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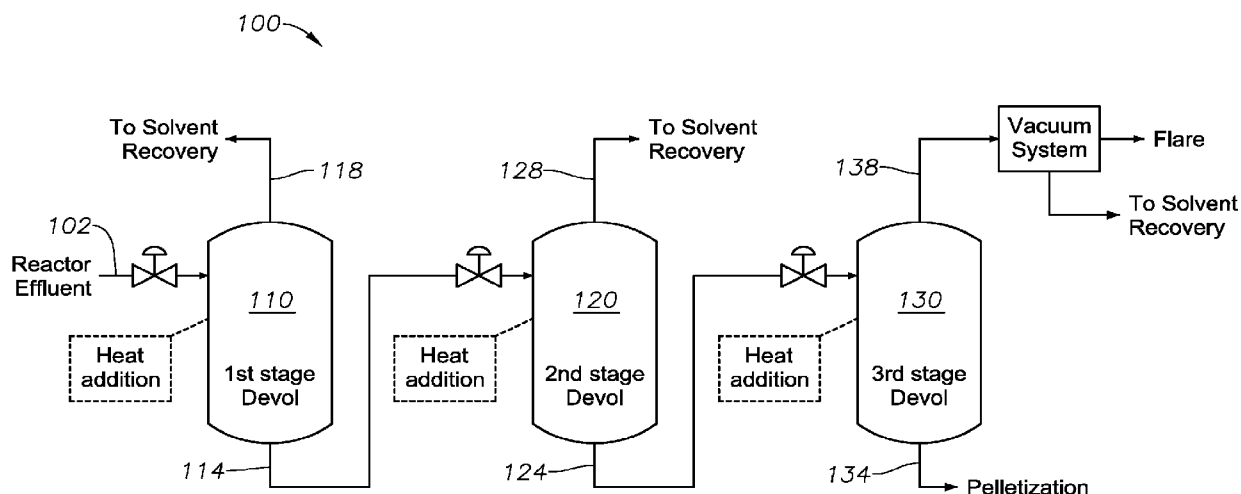


FIG. 1

(57) Abstract: Systems and methods for devolatilizing a low viscosity polymer. The method comprises providing a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.

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ENHANCED POLYMER DEVOLATILIZATION VIA CONTROLLED FOAMING

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/476,390, filed on December 21, 2022, the entire contents of which are incorporated herein by reference.

FIELD

[0002] Systems and methods for polymer resin devolatilization are provided. More particularly, systems and methods for devolatilizing poly alpha olefins made in solution are provided herein.

BACKGROUND

[0003] Solution polymerization is one of many methods by which polymerization can be performed on an industrial scale. In solution polymerization processes, monomers are reacted in the presence of catalysts and a solvent, typically a solvent that does not react with the catalysts or monomers. The monomers and polymers resulting from the polymerization reaction are solubilized in a reactor by a solvent. Heat released by the reaction is absorbed by the solvent and removed by various methods, including but not limited to chilled feed, reflux cooling, cooling jacket, and heat exchangers. The effluent exiting from the reactor is a mixture of polymer, solvent, and unconverted monomers. The polymer is separated from the rest of the effluent, i.e. the solvent and unconverted monomers. Then, the polymers are pelletized to form small pellets, which are dried and bagged. Continuous stirred-tank reactor (CSTR) and non-adiabatic loop reactor are examples of reactors that can be used in the solution polymerization process.

[0004] The polymer product is separated from the solvent and unreacted monomers in a polymer devolatilization unit (Devol unit), which is a multistage process with various process conditions. As the polymer solution passes through the different stages of the Devol unit, the polymer concentration is increased, and the solvent and monomer concentrations are decreased. The maximum amount of devolatilization at each stage is governed (i.e. limited) by the equilibrium conditions at a specific temperature and pressure. The goal is to produce a polymer product with the lowest amount of Volatile Organic Compounds (VOC) in part-per-million levels.

[0005] In each stage of the Devol unit, a sufficient heat of vaporization, maximum interface between liquid and vapor, and time are needed at a specific temperature and pressure. In general, a significant amount of solvent and monomers are separated from the polymer in the initial stages of the Devol unit. The amount of solvent separated in each stage is determined by the operating temperature and pressure at each stage. Higher temperatures and lower pressures lead to higher devolatilization rates and hence lower solvent concentration in the polymer product.

[0006] In the final stages of the Devol unit, where the solvent concentration of the polymer solution is lowest, the rate of devolatilization is minimal. This is because the separation process is limited by the solvent mass transfer rate through the polymer, which is a very slow phenomenon. In order to increase the mass transfer rate, the interface between the solvent and polymer needs to be increased. One way to increase the interface between the solvent and polymer is by using distributors that spread out the polymer solution in a vessel at low pressure. However, such distributors are limited by practicality and do not provide large enough surface to volume ratio in an economic way. In other words, to increase the surface area to volume ratio, the sizes of the vessels and distributors get very large and the distributor holes need to be very small, which is limited because the pressure drop across the holes becomes an issue.

[0007] Another way to increase the solvent-polymer interface is to generate bubbles or foams in the polymer solution. The thin films of liquid making bubbles and foams will increase the surface to volume ratio significantly. Generating bubbles and foams in polymer solutions containing high molecular weight polymers happens readily in the typical process operating window of a conventional Devol process (*e.g.* T=140-210°C; P=10-50 Torr). However, foam formation is not easy for low molecular weight (low viscosity) polymers because of their low melt strength.

[0008] There is a need, therefore, for new systems and methods for devolatilizing low molecular weight (low viscosity) polymers with low melt strengths.

SUMMARY

[0009] Systems and methods for devolatilizing low viscosity polymers with low melt strength are provided. In one embodiment, the method includes providing a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.

[0010] In one other embodiment, the method includes providing a reaction mixture comprising a polymer having a Brookfield viscosity of less than 40,000 cP and a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a

polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.

[0011] In one other embodiment, the method includes providing a reaction mixture comprising a polymer having a Brookfield viscosity of less than 40,000 cP, a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and an MFR of 500-40,000 g/10min (ASTM D1238), and one or more volatiles comprising one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds at the third separator conditions within a separator conduit located between the second separator and the third separator.

[0012] In one embodiment, the system includes a first separator for separating a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent into a polymer-rich phase and a polymer-lean phase, a second separator for separating the polymer-rich phase into a vapor hydrocarbon phase and a concentrated polymer phase; a third separator for removing at least a portion of the volatiles from the concentrated polymer phase; and a separator conduit located between the second separator and the third separator, the separator conduit configured to provide a residence time of about 0.2 seconds to 10 seconds therein.

[0013] These and other features and attributes of the present disclosure and their advantageous applications and/or uses will be apparent from the detailed description which follows.

BRIEF DESCRIPTION OF DRAWINGS

[0014] To assist those of ordinary skill in the relevant art in making and using the subject matter hereof, reference is made to the appended drawings, wherein:

[0015] Figure 1 depicts an illustrative process flow diagram of a devolatilization unit, according to one or more embodiments provided herein.

[0016] Figure 2 depicts an enlarged schematic view of an illustrative vacuum flash drum that can be used as the third stage flash drum depicted in Figure 1, according to one or more embodiments provided herein.

[0017] Figure 3 depicts an enlarged schematic view of the polymer solution feed assembly 300 for entering the flash drum 130 depicted in Figure 2, according to one or more embodiments provided herein.

[0018] Figure 4 depicts an enlarged schematic view of an alternative polymer solution feed segment 400 for entering the flash drum 130 depicted in Figure 2, according to one or more embodiments provided herein.

[0019] Figure 5 depicts a schematic view of the vacuum flash drum 130 of Figure 2 that can be configured to utilize multiple feed assemblies 300 and/or 400, according to one or more embodiments provided herein.

[0020] Figure 6 depicts the VOC HSGC obtained from the examples plotted against equilibrium HSGC.

DETAILED DESCRIPTION

[0021] Systems and methods for devolatilizing low viscosity polymers with low melt strength are provided herein. It has been unexpectedly and surprisingly discovered that low viscosity polymers with low melt strength can be devolatilized to equilibrium VOC's at conventional operating temperatures and pressures of a final stage devolatilizer. According to one or more embodiments provided herein, polymers having low viscosity (*i.e.* Brookfield viscosity of less than 40,000 cP, melt flow rate (MFR) of from 500 to 40,000 g/10 min (ASTM D1238) and/or a zero shear viscosity of less than 200 Pa-s (measured at 190°C and 0.1 s⁻¹ frequency)) and low molecular weight (*i.e.* Mw less than 62,000 g/mole) can be sufficiently devolatilized by creating foam or a plurality of bubbles during a final stage of devolatilization. Controlled foaming can be created and maintained to reduce the polymer's VOC to the lowest concentrations that are thermodynamically possible at a given temperature and pressure. By "foam", it is meant the process solvent dissolved in the low viscosity polymers with low melt strength to be volatilized, forms a light frothy mass of bubbles or gas pockets in or on the surface of the polymer, in which those bubbles or gas pockets contain the evaporating hydrocarbons.

