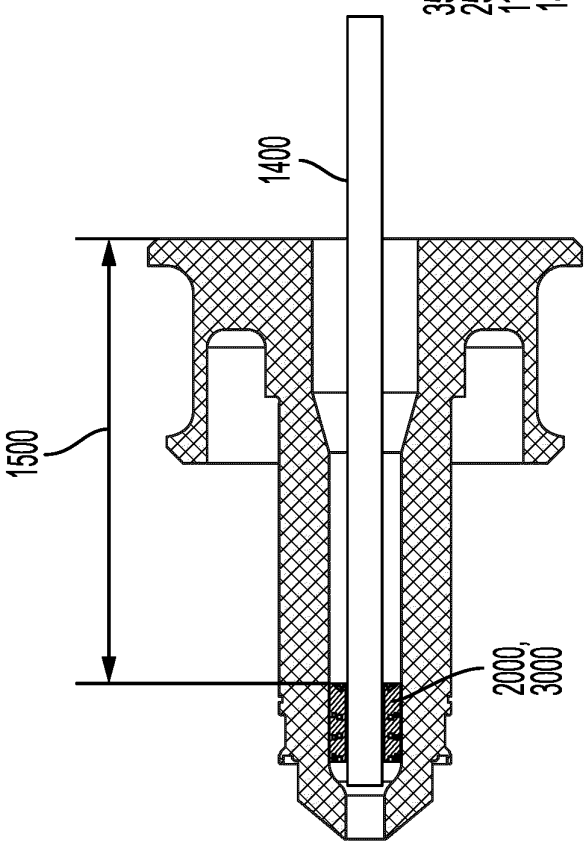

1400
1500
2000,
3000

FIG. 4A

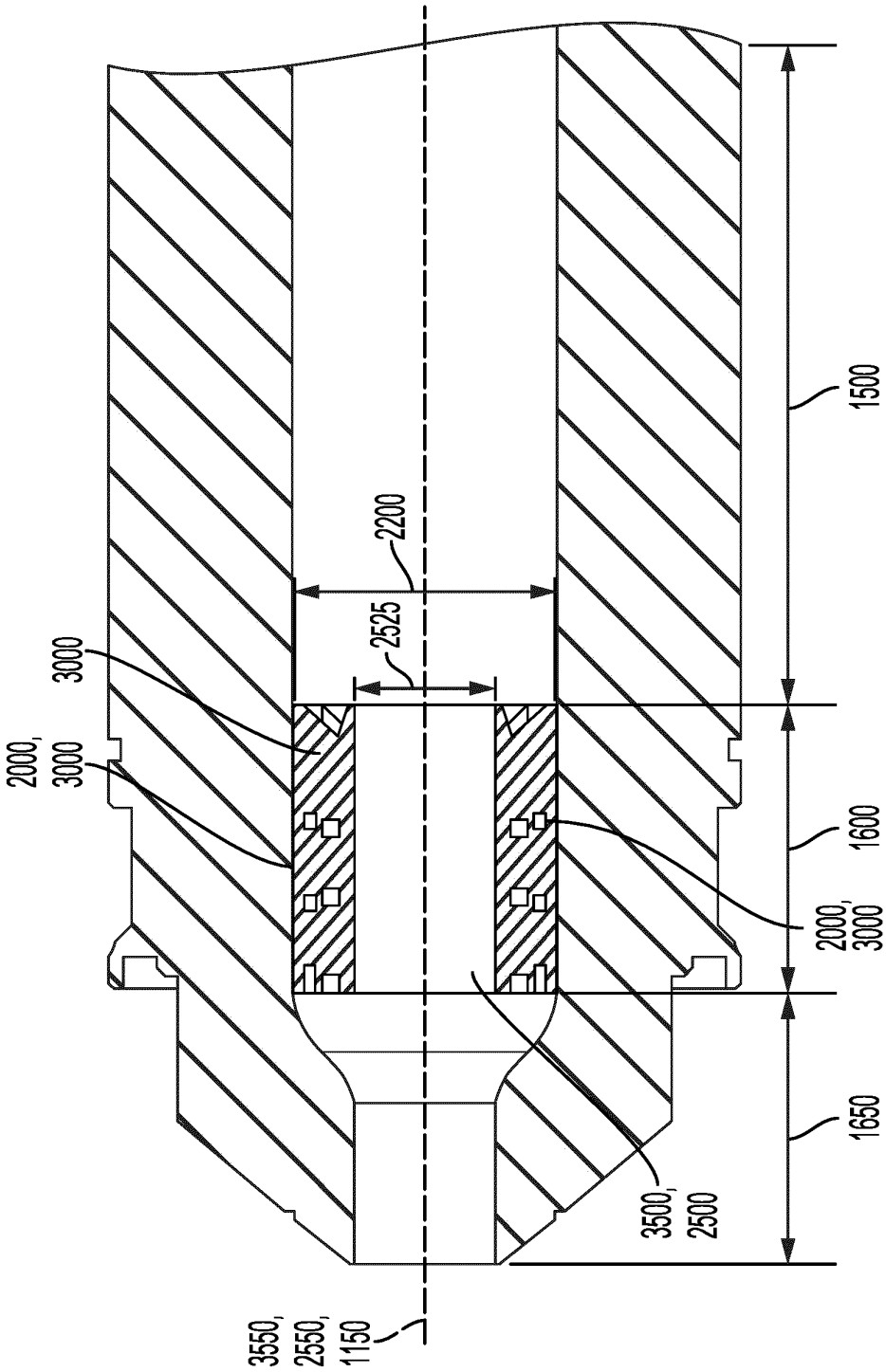

1500
2200
2525
3000
2000,
3000
1600
2000,
3000
1650
3500,
2500
3550,
2550,
1150

FIG. 4C

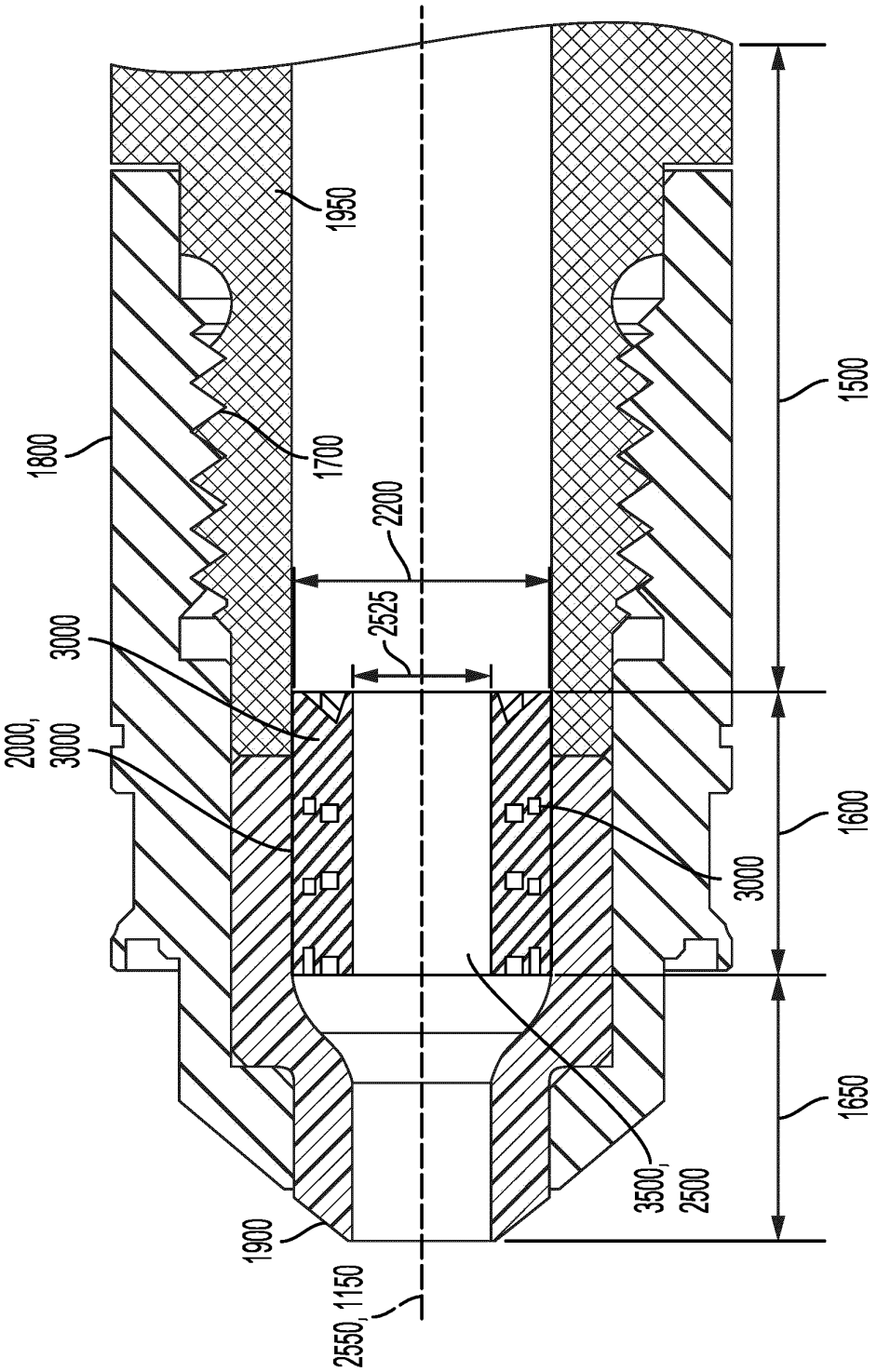

1950
1800
1700
2200
1500
2525
3000
2000,
3000
1600
3000
1650
3500,
2500
1900
2550, 1150