[0022] The low viscosity polymers with low melt strength have a Brookfield viscosity of from 300 cP to 40,000 cP, a melt flow rate (MFR) of from 500 to 40,000 (g/10min) (ASTM D1238), and/or a zero shear viscosity of less than 200 Pa-s (measured at 190 C and 0.1 s⁻¹ frequency). The Brookfield viscosity can also range from a low of about 300 cP, 400 cP, 600 cP, or 1,000 to a high of 3,000 cP, 10,000 cP, 15,000 cP, or 40,000 cP. The MFR can also range from a low of about 500 g/10min, 1,000 g/10min, or 2,000 g/10min to a high of 3,000 g/10min, 15,000 g/10min, 25,000 g/10min, or 40,000 g/10min. The low viscosity polymers with low melt strength also have a low

weight average molecular weight (Mw), such as less than 62,000 g/mole, less than 56,000 g/mole, less than 46,000 g/mole, less than 36,000 g/mole, or less than 26,000 g/mole .

[0023] It has been unexpectedly and surprisingly discovered that low viscosity polymers with low melt strength having a Brookfield viscosity of less than 40,000 cP, MFR of greater than 500 g/10 min, and/or a zero shear viscosity of less than 200 Pa-s can be sufficiently devolatilized to the equilibrium VOC concentration, which will be the lowest VOC concentration at a given temperature and pressure. Such low viscosity polymers can be elastomers, plastomers, thermoplastics, thermoplastic elastomers, or other types of elastic polymers. Such low viscosity polymers can also be a polyolefin, such as a polypropylene, propylene-based polyolefin, polyethylene, ethylene-based polyolefin, polystyrene, or combinations thereof. Preferred polyolefins are copolymers or terpolymers with dienes or other polar comonomers including silane-modified polyethylene, ethylene vinyl acetate, ethylene acrylate, organic acid-modified polyethylene. The low viscosity polymers can be propylene rich (>50 wt % C3) or ethylene rich (>50 wt%) with comonomer units derived from ethylene or higher alpha olefins from C4 up to C40 with insertion in random or blocky mode.

[0024] It is to be understood that the systems and methods, as described herein, are equally suitable for devolatilizing polymers derived from any liquid phase polymerization process. For example, the polymers to be devolatilized can derive from high pressure fluid, slurry, bulk, or solution phase polymerization processes or combinations thereof. For sake of simplicity and ease of description, however, embodiments provided herein for devolatilizing low melt strength polymers will be further described with reference to polymers made using solution polymerization techniques.

[0025] It is also to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, and/or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the Figures. Moreover, the exemplary embodiments presented below can be combined in any combination of ways, *i.e.*, any element from one exemplary embodiment can be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0026] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities can refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function.

[0027] In the following discussion and in the claims, the terms “including” and “comprising” are meant to be open-ended, and thus should be interpreted to mean “including, but not limited to.” The phrase “consisting essentially of” means that the described/claimed composition does not include any other components that will materially alter its properties by any more than 5% of that property, and in any case does not include any other component to a level greater than 3 mass%.

[0028] The term “or” is intended to encompass both exclusive and inclusive cases, i.e., “A or B” is intended to be synonymous with “at least one of A and B,” unless otherwise expressly specified herein.

[0029] The indefinite articles “a” and “an” refer to both singular forms (i.e., “one”) and plural referents (i.e., one or more) unless the context clearly dictates otherwise. For example, embodiments using “an olefin” include embodiments where one, two, or more olefins are used, unless specified to the contrary or the context clearly indicates that only one olefin is used.

[0030] The term “wt%” means percentage by weight, “vol%” means percentage by volume, “mol%” means percentage by mole, “ppm” means parts per million, and “ppm wt” and “wppm” are used interchangeably and mean parts per million on a weight basis. All concentrations herein, unless otherwise stated, are expressed on the basis of the total amount of the composition in question.

[0031] The term “polymer” refers to any two or more of the same or different repeating units/mer units or units. The term “homopolymer” refers to a polymer having units that are the same. The term “copolymer” refers to a polymer having two or more units that are different from each other and includes terpolymers and the like. The term “terpolymer” refers to a polymer having three units that are different from each other. The term “different” as it refers to units indicates that the units differ from each other by at least one atom or are different isomerically. Likewise, the definition of polymer, as used herein, includes homopolymers, copolymers, and the like. By way of example, when a copolymer is said to have a “propylene” content of 10 wt% to 30 wt%, it is understood that the repeating unit/mer unit or simply unit in the copolymer is derived from propylene in the polymerization reaction and the derived units are present at 10 wt% to 30 wt%, based on a weight of the copolymer.

[0032] As used herein, "Mn" refers to the number average molecular weight of the different polymers in a polymeric material, "Mw" refers to the weight average molecular weight of the different polymers in a polymeric material, and "Mz" refers to the z average molecular weight of the different polymers in a polymeric material. The terms "molecular weight distribution" (MWD) and "polydispersity index" (PDI) are used interchangeably to refer to the ratio of Mw to Mn. Unless otherwise noted, all molecular weights (e.g., Mw, Mn, Mz) are reported in units of g/mol.

[0033] Nomenclature of elements and groups thereof used herein are pursuant to the Periodic Table used by the International Union of Pure and Applied Chemistry after 1988. An example of the Periodic Table is shown in the inner page of the front cover of Advanced Inorganic Chemistry, 6th Edition, by F. Albert Cotton et al. (John Wiley & Sons, Inc., 1999).

[0034] As used herein, a "polymer" can be used to refer to homopolymers, copolymers, interpolymers, terpolymers, etc. When a polymer is referred to as comprising a monomer, the monomer is present in the polymer in the polymerized form of the monomer or in the derivative form of the monomer. Thus, when a polymer is said to comprise a certain percentage (e.g., wt %) of a monomer, that percentage of monomer is based on the total amount of monomer units in all the polymer components of the composition or blend. That is, a polymer comprising 30 wt% ethylene and 70 wt% propylene is a polymer where 30 wt% of the polymer is ethylene-derived units and 70 wt% of the polymer is propylene-derived units.

[0035] As used herein, "solution polymerization" refers to a polymerization process that takes place in the presence of a liquid polymerization system, such as an inert solvent or monomer(s) or their blends, in which the produced polymer dissolves. Solution polymerization comprises a homogeneous liquid polymerization system in the reactor. A homogeneous polymerization process is typically a process where at least 90 wt% of the product is soluble in the reaction media, such as at least 95 wt%, at least 98 wt%, or 100 wt%. The temperature of a liquid polymerization system is below its supercritical or pseudo supercritical temperature, thus, solution polymerizations are performed below the supercritical temperature and/or pressure of the system.

[0036] As used herein, the "polymer concentration" is a weight percent of polymer relative to the solution mixture total weight.

[0037] As used herein, the "monomer concentration" is a weight percent of monomer relative to the solution mixture total weight.

[0038] As used herein, the "melt flow rate" is the ability of a polymer to flow in limited interval of time. The melt flow rate of a polymer is calculated as the weight/10 min through a melt flow testing machine at standard temperature.

[0039] Figure 1 depicts an illustrative process flow diagram of a devolatilization unit 100, according to one or more embodiments provided herein. The devolatilization unit 100 (“Devol unit”) includes any number of separators or flash drums (three are shown 110, 120, 130). The reactor effluent enters the first flash drum 110 via stream or conduit 102. The reactor effluent stream 102 is a polymer solution and contains varying amounts of polymer, solvent and other unconverted monomers. The reactor effluent can have a polymer weight fraction ranging from about 1 wt% to about 75 wt%, such as about 2 wt% to about 50 wt%, or about 5 wt% to about 40 wt%, or about 7 wt% to about 35 wt%, and the balance to 100% will be volatile organic compounds (“VOC”). The VOCs in the reactor effluent stream 102 are solvent, any unconverted monomers, and any other free hydrocarbons.

[0040] Each flash drum 110, 120, 130 operates at a certain temperature and pressure to best effectuate a vapor-liquid or liquid-liquid separation therein. For example, the first flash drum 110 can operate at a temperature of 100 to 160°C and a pressure of 70 to 700 psig. The second flash drum 120 can operate at a temperature of 130 to 180 C and a pressure of 30 to 60 psig. The third flash drum 130 can operate at a temperature of 130 C to 220 C and a pressure of 10 to 50 Torr.

[0041] Within the first flash vessel or flash unit 110, a majority of unreacted monomers, comonomers and solvent (*i.e.*, the volatiles) are separated from the polymer. Within the second flash vessel or flash unit 120, the temperature and pressure conditions are changed to allow further separation of the remaining volatiles from the polymer. And within the third flash vessel or flash unit 130, the temperature and pressure conditions are changed yet again to further separate any residual volatiles from the polymer to meet a desired specification of volatiles in the parts per million range.

[0042] For example, the polymer stream 114 exiting the first separation drum 110 and entering the second flash drum 120 can contain anywhere from 30 wt% to 60 wt% polymer and 40-70 wt% volatile organic compounds (“VOC”). The polymer stream 124 exiting the second flash drum 120 and entering the third flash drum 130 can contain anywhere from 85 wt% to 95 wt% polymer and 5-15 wt% volatile organic compounds (“VOC”). The polymer stream 134 exiting the third flash drum 130 can contain polymer with less than 2,000 ppmw volatile organic compounds (“VOC”), such as less than 1,800 ppmw, 1,600 ppmw, 1,500 ppmw, 1,200 ppmw, 1,000 ppmw, 500 ppmw, or 200 ppmw.

[0043] The overhead streams 118, 128, 138 from each separation drum 110, 120, 130 contain the VOCs that have been separated from the polymer. Each overhead stream 118, 128, 138 can be reused and/or recycled to the polymerization process. For example, the first overhead stream 118 exiting the first flash drum 110 can be sent to a solvent drum (not shown) and recycled for use in

the polymerization system. The second overhead stream 128 exiting the second flash drum 120 can be sent to a heavies tower (not shown) for further separation and recycled for use in the polymerization system. The third overhead stream 138 exiting the third flash drum 130 can be sent to a separation tower (not shown) for further separation and recycled for use in the polymerization system. The devolatilized polymer stream 134 exiting the third flash drum 130 is then cooled and pelletized.

[0044] Figure 2 depicts an enlarged schematic view of an illustrative vacuum flash drum that can be used as the third flash drum 130 depicted in Figure 1, according to one or more embodiments provided herein. The flash drum 130 includes a housing 210, a polymer inlet 215, a polymer outlet 225, and a volatiles outlet 235.

[0045] The volatiles evaporated from the polymer are discharged from the housing 210 through the volatiles outlet 235. A collection system, such as a condensing system (not shown), can also be coupled to the volatiles outlet 235 to collect the volatiles for disposal, recycling, and/or recirculation. The polymer outlet 225 contains the devolatilized polymer and directs the polymer to other downstream processing, such as a pelletizer, extruder, or other handling system.

[0046] Although not shown, the housing 210 provides the desired temperature and pressure environment to devolatilize the polymer within the flash drum 130. To control pressure within the flash drum 130, a pressure control valve is coupled to the volatiles outlet 235. An external and/or internal heat exchangers are used to maintain desired temperature within the separator 130. The heat exchange fluid can be high pressure steam or heating oil (e.g., hydrocarbons, such as mineral oil and the like), or a synthetic media. The housing 210 can also include resistive heating elements (also not shown) to control the temperature.

[0047] The housing 210 can optionally contain one or more devolatilization plates (three plates are shown 260, 262, 264). Each devolatilization plate 260, 262, 264 contains a plurality of hole or apertures (not shown) formed therethrough that allow fluid communication between plates within the housing 210. The distance between each of the devolatilization plates 260, 262, 264 can be the same or can vary. The devolatilization plates allow for and provide additional residence time and polymer solution surface renewal for enhanced volatiles mass transport from the polymer versus having no plates. The residence time on each devolatilization plate 260, 262, 264 can vary and can be about 5 seconds to 10 minutes, or from 10 seconds to 5 minutes. The residence time can also range from a low of about 5 sec, 10 sec, or 30 sec to a high of about 1 min, 5 min, or 10 min. Additional design and operating details of suitable devolatilization plates are found in US Publication No. 2021/0221925A1.

[0048] Figure 3 depicts an enlarged schematic view of the polymer solution feed assembly 300 for entering the flash drum 130 depicted in Figure 2, according to one or more embodiments provided herein. The polymer solution feed assembly 300 contains the solvent and unconverted monomers that remain entrained in the polymer melt. The feed assembly 300 can contain a control valve 305 and a length of piping or other conduit 310 downstream of the control valve 305. The downstream separator conduit 310 connects the control valve 305 at one end thereof 312 (the “first end”) and projects through the drum housing 210 at the opposite end thereof 314 (the “second end”), as shown in Figure 2. The downstream conduit 310 defines a feed chamber 325 for feeding or otherwise delivering the polymer solution into the flash drum 130.

[0049] The downstream conduit 310 and hence the feed chamber 325 therein can have any suitable shape and size. For example, a cross section of the downstream conduit 310 and feed chamber 325 can resemble any shape, such as circular, oval, elliptical, square, rectangular, or other polygonal shape. The inner diameter of the downstream conduit 310 in pilot plant scale can range from 5 mm, 10 mm, or 15 mm to 30 mm, 35 mm, or 40 mm. The length of the downstream conduit 310 can range from 5 cm to 50 cm.

[0050] The inner diameter of the downstream conduit 310 can be constant from one end 312 to the other end 314. In certain embodiments, the inner diameter of the downstream conduit 310 can vary at one or more locations throughout its length, thereby providing one or more variable chokes within the chamber 325.

[0051] Referring to Figures 2 and 3, the polymer solution (steam 215) entering the drum 130 has a higher pressure before reaching the pressure control valve 305 where its pressure is reduced. The pressure drop across the valve 305 can range from a low of about 50 psig (2586 Torr), 100 psig (5,171 Torr) or 150 psig (7,757) to a high of about 200 psig (10,343 Torr), 300 psig (15,515 Torr) or 400 psig (20,686 Torr). The drum 130 is kept in vacuum pressure (*i.e.* less than 0 psig) using a vacuum system (not shown). The downstream conduit 310 after the control valve 305 carries the polymer solution to the drum 130 and will also have vacuum pressure as there is minimal pressure drop along the open-end 314 of the conduit 310. Due to this pressure differential, the volatiles will be evaporated while passing through the control valve 305, thereby creating a two phase fluid, *i.e.*, liquid polymer and vapor volatiles within the chamber 325 of the conduit 310. This significant pressure drop across the valve 305 leads to nucleation and foaming within the chamber 325 that has open fluid communication and further feeds into the drum 130.

[0052] To create the foam, the vaporized volatiles need to be contacted with the liquid polymer for a pre-determined amount of time, *i.e.* residence time, within the chamber 325 before releasing into the drum 130. This residence time is a function of the volumetric flowrate of the polymer

solution and the length and diameter of the conduit 310. Suitable residence times can range from a low of about 0.2, 0.4, or 0.6 seconds to a high of 10, 15 or 20 seconds in vacuum Devol conditions.

[0053] The devolatilization vessel temperature can range from 130°C to 210°C and the pressure can be less than 100 Torr, 90 Torr, 80 Torr, or 70 Torr. No foaming agent is required or needed.

5 Up to 3 wt% of one or more stripping agents (light gasses) can be added to the polymer solution to improve VOC separation. Suitable stripping agents include C₂-C₅ olefins, C₂-C₅ alkanes, steam, carbon dioxide, or any combinations thereof.

[0054] As mentioned above, the volume and diameter of the conduit 310 are important design parameters to induce foaming at the right process conditions. This means that for a specific
10 diameter of the conduit 310, the length of the conduit 310 can be adjusted to define the volume of the chamber 325 and vice versa. It is also important to provide a sufficient shear rate between the vapor and liquid within the chamber 325 of the conduit 310. This shear rate is a function of the volumetric flowrate of the polymer solution and the diameter of the conduit 310. Suitable shear rates for the low viscosity polymers described herein can range from 2,000 to 200,000 1/s at the
15 vacuum stage conditions.

[0055] Figure 4 depicts an enlarged schematic view of an alternative polymer solution feed assembly 400 for entering the flash drum 130 depicted in Figure 2, according to one or more embodiments provided herein. This alternative polymer solution feed assembly 400 is similar to the feed assembly 300 of Figure 3 but differs at its second end 414, which opens to the inside of
20 the drum housing 210. The second end 414 of the assembly 400 has a reduced inner diameter (“D”) 420 to restrict the fluid flow therethrough, thereby increasing pressure drop from the assembly 400 to the flash drum 130. The diameter 420 can range from a low of about 0.5 mm, 1.0 mm, or 1.25 mm to a high of about 1.5 mm, 2.0 mm or 2.5 mm.