FIG. 4D

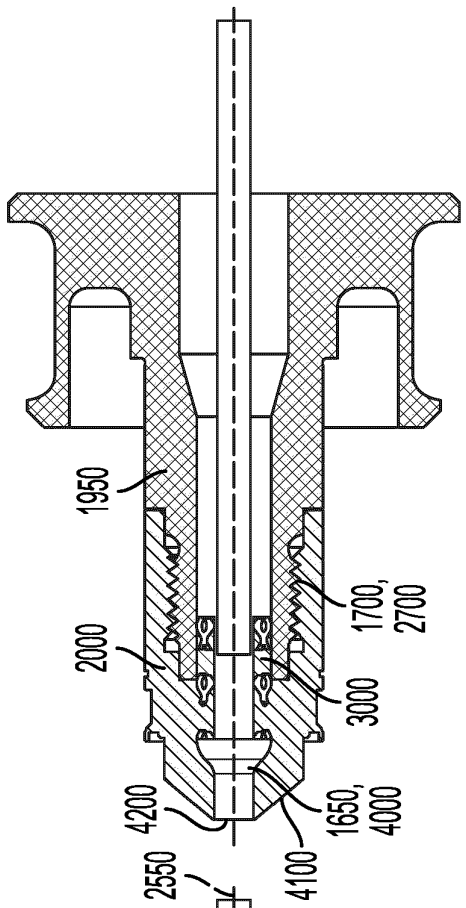

1950
2000
1700,
2700
3000
4200
1650,
4000
4100
2550

FIG. 5B

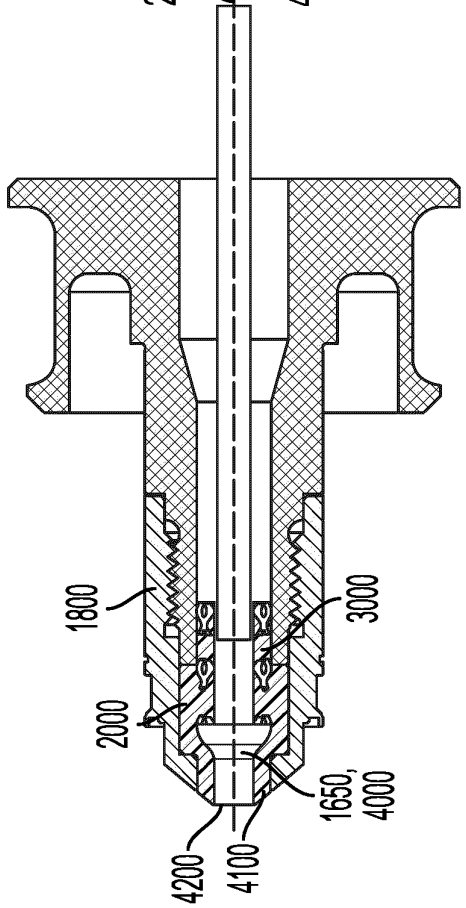

1800
3000
2000
1650,
4000
4200
4100

FIG. 5A

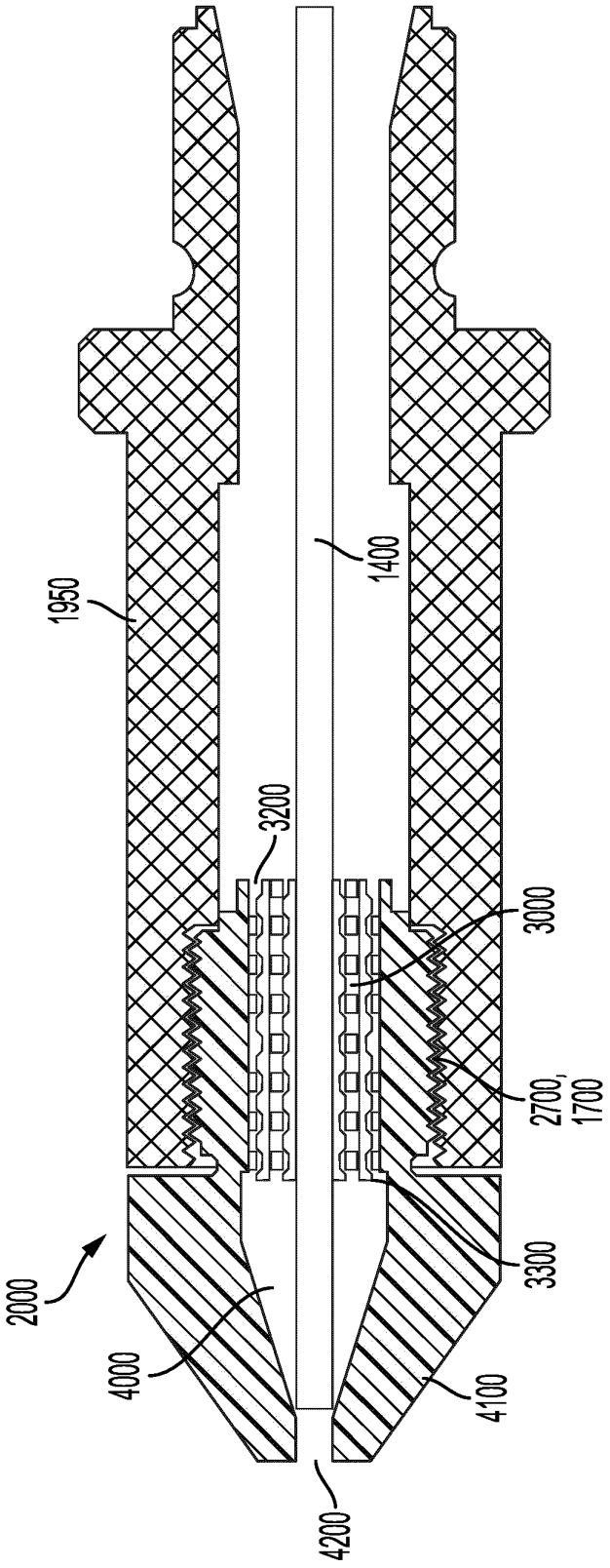


FIG. 5C

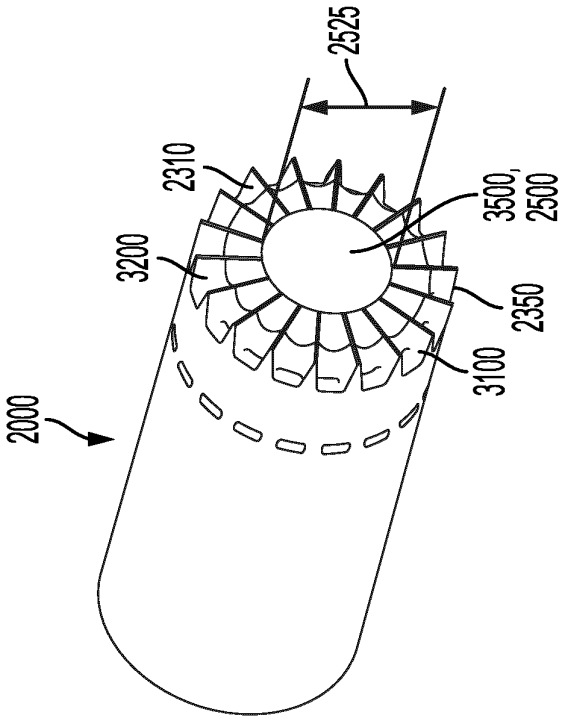

2525
2310
3500,
2500
3200
2350
3100
2000

FIG. 6B

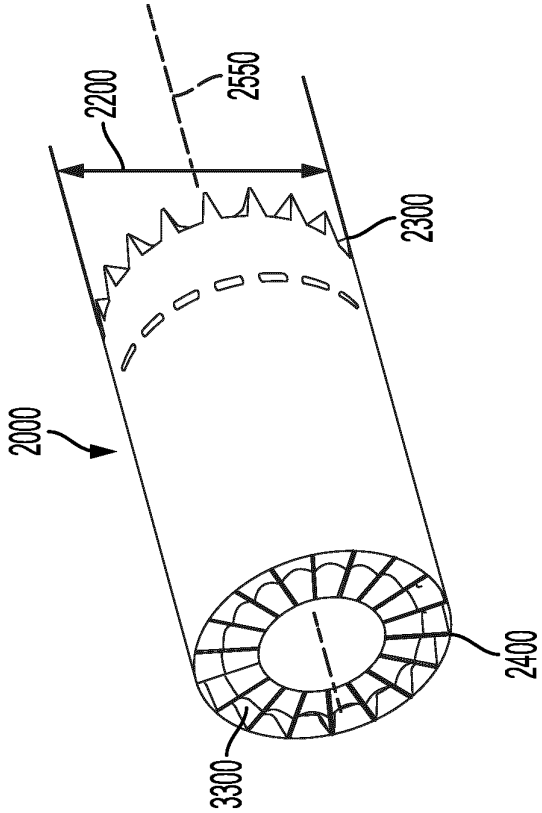

2200
2550
2300
2000
2400
3300

FIG. 6A

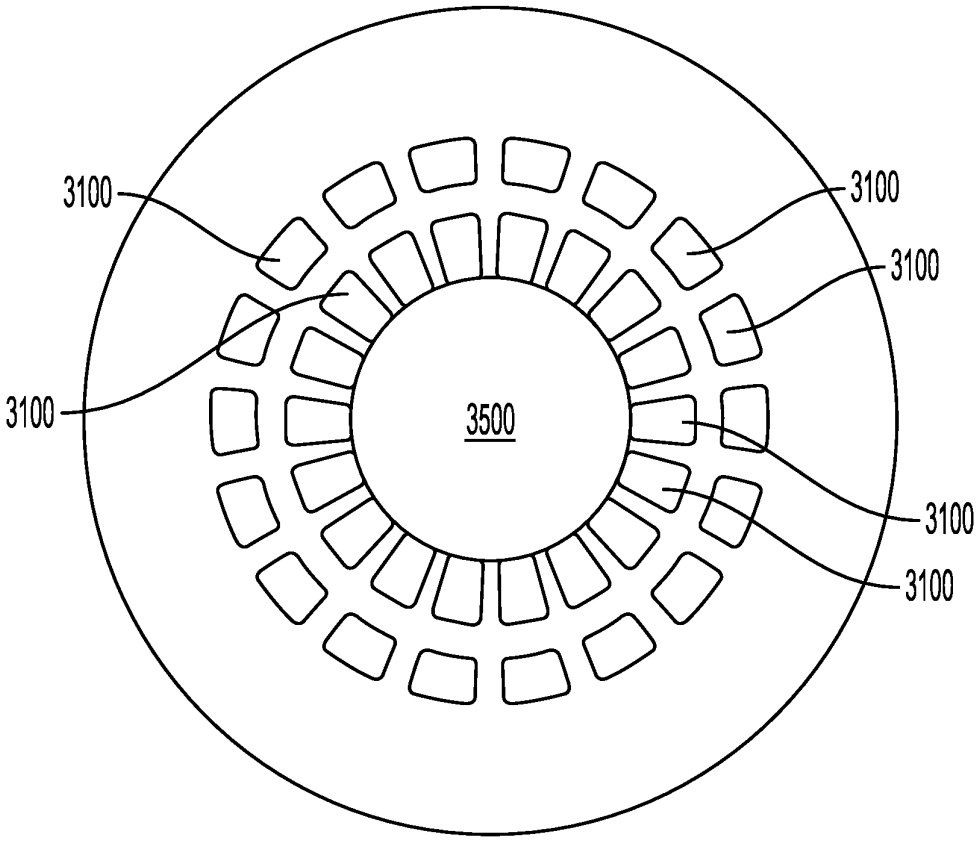


FIG. 6C

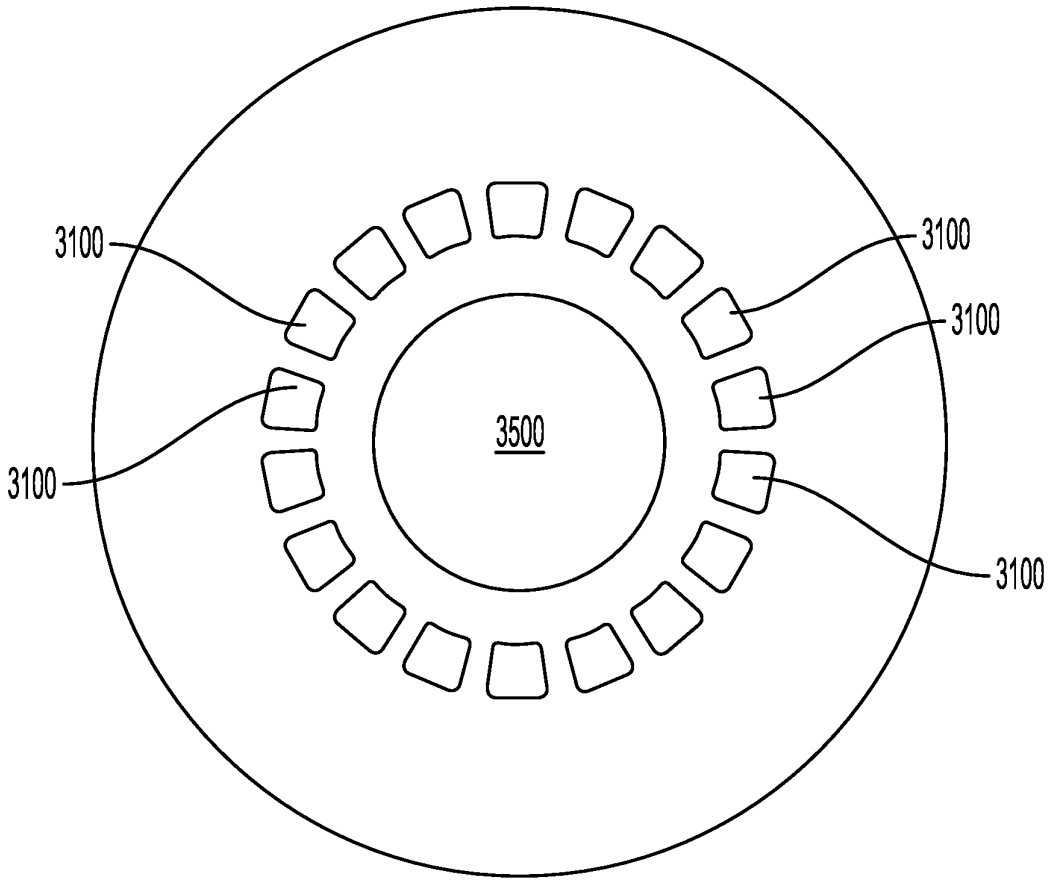


FIG. 6D

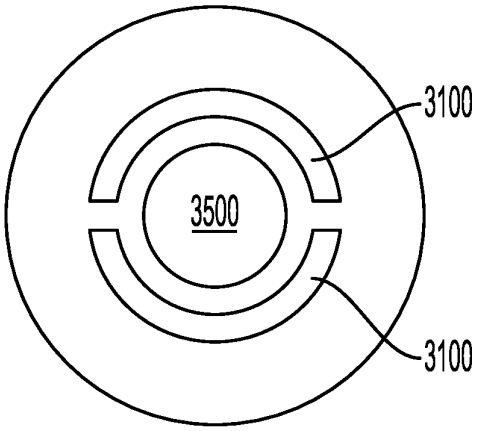