[0056] Figure 5 depicts a schematic view of the vacuum flash drum 130 that can be configured
25 to utilize multiple feed assemblies 300, 400, according to one or more embodiments provided herein. In such embodiments, any number of feed assemblies 300, 400 can be used, whether individually or in combination with one another. The different feed assemblies 300, 400 can be located anywhere along the sidewall 510 or head 520 of the drum 130. In Figure 5, the top or upper feed assembly is shown as the feed assembly 300 type and the bottom or lower feed assembly is shown as the feed assembly 400 type although any number and configuration of the assemblies
30 300, 400 can be used. For example, the flash drum 130 can be configured with one or more feed assemblies 300 and one or more feed assemblies 400, such that the polymer feed stream 215 is split or otherwise divided to provide feed through any or more of the feed assemblies 300 and/or feed assemblies 400 into the flash drum 130. The flash drum 130 can also be configured with two

or more feed assemblies 300 and/or two or more feed assemblies 400, such that the polymer feed stream 215 can be split to feed through any combination of the two or more feed assemblies 300 and/or two or more feed assemblies 400 into the flash drum 130. As mentioned above, when two or more assemblies 300, 400 are used, each assembly can be the same type (300 or 400) or a combination of types (300 and 400), and the assemblies can be arranged anywhere along the sidewall 510 or top head 520 of the drum 130.

[0057] The number and location of the feed assembly 300, 400 types can be determined by the polymer itself. For example, polymers having a Brookfield viscosity of less than 40,000 cP would favor the feed assembly 300 and polymers having a Brookfield viscosity of 40,000 cP or more would favor the feed assembly 400. To have full production capability, meaning the ability to make different polymer types and different polymer grades using the same Devol unit, the assembly 300, 400 types can be easily swapped or replaced.

[0058] The system and methods for devolatilizing the low viscosity polymer, according to the one or more embodiments provided herein, can be used with any liquid phase polymerization process. Solution polymerization processes is preferred. A suitable solution polymerization process is generally described in more detail in U.S. Patent Nos. 9,359,535, 7,470,118, 7,226,553; and 7,033,152, which are incorporated by reference herein in their entirety. WO 2017/058385A1 describes a solution polymerization process using single or multiple spiral heat exchanger systems for continuous polymerization of C2 to C40 olefins, which can also be used and is also incorporated by reference herein in its entirety.

[0059] The polymerization process can be conducted under conditions including a temperature of about 50°C to about 220°C, preferably about 70°C to about 210°C, preferably about 90°C to about 200°C, preferably about 100°C to about 190°C, preferably about 130°C to about 160°C. The polymerization process can be conducted at a pressure of from about 350 psi to about 1800 psi (about 2,413 to about 12,411 kPa), preferably 200 psi to 1000 psi (about 1379 kPa to 6895 kPa), preferably 300 psi to 600 psi (about 2068 kPa to 4137 kPa). Preferably, the pressure is about 450 psi (about 3103 kPa).

[0060] Hydrogen can be present during the polymerization process at a partial pressure of 0.001 psig to 50 psig (0.007 kPa to 345 kPa), preferably 0.01 psig to 25 psig (0.07 kPa to 172 kPa), preferably 0.1 psig to 10 psig (0.7 kPa to 70 kPa).

[0061] Catalyst systems suitable for use in conjunction with the methods and systems provided herein include one or more metallocene catalysts and other single site catalysts. Other suitable catalysts include, but are not limited to, Ziegler-Natta catalyst compounds, late transition metal catalyst compounds, and other non-metallocene catalyst compounds. Non-metallocene metal-

centered, heteroaryl ligand catalyst compounds are described in detail in PCT Patent Publications Nos. WO 02/38628, WO 03/040095 (pages 21 to 51), WO 03/040201 (pages 31 to 65), WO 03/040233 (pages 23 to 52), WO 03/040442 (pages 21 to 54), WO 2006/38628, and U.S. Patent Application Publication No. 2008/0153997, each of which is herein incorporated by reference.

5 **[0062]** As mentioned above, the low viscosity polymers can be elastomers, plastomers, thermoplastics, thermoplastic elastomers, or other types of elastic polymers. The low viscosity polymers can also be polyolefins, such as a polypropylene, propylene-based polyolefin, polyethylene, ethylene-based polyolefin, polystyrene, or combinations thereof. Preferred polyolefins are copolymers or terpolymers with dienes or other polar comonomers including
10 silane-modified polyethylene, ethylene vinyl acetate, ethylene acrylate, organic acid-modified polyethylene. The low viscosity polymers can be propylene rich (>50 wt % C3) or ethylene rich (>50 wt%) with comonomer units derived from ethylene or higher alpha olefins from C4 up to C40 with insertion in random or blocky mode.

[0063] In one or more embodiments, the low viscosity polymers can be derived from any
15 monomer having one or more non-conjugated aliphatic double bond(s) and two or more carbon atoms. Examples of monomers include substituted or unsubstituted C₂ to C₄₀ alpha-olefins. For example, suitable monomers can be, but are not limited to, one or more α -olefins (e.g., ethylene, propylene, butene-1, hexene-1, octene-1, decene-1, and dodecene-1), substituted olefins (e.g., styrene, paramethylstyrene, and vinylcyclohexane), non-conjugated dienes (e.g.,
20 vinylcyclohexene), α,ω -dienes (e.g., 1,5-hexadiene and 1,7-octadiene), cycloolefins (e.g., cyclopentene, cyclohexene, and cyclohexadiene), norbornene, and the like, and any combination thereof. Additional monomers include 4-methylpentene-1, 3-methylpentene-1, 3,5,5-trimethylhexene-1, and 5-ethylnonene-1.

[0064] Aromatic-containing monomers containing up to 30 carbon atoms can be used. Suitable
25 aromatic-group-containing monomers have at least one aromatic structure, advantageously from one to three, more advantageously a phenyl, indenyl, fluorenyl, or naphthyl moiety. The aromatic-group-containing monomer further comprises at least one polymerizable double bond such that after polymerization, the aromatic structure will be pendant from the polymer backbone. The aromatic-group containing monomer can further be substituted with one or more hydrocarbyl
30 groups including but not limited to C₁ to C₁₀ alkyl groups. Additionally, two adjacent substitutions can be joined to form a ring structure. Advantageous aromatic-group-containing monomers contain at least one aromatic structure appended to a polymerizable olefinic moiety. Particularly advantageous aromatic monomers include styrene, alpha-methylstyrene, para-alkylstyrenes,

vinyltoluenes, vinylnaphthalene, allyl benzene, and indene, especially styrene, paramethylstyrene, 4-phenyl-butene-1 and allylbenzene.

[0065] Non-aromatic cyclic group containing monomers can be used. These monomers can contain up to 30 carbon atoms. Suitable non-aromatic cyclic group containing monomers advantageously have at least one polymerizable olefinic group that is either pendant on the cyclic structure or is part of the cyclic structure. The cyclic structure can be further substituted by one or more hydrocarbyl groups such as, but not limited to, C₁ to C₁₀ alkyl groups. Advantageous non-aromatic cyclic group containing monomers include vinylcyclohexane, vinylcyclohexene, vinylnorbornene, ethylidene norbornene, cyclopentadiene, cyclopentene, cyclohexene, cyclobutene, vinyladamantane, and the like.

[0066] Diolefin monomer(s) can also be used. Advantageous diolefin monomers include any hydrocarbon structure, advantageously C₄ to C₃₀, having at least two unsaturated bonds, wherein at least two of the unsaturated bonds are readily incorporated into a polymer by either a stereospecific or a non-stereospecific catalyst(s). It is further advantageous that the diolefin monomers be selected from alpha-omega diene monomers (e.g., divinyl monomers). More advantageously, the diolefin monomers are linear divinyl monomers, most advantageously those containing from 4 to 30 carbon atoms. Examples of such dienes include butadiene, pentadiene, hexadiene, heptadiene, octadiene, nonadiene, decadiene, undecadiene, dodecadiene, tridecadiene, tetradecadiene, pentadecadiene, hexadecadiene, heptadecadiene, octadecadiene, nonadecadiene, icosadiene, heneicosadiene, docosadiene, tricosadiene, tetracosadiene, pentacosadiene, hexacosadiene, heptacosadiene, octacosadiene, nonacosadiene, triacontadiene, particularly advantageous dienes include 1,6-heptadiene, 1,7-octadiene, 1,8-nonadiene, 1,9-decadiene, 1,10-undecadiene, 1,11-dodecadiene, 1,12-tridecadiene, 1,13-tetradecadiene, and low molecular weight polybutadienes (weight average molecular weight less than 1000 g/mol). Advantageous cyclic dienes include cyclopentadiene, vinylnorbornene, norbornadiene, ethylidene norbornene, divinylbenzene, dicyclopentadiene or higher ring containing diolefins with or without substituents at various ring positions.

[0067] In one or more embodiments, the low viscosity polymer is a propylene-based elastomer containing greater than 50 wt%, preferably greater than 60 wt%, more preferably greater than 65 wt%, even more preferably greater than 75 wt% and up to 99 wt% propylene-derived units, based on the total weight of the polymer. In some preferable embodiments, the propylene-based elastomer includes propylene-derived units in an amount based on the weight of propylene-based elastomer of from 75 wt% to 95 wt%, more preferably 75 wt% to 92.5 wt%, and even more preferably 82.5 wt% to 92.5 wt%, and most preferably 82.5 wt% to 90 wt%. Correspondingly, the

units, or comonomers, derived from at least one of ethylene or a C4 to C10 α -olefin can be present in an amount of 5, or 10, or 14 wt% to 22, or 25 wt% by weight of the elastomer. The comonomer content can be adjusted so that the propylene-based elastomer can have a heat of fusion of 100 J/g, 90 J/g, 85 J/g, 80 J/g, 75 J/g, 70 J/g, or 65 J/g or less, a melting point (T_m) of 100°C or 90°C or less, and crystallinity of 2% to 65% of isotactic polypropylene.

[0068] In one or more embodiments, the low viscosity polymer is an ethylene-based elastomer containing greater than 50 wt%, preferably greater than 60 wt%, more preferably greater than 65 wt%, even more preferably greater than 75 wt% and up to 99 wt% ethylene-derived units, based on the total weight of the polymer. In some preferable embodiments, the ethylene-based elastomer of from 75 wt% to 95 wt%, more preferably 75 wt% to 92.5 wt%, and even more preferably 82.5 wt% to 92.5 wt%, and most preferably 82.5 wt% to 90 wt% of ethylene-derived units, based on the total weight of the polymer. Correspondingly, the units, or comonomers, derived from C3 to C10 α -olefins can be present in an amount ranging from a low of 5, 10, or 15 wt% to a high of about 20, 25, or 30 wt% of the polymer.

[0069] The low viscosity polymers can be branched or unbranched as determined by g' avg from GPC-4D measurements. A typical GPC-4D profile has Log M vs. g' and is used to estimate a g' average, based on the average across the molecular weight. The branching index g' avg values range from 1 to 0 with 1 being linear (no branching) and 0 being fully branched. In one or more embodiments, the low viscosity polymers can have a g' of less than 0.99, less than 0.98, less than 0.97, less than 0.96, less than 0.95, or less than 0.90.

[0070] In certain embodiments, an inert solvent can be used during the polymerization process. The solvent will form part of the reactor effluent. Examples of inert solvents include straight, branched-chain, cyclic, alicyclic, halogenated, or aromatic hydrocarbons and mixtures thereof. Examples of straight and branched-chain hydrocarbons include isobutane, butane, pentane, isopentane, hexane, isohexane, heptane, octane, dodecane, and mixtures thereof. Examples of cyclic and alicyclic hydrocarbons include cyclohexane, cycloheptane, methylcyclohexane, methylcycloheptane, and mixtures thereof. Examples of halogenated hydrocarbons include fluorinated C4-C10 alkanes and chlorobenzene. Examples of aromatic compounds include benzene, toluene, mesitylene, and xylene.

Additional Embodiments

[0071] Other embodiments provided herein include any one or more of the following numbered embodiments:

[0072] Embodiment 1: A method for devolatilizing a low viscosity polymer, comprising: providing a reaction mixture comprising polymer and one or more volatiles, wherein the one or

more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.

[0073] Embodiment 2: The method according to embodiment 1, wherein the polymer comprises propylene and up to 20 wt% of ethylene and/or one or more monomers having four or more carbon atoms.

[0074] Embodiment 3: The method according to embodiments 1 or 2, wherein the polymer has a Brookfield viscosity of 300 cP to 40,000 cP or a zero shear viscosity of less than 200 Pa-s when measured at 190°C and 0.1 s⁻¹ frequency.

[0075] Embodiment 4: The method according to any embodiment 1 to 3, wherein the polymer has a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, or a melt flow rate (MFR) of from 500 to 40,000 g/10min as measured by ASTM D1238.

[0076] Embodiment 5: The method according to any embodiment 1 to 4, wherein the concentrated polymer phase has a volatiles concentration of 4 to 15 wt%, based on the total weight of the concentrated polymer phase.

[0077] Embodiment 6: The method according to any embodiment 1 to 5, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s.

[0078] Embodiment 7: The method according to any embodiment 1 to 6, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.

[0079] Embodiment 8: A method for devolatilizing a low viscosity polymer, comprising: providing a reaction mixture comprising a polymer having a Brookfield viscosity of less than 40,000 cP and a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2

seconds to 10 seconds within a separator conduit located between the second separator and the third separator.

[0080] Embodiment 9: The method according to embodiment 8, wherein the polymer comprises propylene and up to 20 wt% of ethylene and/or one or more monomers having four or more carbon atoms.

[0081] Embodiment 10: The method according to embodiments 8 or 9, wherein the polymer has a Brookfield viscosity of less than 15,000 cP.

[0082] Embodiment 11: The method according to any embodiment 8 to 10, wherein the concentrated polymer phase has a volatiles concentration of 4 to 15 wt%, based on the total weight of the concentrated polymer phase.

[0083] Embodiment 12: The method according to any embodiment 8 to 11, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s at the third separator conditions.

[0084] Embodiment 13: The method according to any embodiment 8 to 12, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.

[0085] Embodiment 14: A method for devolatilizing a low viscosity polymer, comprising: providing a reaction mixture comprising: a polymer having a Brookfield viscosity of less than 40,000 cP, a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and an MFR of 500-40,000 g/10min (ASTM D1238), and one or more volatiles comprising one or more unreacted monomers and at least one hydrocarbon solvent; separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase; separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase; removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and providing a residence time of about 0.2 seconds to 10 seconds at the third separator conditions within a separator conduit located between the second separator and the third separator.

[0086] Embodiment 15: The method according to embodiment 14, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s at the third separator conditions.

[0087] Embodiment 16: The method according to embodiment 14 or 15, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.

[0088] Embodiment 17: The method according to any embodiment 14 to 16, wherein the polymer is 85 to 99 wt% of propylene derived units and 1-15 wt% of ethylene derived units.

[0089] Embodiment 18. The method according to any embodiment 14 to 17, wherein the polymer has a zero shear viscosity of less than 200 Pa-s when measured at 190°C and 0.1 s⁻¹ frequency.

[0090] Embodiment 19. The method according to any embodiment 14 to 18, wherein the polymer has a weight average molecular weight (Mw) of less than 46,000 g/mole.

[0091] Embodiment 20: A system for devolatilizing a low viscosity polymer, comprising: a first separator for separating a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent into a polymer-rich phase and a polymer-lean phase, a second separator for separating the polymer-rich phase into a vapor hydrocarbon phase and a concentrated polymer phase; a third separator for removing at least a portion of the volatiles from the concentrated polymer phase; and a separator conduit located between the second separator and the third separator, the separator conduit configured to provide a residence time of about 0.2 seconds to 10 seconds therein.

Examples:

[0092] The foregoing discussion can be further described with reference to the following non-limiting examples. Three low viscosity polymers in the viscosity range of 1,100 to 11,500 cP were devolatilized in a vacuum flash vessel. The inlet polymer solution feed had a volatiles concentration of 4 to 10 wt% in the three cases. The polymers were propylene-ethylene elastomers ("PBE") obtained from ExxonMobil Product Solutions Company. All three polymers had an ethylene content of 6 wt% with the balance being propylene and are summarized below in Table 1.