FIG. 6E

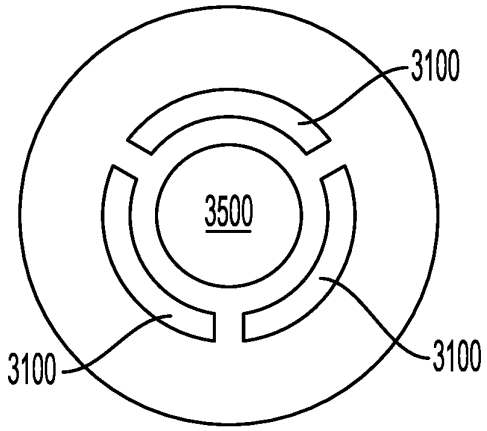


FIG. 6F

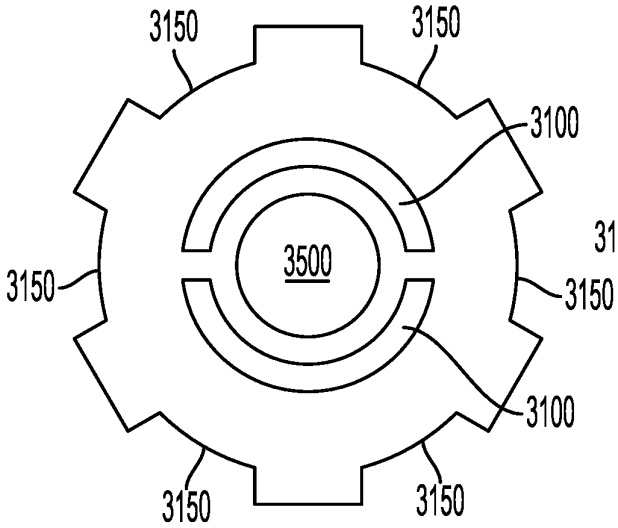


FIG. 6G

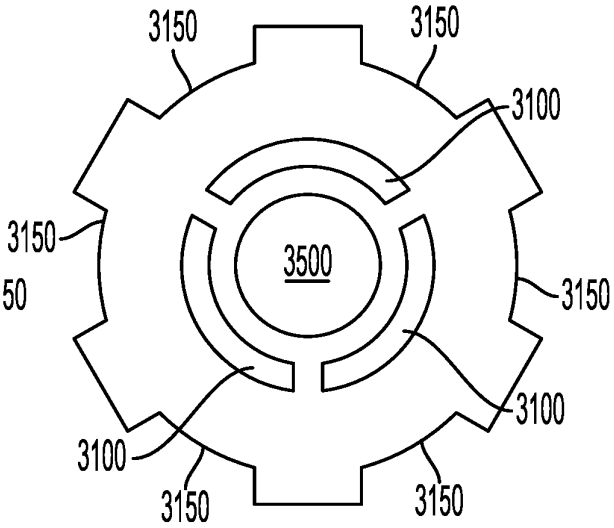


FIG. 6H

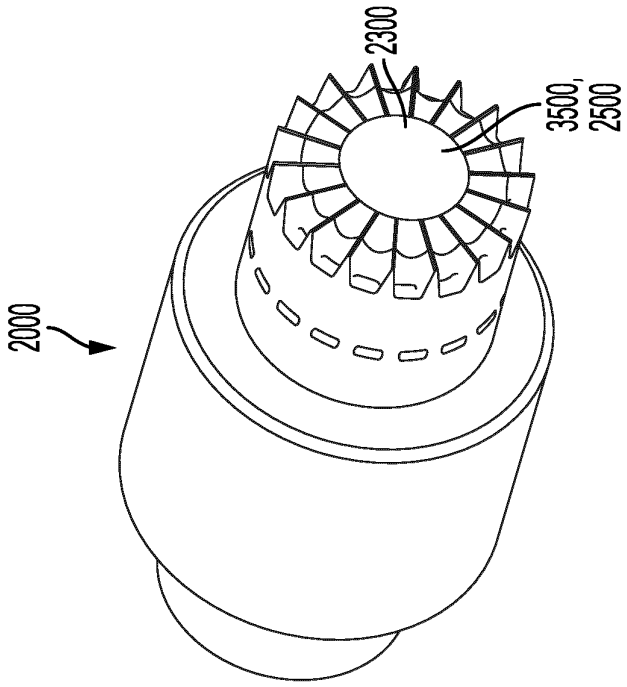


FIG. 7B

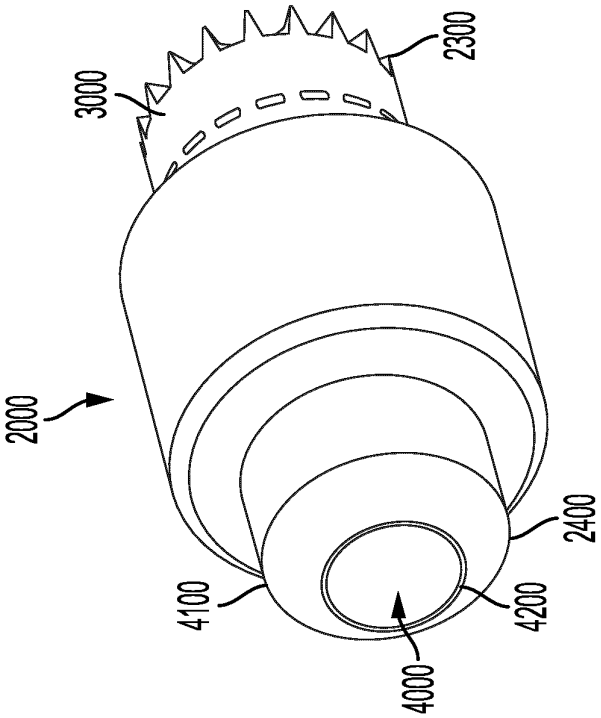


FIG. 7A

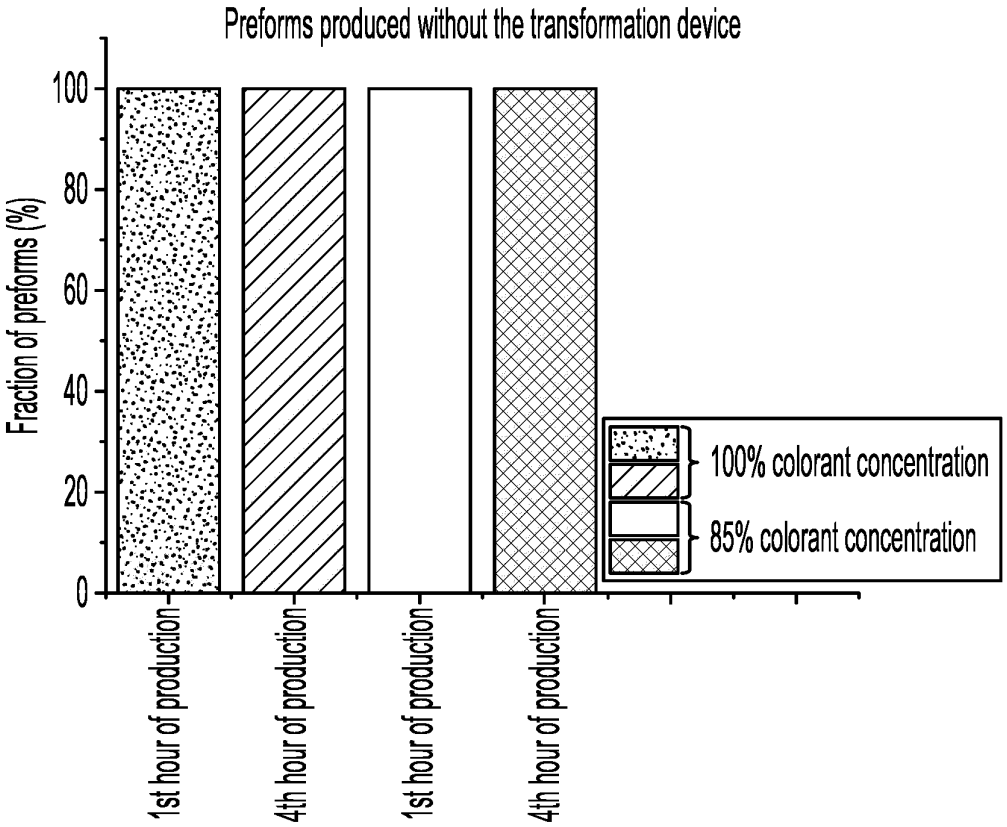

Preforms produced without the transformation device
Fraction of preforms (%)
100
80
60
40
20
0
1st hour of production
4th hour of production
1st hour of production
4th hour of production
100% colorant concentration
85% colorant concentration

FIG. 8