[0093] Table 1: Physical properties of the three PBE's are summarized below:

Polymer name	Brookfield Viscosity (cP)	Mw (g/mole)	MFR (g/10 min)	C2 wt%
PBE-1	1,100	25,500	14,200	6
PBE-2	7,500	41,100	2,400	6
PBE-3	11,500	45,700	1,600	6

[0094] A range of temperatures and vacuum pressures were tested in each case. The devol pressure ranged from 20 -100 Torr and the temperature ranged from 135-165°C. Two polymer inlet feed configurations were used. The first configuration was the open-ended conduit feed assembly 300, and the second configuration was the choked conduit feed assembly 400. In the first, open-ended configuration, the pressure of the conduit section downstream of the control valve was equalized with the flash drum pressure and two phases (liquid and vapor) were observed in the conduit chamber. In the second, choked configuration, the pressure of the conduit section downstream of the control valve was higher than the drum pressure and higher than the vapor

pressure of the polymer solution. Only a single liquid phase inside the inlet pipe chamber was observed, such that any evaporation of the volatiles occurred after the solution exited the choke and entered the flash drum. Results are reported below in Tables 2 and 3.

[0095] Table 2: Process conditions and results for each polymer devolatilization using the open-ended feed configuration 300.

Polymer	PBE-1	PBE-2	PBE-3
C2 wt%	6	6	6
Brookfield Viscosity (cP)	1,100	7,500	11,500
Mw (g/mole)	25,500	41,100	45,700
MFR (g/10 min)	14,200	2,400	1,600
Initial volatile conc., wt%	5	5	5
Flash drum Temp, °C	160	160	160
Flash drum Pressure, Torr	25	25	25
shear rate, s ⁻¹	3000	3000	3000
Feed conduit residence time, seconds	0.05-0.30	0.05-0.30	0.05-0.30
HSGC, ppmw	285	275	280
Calc. Equil HSGC, ppmw	260	260	260

[0096] Table 3: Process conditions and results for each polymer devolatilization using the choke feed configuration 400.

Polymer	PBE-1	PBE-2	PBE-3
C2 wt%	6	6	6
Brookfield Viscosity (cP)	1,100	7,500	11,500
Mw (g/mole)	25,500	41,100	45,700
MFR (g/10 min)	14,200	2,400	1,600
Initial volatile conc., wt%	5	5	5
Flash drum Temp, °C	160	160	160
Flash drum Pressure, Torr	25	25	25
Feed Conduit Press., Torr			
shear rate, s ⁻¹	0	0	0
Feed chamber residence time, seconds	0	0	0
HSGC, ppmw	810	785	720
Calc. Equil HSGC, ppmw	260	260	260

[0097] Figure 6 graphically depicts the VOC HSGC obtained from the two inlet feed configurations plotted against equilibrium HSGC. This shows the measured VOC's with calculated equilibrium VOC's for the range of process operating windows that were tested (*i.e.*, 20 -100 Torr and 135-165°C). This HSGC data shows the positive impact of foaming to reduce the

VOC content of the polymers and approaching the equilibrium VOC's. As depicted in Figure 6, the polymers devolatilized using the open-ended inlet pipe configuration resulted in foaming and polymer having at or near equilibrium VOCs. On the contrary, the same polymers devolatilized using the choked inlet pipe configuration led to much higher amounts of VOC in the polymer.

Based on this data, and not wishing to be bound by theory, it appears, both surprisingly and unexpectedly, that the foaming nucleation and foaming intensity was not only a function of the initial volatiles concentration, temperature, and pressure (degree of superheat), but was also a function of the shear rate and residence time (*i.e.* volatile-polymer exposure time) within the feed conduit chamber 325.

Test Procedures

[0098] In the foregoing Examples, the following test methods and procedures were used:

[0099] Head Space Gas Chromatography (HSGC) was used to measure volatile content of the polymer pellets. In this method, 2 gr pellets was placed in a 20 ml vial. The vial was heated at 130°C for 35 minutes. Then the vial head space was injected to a GC.

[0100] Shear rate inside the conduit 310 was calculated using the Hagen-Poiseuille equation: Shear rate (1/s) = $4Q/\pi r^3$ where Q is the polymer solution volume flow rate at vacuum Devol conditions and r is pipe radius. By "vacuum Devol conditions", it is meant the same temperature and pressure as within the third and/or final flash drum 130.

[0101] Brookfield viscosity was measured at 190 C. The spindle rotates at 20 rpm to measure the viscosity and data will be collected at every 30 second interval for 15 minutes. The torque is maintained at 45-55% level during the test.

[0102] MFR was measure according to (ASTM D1238). For low viscosities, which are difficult to measure, the MFR is calculated based on the relationship: MFR (ASTM D1238) = $9591437 \cdot B.V^{-0.93}$, ($R^2 = 0.99$), where B.V is Brookfield Viscosity.

[0103] The distribution and the moments of molecular weight (M_w , M_n , M_z , M_w/M_n , M_z/M_n , etc.), and the comonomer content (C2, C4, C8) were determined using a high temperature Gel Permeation Chromatography (Polymer Char GPC-IR) equipped with a multiple-channel band-filter based Infrared detector IR5, an 18-angle light scattering detector and a viscometer. Three Agilent Plgel 10 μ m Mixed-B LS columns are used to provide polymer separation. Detailed analytical principles and methods for molecular weight determinations are described in paragraphs [0044] – [0051] of International Publication No. WO/2019/246069A1, which is herein incorporated herein by reference (noting that the equation for c referenced in Paragraph [0044] therein for concentration I at each point in the chromatogram, is $c = \beta I$, where β is mass constant and I is the baseline-subtracted IR5 broadband signal intensity (I)). Unless specifically mentioned,

all the molecular weight moments used or mentioned in the present disclosure are determined according to the conventional molecular weight (IR molecular weight) determination methods (e.g., as referenced in Paragraphs [0044] – [0045] of the just-noted publication), noting that for the equation in such Paragraph [0044], $\alpha = 0.695$ and $K = 0.000579(1-0.75Wt)$ are used, where Wt is the weight fraction for hexane comonomer, and further noting that comonomer composition is determined by the ratio of the IR5 detector intensity corresponding to CH₂ and CH₃ channel calibrated with a series of PE and PP homo/copolymer standards whose nominal values are predetermined by NMR or FTIR (providing methyls per 1000 total carbons (CH₃/1000 TC)) as noted in Paragraph [0045] of the just-noted International Publication).

[0104] All numerical values are "about" or "approximately" the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0105] Many alterations, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description without departing from the spirit or scope of the present disclosure and that when numerical lower limits and numerical upper limits are listed herein, ranges from any lower limit to any upper limit are contemplated.

[0106] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which such incorporation is permitted.

[0107] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention can be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS:

What is claimed is:

1. A method for devolatilizing a low viscosity polymer, comprising:
providing a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent;
separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase;
separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase;
removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and
providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.
2. The method of claim 1, wherein the polymer comprises propylene and up to 20 wt% of ethylene and/or one or more monomers having four or more carbon atoms.
3. The method of claim 1, wherein the polymer has a Brookfield viscosity of 300 cP to 40,000 cP or a zero shear viscosity of less than 200 Pa-s when measured at 190°C and 0.1 s⁻¹ frequency.
4. The method of claim 1, wherein the polymer has a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC or a melt flow rate (MFR) of from 500 to 40,000 g/10min as measured by ASTM D1238.
5. The method of claim 1, wherein the concentrated polymer phase has a volatiles concentration of 4 to 15 wt%, based on the total weight of the concentrated polymer phase.
6. The method of claim 1, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s.

7. The method of claim 1, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.
8. A method for devolatilizing a low viscosity polymer, comprising:
 - providing a reaction mixture comprising a polymer having a Brookfield viscosity of less than 40,000 cP and a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent;
 - separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase;
 - separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase;
 - removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and
 - providing a residence time of about 0.2 seconds to 10 seconds within a separator conduit located between the second separator and the third separator.
9. The method of claim 8, wherein the polymer comprises propylene and up to 20 wt% of ethylene and/or one or more monomers having four or more carbon atoms.
10. The method of claim 8, wherein the polymer has a Brookfield viscosity of less than 15,000 cP.
11. The method of claim 8, wherein the concentrated polymer phase has a volatiles concentration of 4 to 15 wt%, based on the total weight of the concentrated polymer phase.
12. The method of claim 8, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s at the third separator conditions.
13. The method of claim 8, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.

14. A method for devolatilizing a low viscosity polymer, comprising:
providing a reaction mixture comprising:
a polymer having a Brookfield viscosity of less than 40,000 cP, a weight average molecular weight (Mw) of less than 62,000 g/mole, as determined by GPC, and an MFR of 500-40,000 g/10 min (ASTM D1238), and
one or more volatiles comprising one or more unreacted monomers and at least one hydrocarbon solvent;
separating the reaction mixture, within a first separator, into a polymer-rich phase and a polymer-lean phase;
separating the polymer-rich phase, within a second separator, into a vapor hydrocarbon phase and a concentrated polymer phase;
removing at least a portion of the volatiles from the concentrated polymer phase, within a third separator, to provide a devolatilized polymer; and
providing a residence time of about 0.2 seconds to 10 seconds at the third separator conditions within a separator conduit located between the second separator and the third separator.
15. The method of claim 14, wherein the separator conduit is configured to provide a shear rate of 2,000 to 200,000 1/s at the third separator conditions.
16. The method of claim 15, wherein the devolatilized polymer has a volatiles concentration of less than 600 ppmw, based on the total weight of the concentrated polymer phase.
17. The method of claim 15, wherein the polymer is 85 to 99 wt% of propylene derived units and 1-15 wt% of ethylene derived units.
18. The method of claim 15, wherein the polymer has a zero shear viscosity of less than 200 Pa-s when measured at 190°C and 0.1 s⁻¹ frequency.
19. The method of claim 15, wherein the polymer has a weight average molecular weight (Mw) of less than 46,000 g/mole.

20. A system for devolatilizing a low viscosity polymer, comprising:
- a first separator for separating a reaction mixture comprising polymer and one or more volatiles, wherein the one or more volatiles comprises one or more unreacted monomers and at least one hydrocarbon solvent into a polymer-rich phase and a polymer-lean phase,
 - a second separator for separating the polymer-rich phase into a vapor hydrocarbon phase and a concentrated polymer phase;
 - a third separator for removing at least a portion of the volatiles from the concentrated polymer phase; and
 - a separator conduit located between the second separator and the third separator, the separator conduit configured to provide a residence time of about 0.2 seconds to 10 seconds therein.

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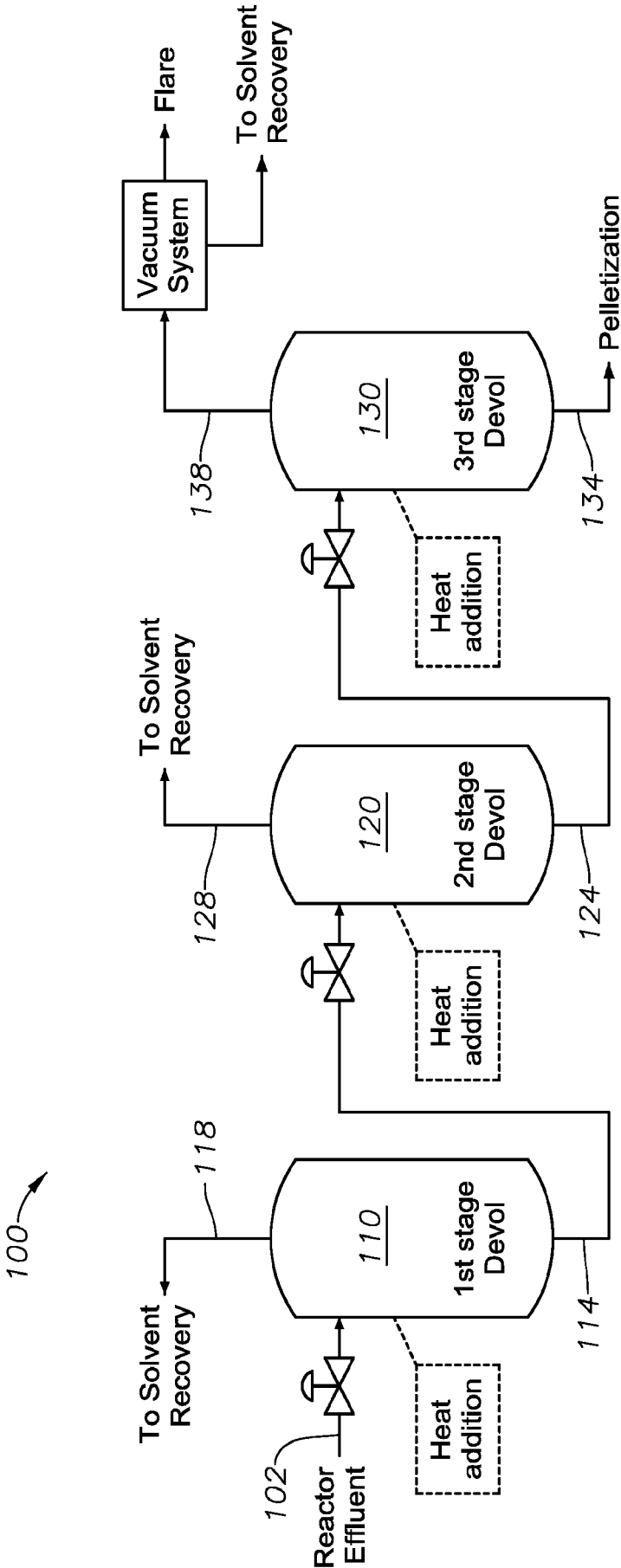


FIG. 1

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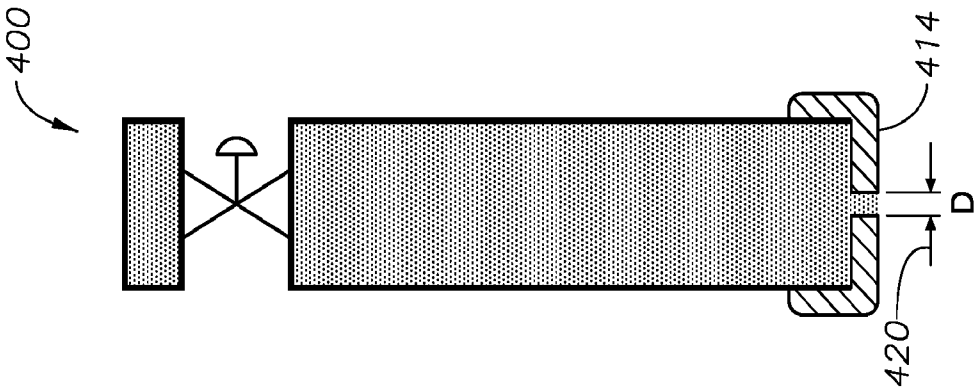