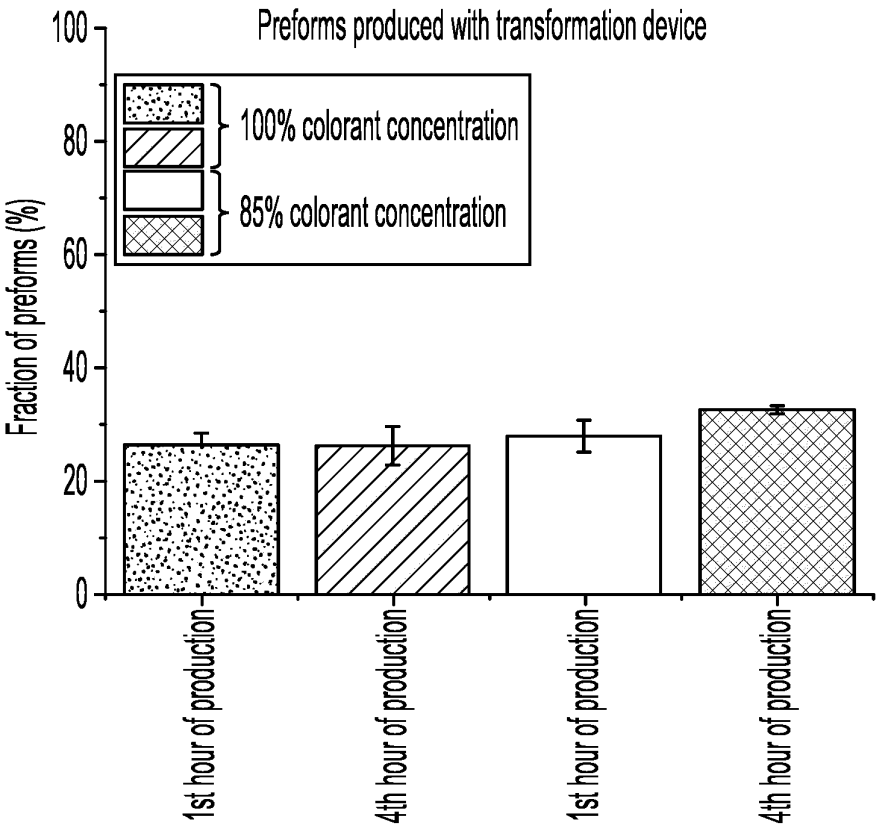

Preforms produced with transformation device
100% colorant concentration
85% colorant concentration
Fraction of preforms (%)
100
80
60
40
20
0
1st hour of production
4th hour of production
1st hour of production
4th hour of production

FIG. 9

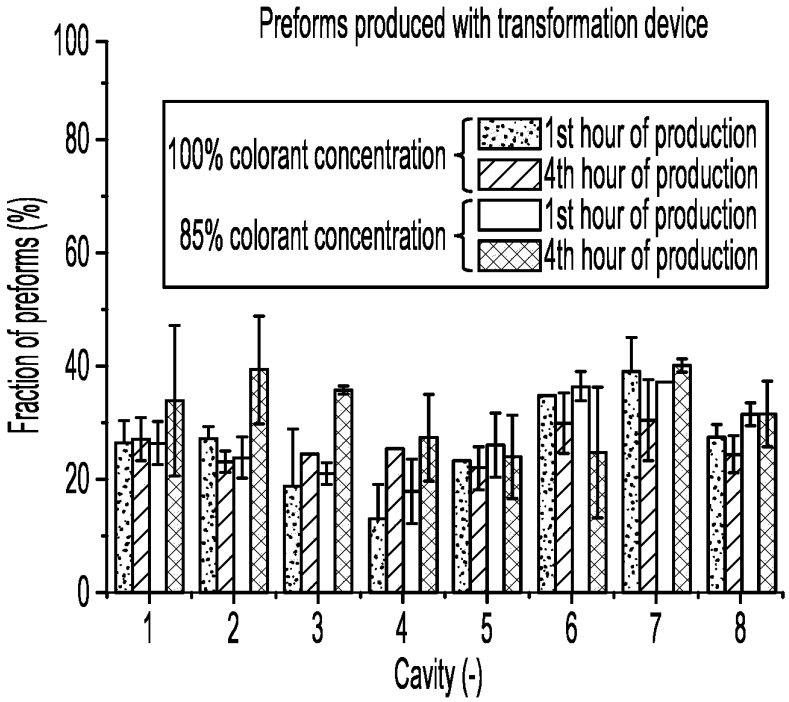

Preforms produced with transformation device
100% colorant concentration
1st hour of production
4th hour of production
85% colorant concentration
1st hour of production
4th hour of production
Fraction of preforms (%)
0
20
40
60
80
100
1
2
3
4
5
6
7
8
Cavity (-)

FIG. 10

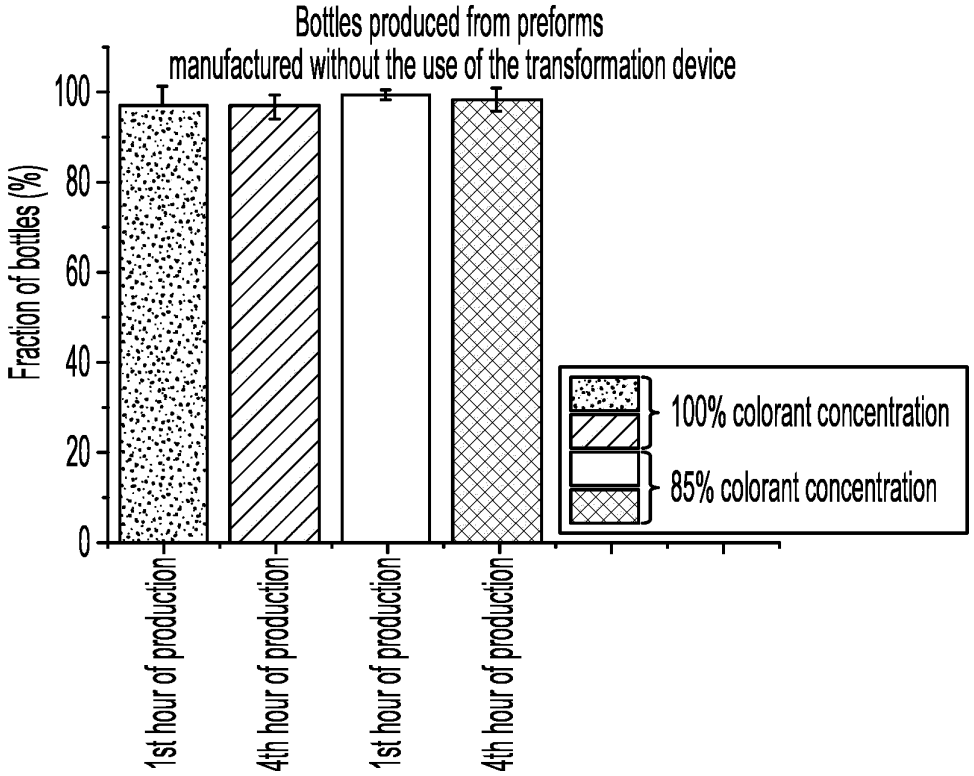

Bottles produced from preforms
manufactured without the use of the transformation device
Fraction of bottles (%)
0
20
40
60
80
100
1st hour of production
4th hour of production
1st hour of production
4th hour of production
100% colorant concentration
85% colorant concentration

FIG. 11

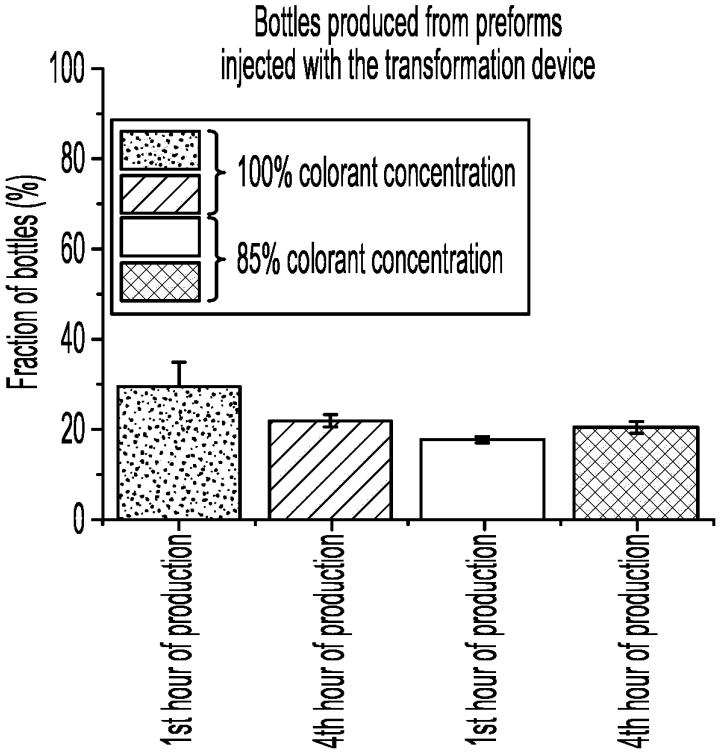

Bottles produced from preforms
injected with the transformation device
Fraction of bottles (%)
100
80
60
40
20
0
100% colorant concentration
85% colorant concentration
1st hour of production
4th hour of production
1st hour of production
4th hour of production

FIG. 12

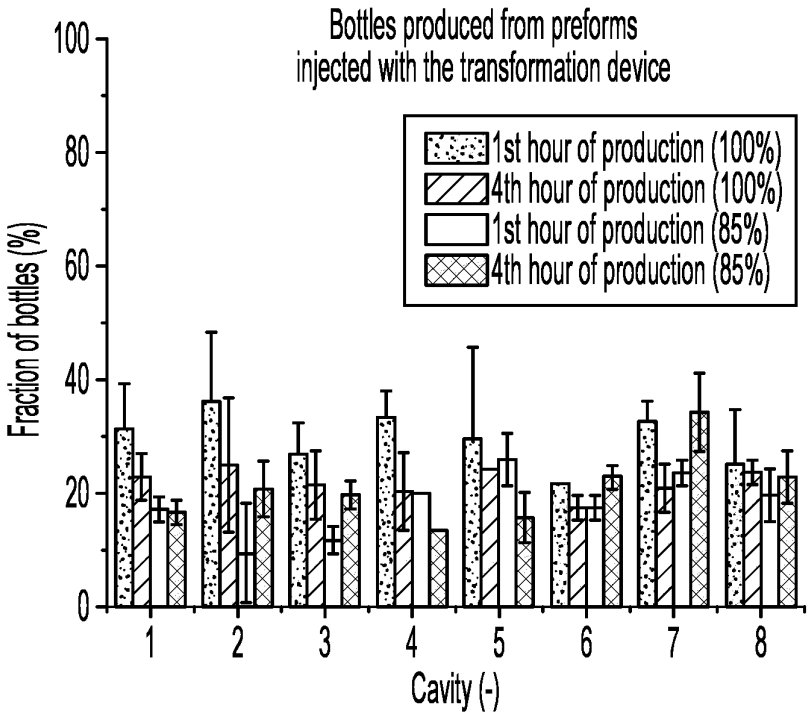

Bottles produced from preforms
injected with the transformation device
1st hour of production (100%)
4th hour of production (100%)
1st hour of production (85%)
4th hour of production (85%)
Fraction of bottles (%)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
Cavity (-)