FIG. 4

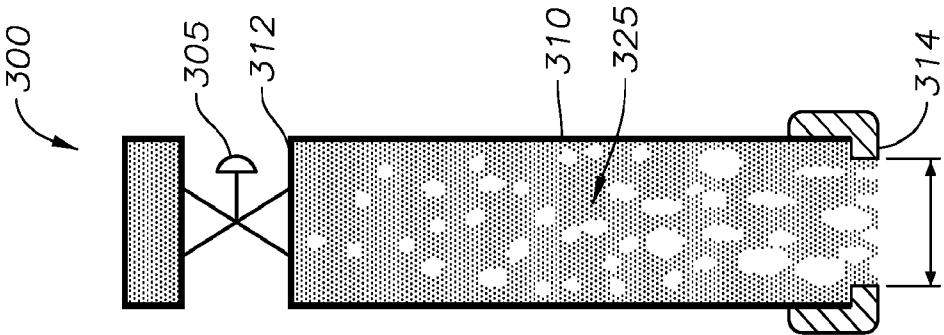


FIG. 3

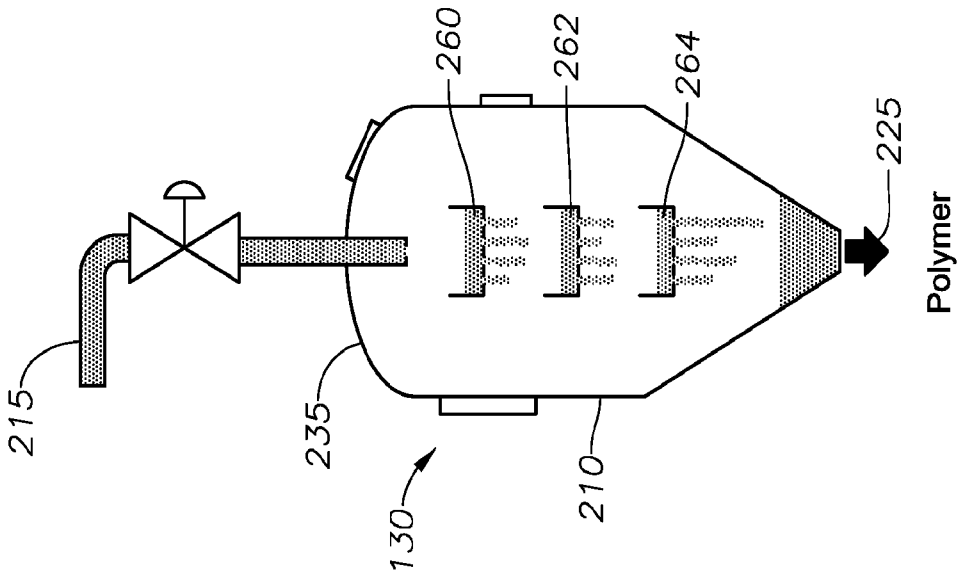


FIG. 2

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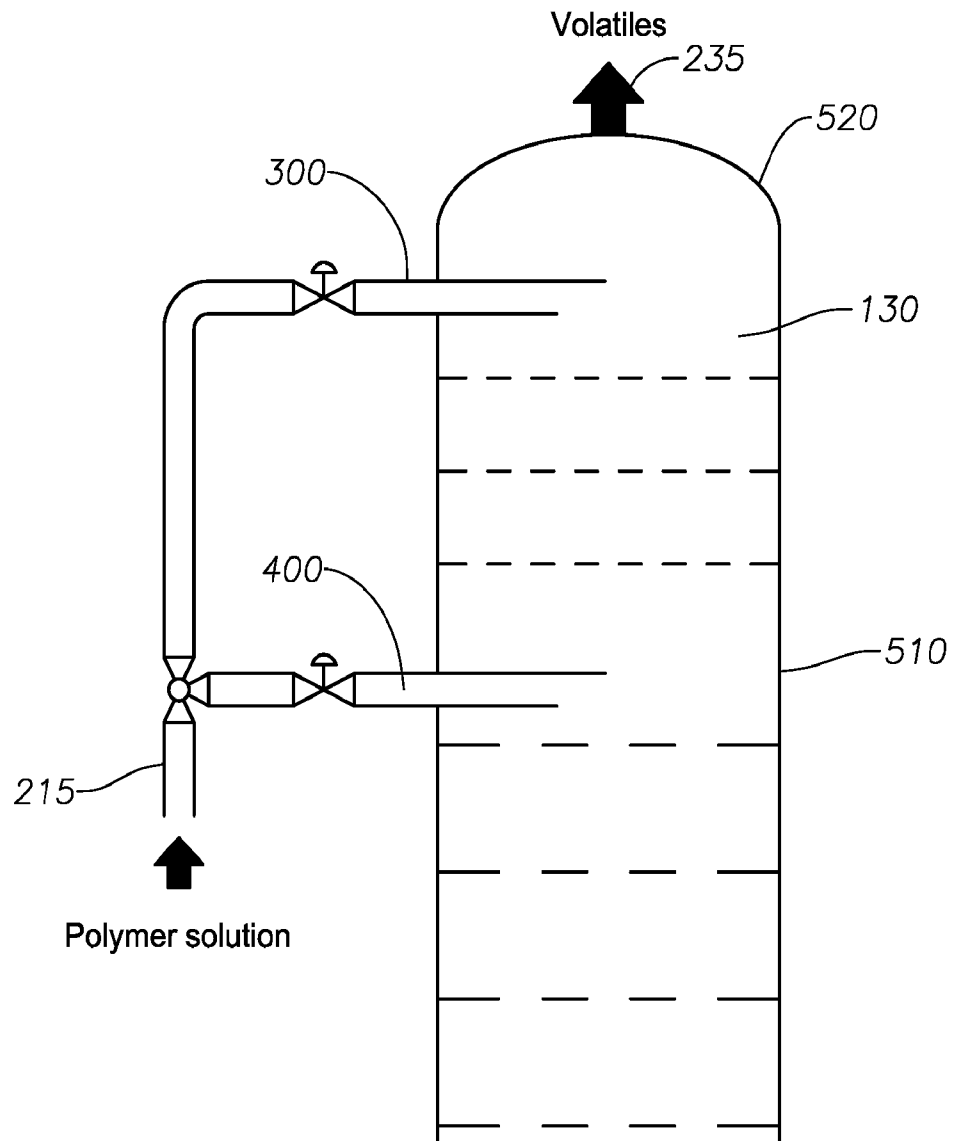


FIG. 5

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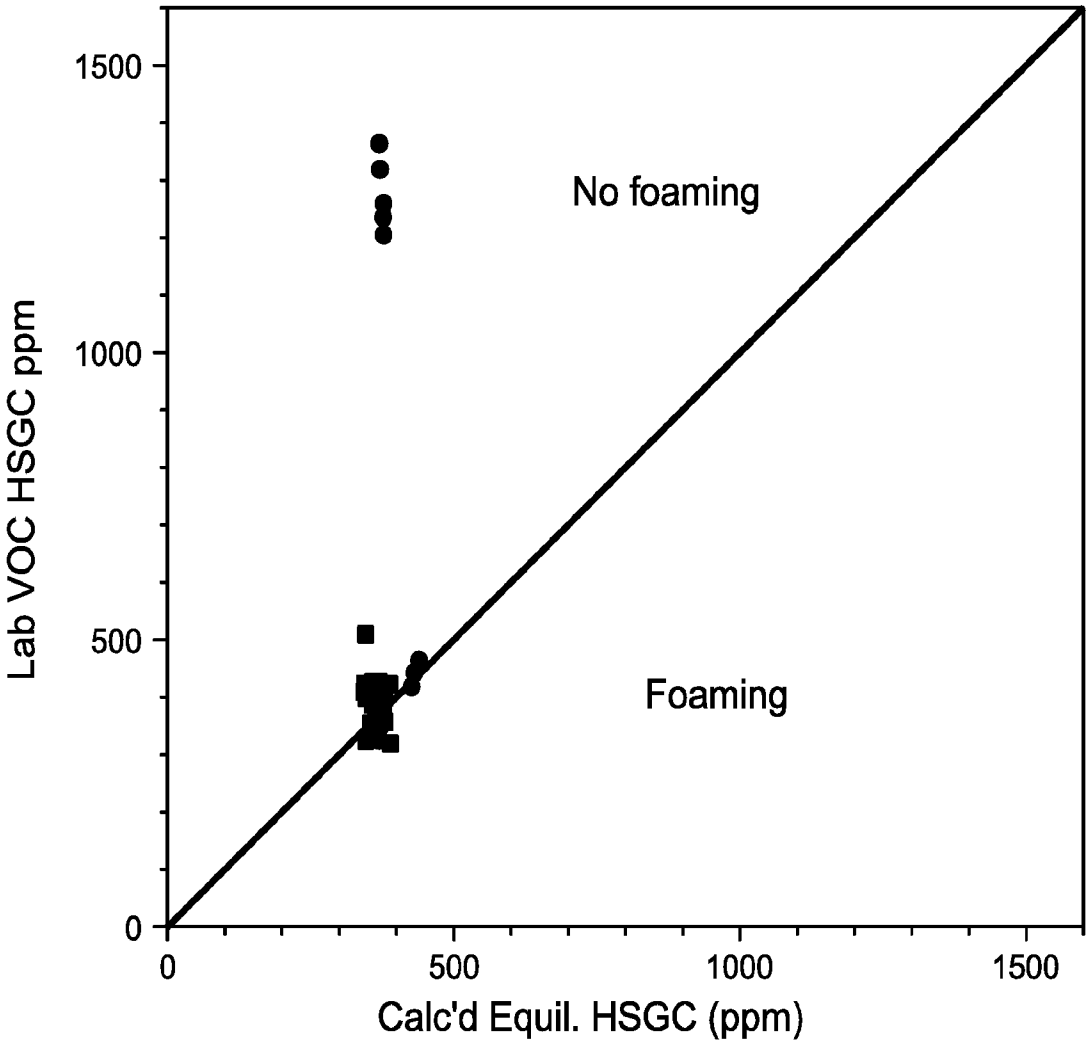


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2023/068772

A. CLASSIFICATION OF SUBJECT MATTER

INV. C08F6/00 C08J11/02
 ADD. C08J9/00

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)

C08J C08F C09J

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017/053517 A1 (DOW GLOBAL TECHNOLOGIES LLC [US]) 30 March 2017 (2017-03-30) page 1, line 17 - line 21 page 7, line 4 - line 27 page 17, line 23 - page 18, line 2 -----	1-20
X	WO 2019/232183 A1 (DOW GLOBAL TECHNOLOGIES LLC [US]) 5 December 2019 (2019-12-05) paragraphs [0022], [0023], [0075], [0076] -----	1-20
X	US 2010/203006 A1 (TAYLOR CRAIG S [US] ET AL) 12 August 2010 (2010-08-12) paragraphs [0022], [0023], [0040], [0043], [0046], [0047]; example 1 ----- -/--	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

26 September 2023

Date of mailing of the international search report

06/10/2023

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Gold, Josef

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2023/068772

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Information on patent family members

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