FIG. 13

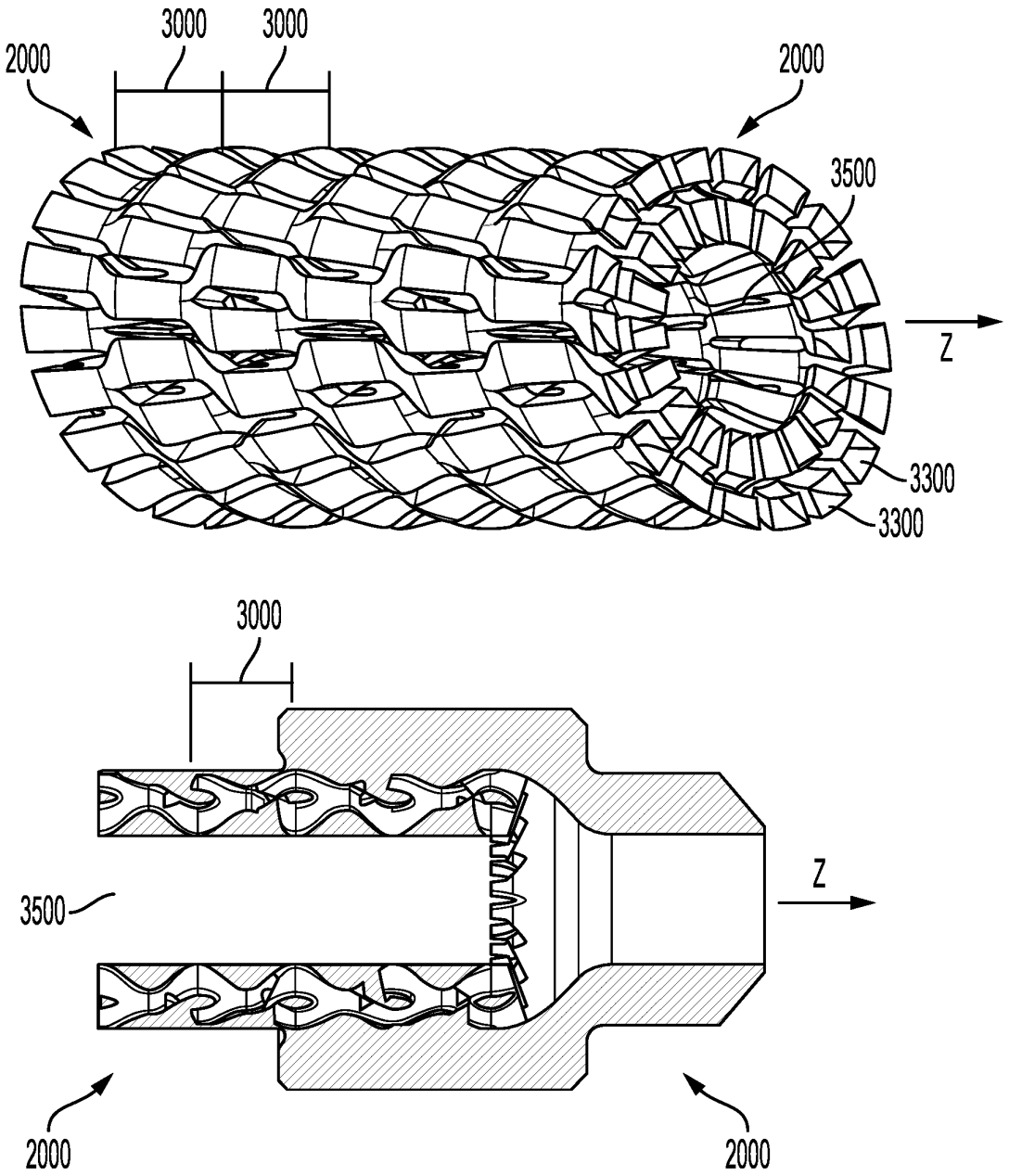


FIG. 14

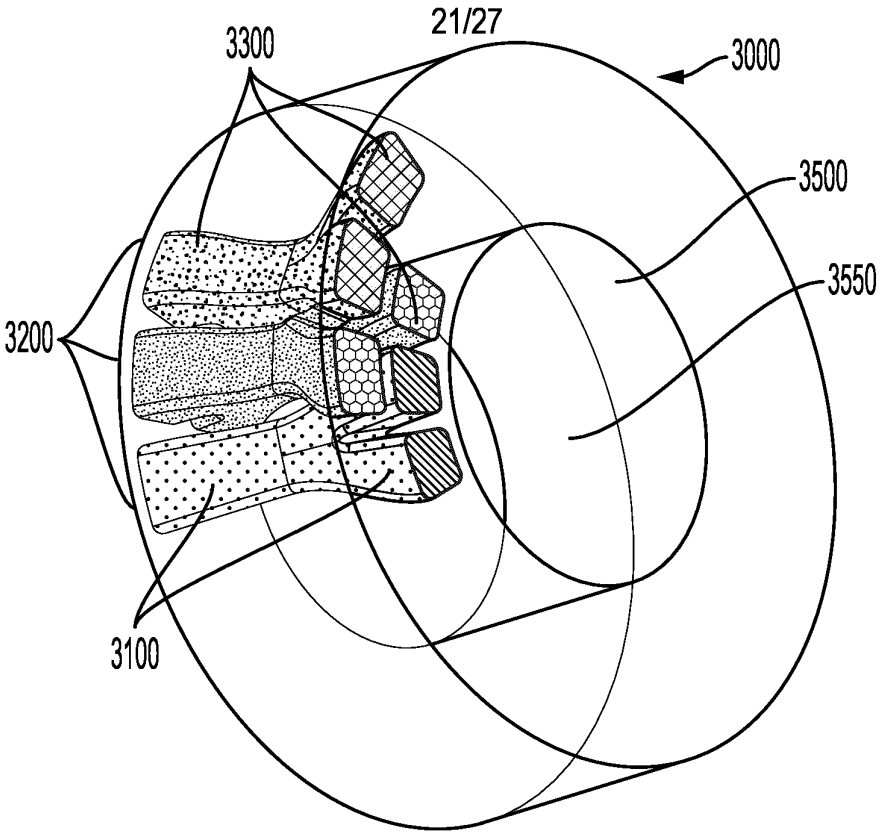


FIG. 15A

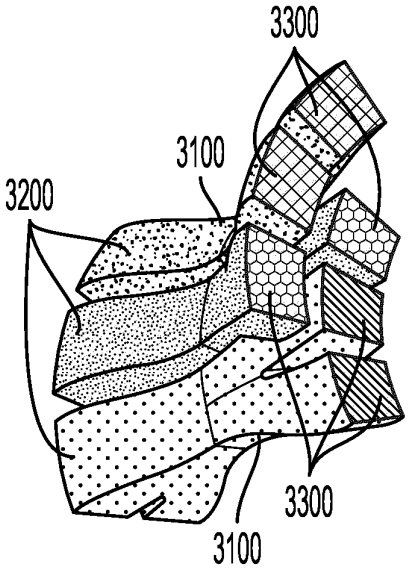


FIG. 15B

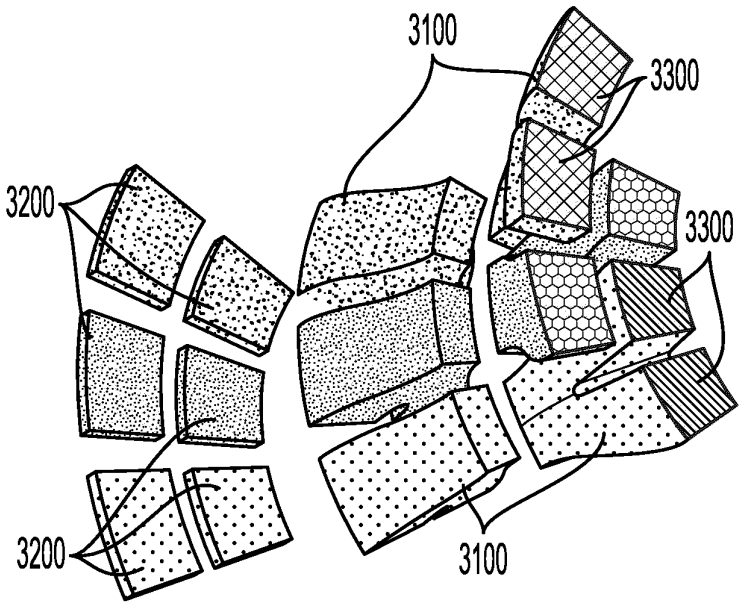


FIG. 15C

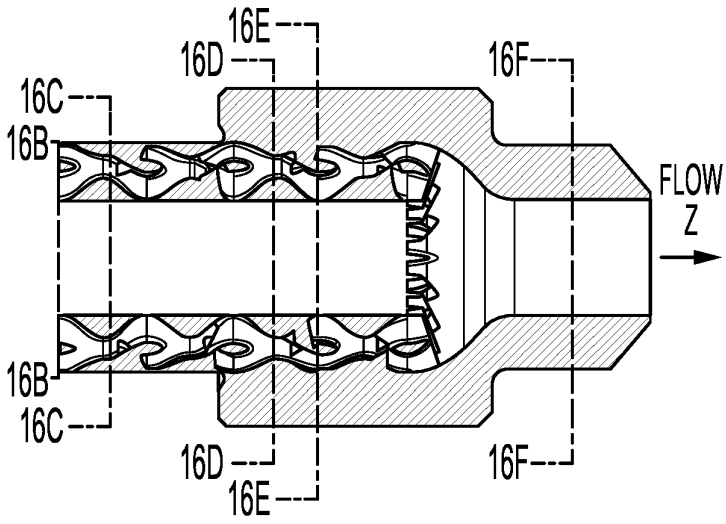


FIG. 16A

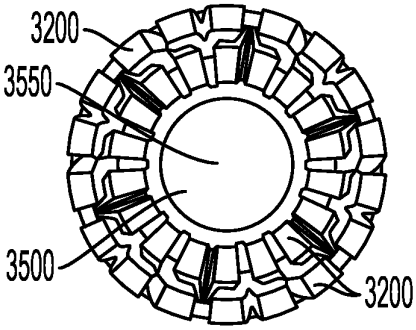


FIG. 16B

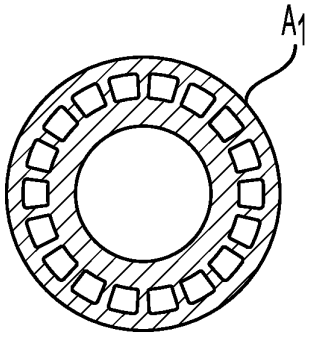


FIG. 16C

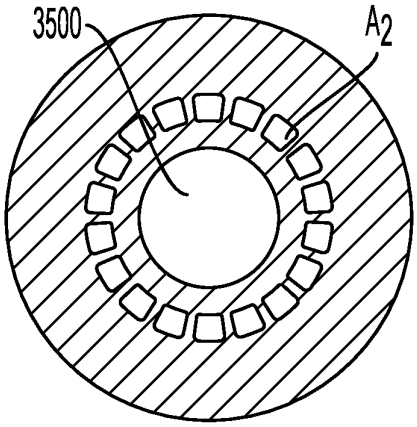


FIG. 16D

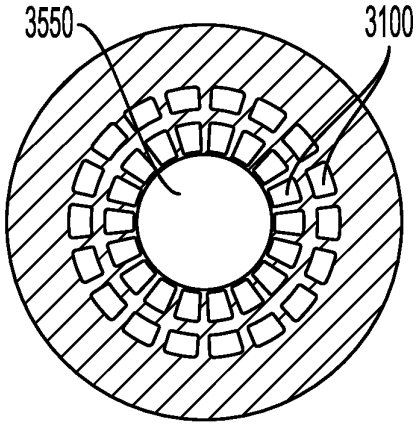


FIG. 16E

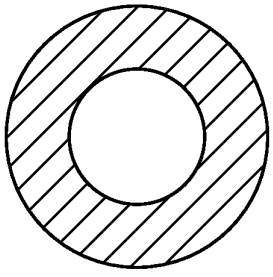


FIG. 16F

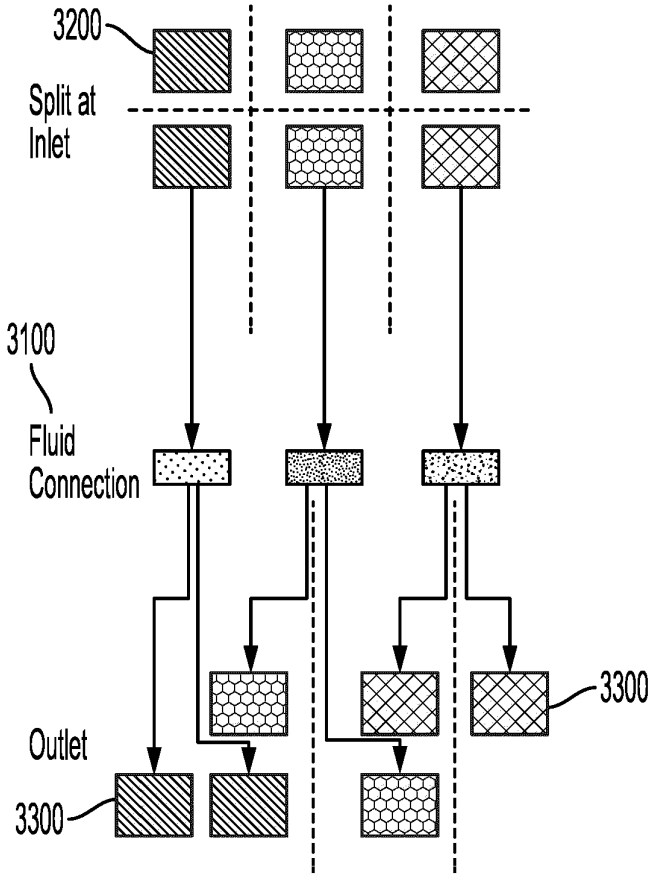


FIG. 17

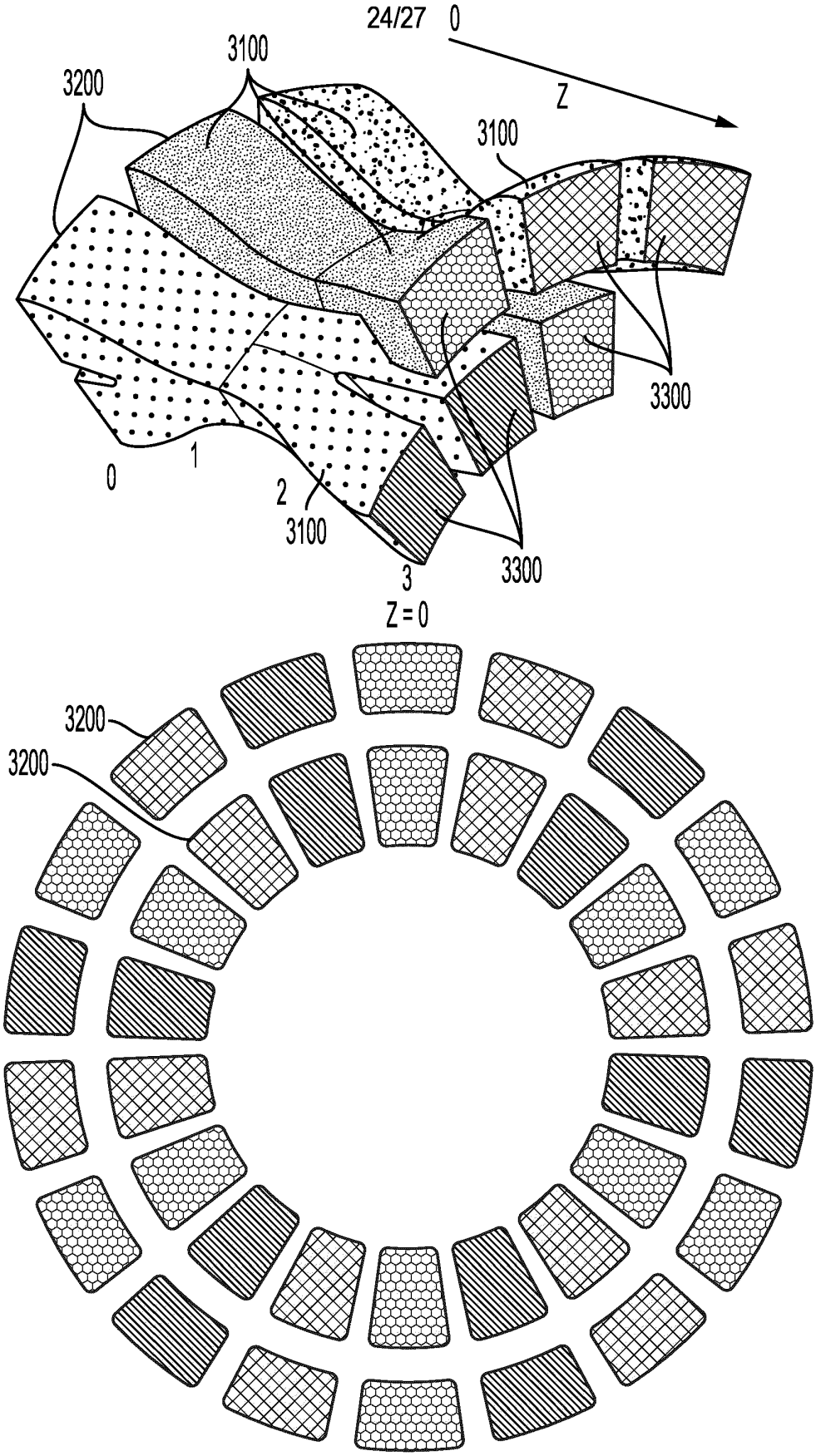


FIG. 18A

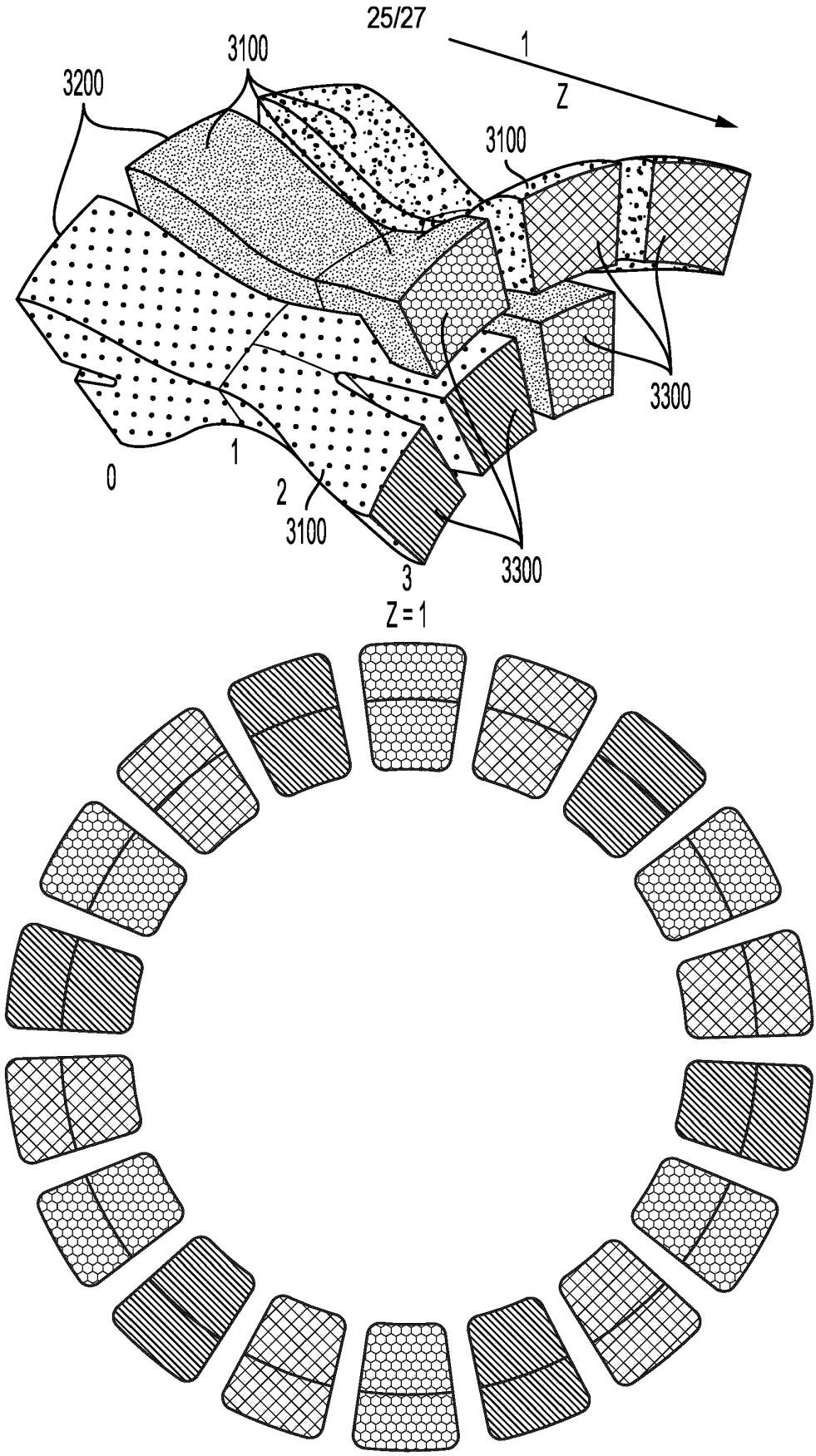


FIG. 18B

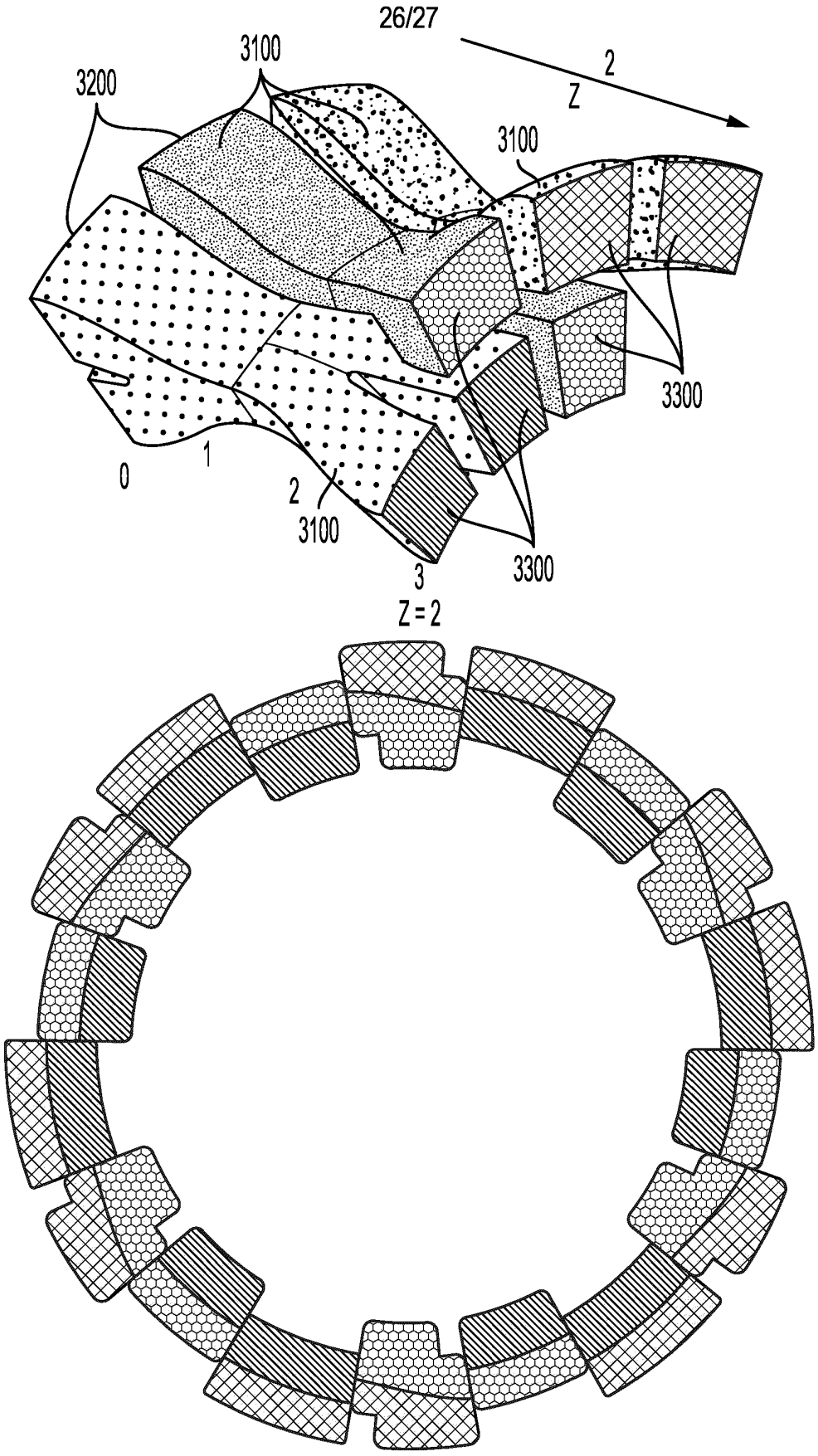


FIG. 18C

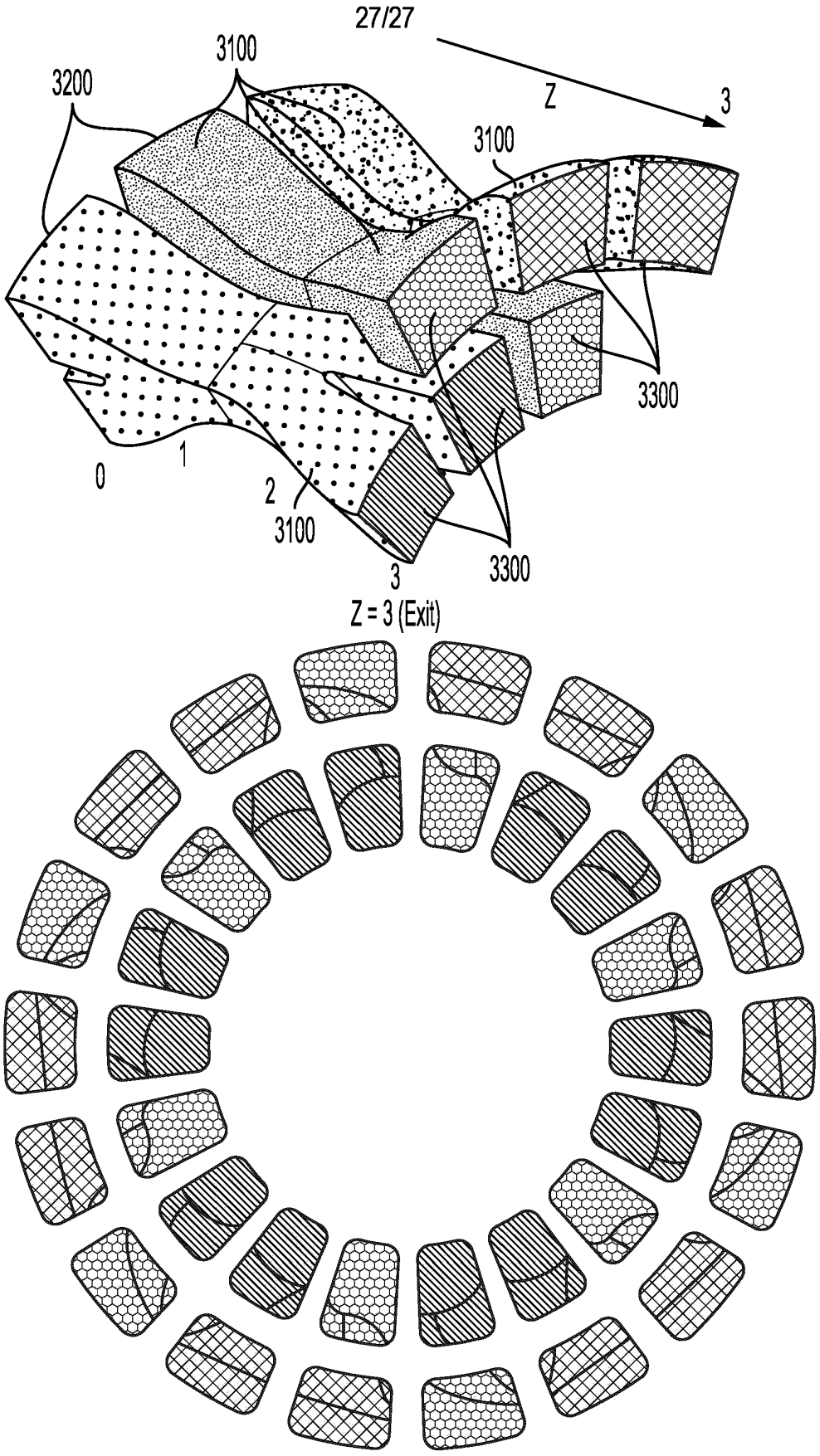


FIG. 18D

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2026/063466

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C45/30 B29C45/58
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 practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/015275 A1 (GUENTHER HERBERT [DE]) 21 January 2010 (2010-01-21)	1,2,4, 7-14,16, 19-25, 27, 30-37, 39,42-46
A	paragraphs [0008], [0018], [0034] figures 3,4	3,5,6, 15,17, 18,26, 28,29, 38,40,41

X	EP 4 045 264 B1 (BASF SE [DE]) 14 August 2024 (2024-08-14)	35, 37-39, 45,46
A	paragraphs [0004], [0029], [0099]; figure 13	1-34,36, 40-44

	-/--	

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 2026	28/09/2026

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	Koning, Erik

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2026/063466

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/110918 A1 (DEZON-GAILLARD PATRICE FABIEN [US] ET AL) 23 April 2015 (2015-04-23) claims 16,17 figure 6	1-46
A	US 3 989 434 A (MERCER JAMES R) 2 November 1976 (1976-11-02) figures 1,2	1-46
A	CN 117 901 344 A (ZHUHAI CPT PREC MOLD CO LTD) 19 April 2024 (2024-04-19) figures 2,3	1-46

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2026/063466

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