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Fractionation for Polymerized Reactor Effluent

Abstract

A method including recovering a polymerization reactor effluent stream from one or more polymerization reactors, flashing the polymerization reactor effluent stream to form a flash gas stream, separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream, separating the first column overhead stream into a gas stream and a liquid stream, and introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream. A second column bottoms stream flow rate can comprise less than or equal to about 25 vol % of a total flow rate and a second column side stream flow rate can comprise greater than or equal to about 75 vol % the total flow rate.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] None.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

TECHNICAL FIELD

[0003] The present disclosure relates to systems and methods for processing an effluent from a polymerization reaction process. More particularly, the disclosure relates to removing one or more undesired components and recycling one or more reusable components from a polymerization reaction effluent stream. Still more particularly, the current disclosure relates to systems and method for treating a polymerization reactor effluent that operates a deethanizer column at a pressure similar to a pressure of an upstream dehexanizer column, with a majority of the isobutane recovered via the deethanizer removed via a side stream of the deethanizer.

BACKGROUND

[0004] The production of polymers such as polyethylene requires a high purity feedstock of various components, including monomers, diluents, and co-monomers. In order to offset some of the costs and maximize production, it can be useful to reclaim and/or recycle some feedstock components from an effluent stream resulting from the polymerization reaction. To accomplish this, the reclaimed effluent streams have conventionally either been routed through a purification process or redirected through other redundant processing steps.

[0005] Conventional attempts to industrially produce high purity feedstock components has required the operation of numerous distillation columns, compressors (e.g., to achieve the high pressures needed in such conventional processes), refrigeration units (e.g., to achieve cryogenic temperatures) and various other equipment. As such, the equipment and energy costs associated with feedstock purification represent a significant proportion of the total cost for the production of such polymers. Further, the infrastructure required for producing, maintaining, and recycling high purity feedstock represents a significant portion of the associated cost.

[0006] Further, such conventional attempts to recover feedstock components have not enabled sufficient control parameters to prevent and/or control deleterious plant conditions. The drawbacks of these designs can lead to process delays, increased costs, and/or other inefficiencies. As such, an improved separation system for polymerization reaction effluent streams is needed.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The detailed description will reference the drawings briefly described below, wherein like reference numerals represent like parts, unless otherwise indicated.

[0008] FIG. 1A is a schematic of a polymerization system or polymer production system (PPS), according to aspects of this disclosure;

[0009] FIG. 1B is a schematic of a flash gas treatment system (FGTS), according to aspects of this disclosure;

[0010] FIG. 1C is a schematic of a flash gas production system (FGPS) operable to produce a flash gas, according to aspects of this disclosure;

[0011] FIG. 1D is a schematic of a polymerization system, according to aspects of this disclosure;

[0012] FIG. 2 is a schematic of a portion of a flash gas treatment system (FGTS), according to aspects of this disclosure;

[0013] FIG. 3 shows deethanizer temperature profiles obtained with different amounts of ethylene

in a substantially olefins-free isobutane stream (OFIC4) and ethylene and hydrogen in a recycle isobutane stream (RIC4);

[0014] FIG. 4 shows deethanizer temperature profiles obtained with different amounts of ethylene in the substantially olefins-free isobutane stream (OFIC4) and ethylene in the recycle isobutane stream (RIC4); and

[0015] FIG. 5 shows deethanizer temperature profiles for 10° F. (colder) deviation on feed at different amounts of ethylene in the substantially olefins-free isobutane stream (OFIC4) and hydrogen in the recycle isobutane stream (RIC4).

DETAILED DESCRIPTION

[0016] Herein disclosed are systems and methods of treating a polymerization reactor(s) effluent stream. In the conventional flash gas treatment processes, a deethanizer column is operated at approximately double the pressure of an upstream dehexanizer column. This change in pressure requires the inclusion of a dehexanizer overhead compressor. This compressor increases the capital cost of such conventional designs, and can present operational difficulties. Furthermore, operating the deethanizer at higher pressures increases the energy consumption of the stripping process occurring therein. Via the system and method of this disclosure, the deethanizer can be operated at a lower pressure, similar to that of the dehexanizer column, such that the dehexanizer compressor can be eliminated. This can also substantially reduce steam/energy consumption and reduce venting of ethylene.

[0017] Conventional designs can utilize higher pressures in the deethanizer in an effort to limit/reduce isobutane losses from the process in the deethanizer overhead. However, as noted above, a downside of this higher pressure in the deethanizer is the requirement of the dehexanizer overhead compressor and increased steam consumption in the deethanizer to accomplish the desired separation, especially when substantial amounts (e.g., 50%) of olefin-free isobutane (OFIC4) are desired, as discussed further hereinbelow.

[0018] Disclosed herein are various aspects of systems, apparatuses, and methods related to polymerization reactions, for example, polyethylene polymerization. The systems, apparatuses, and methods are generally related to a process for the separation and handling of the effluent stream from a polymer (e.g., polyethylene) production process.

[0019] FIG. 1A is a schematic of a polymerization system I comprising a flash gas production system (FGPS) II and a flash gas treatment system (FGTS) III, according to aspects of this disclosure; FIG. 1B is a schematic of a flash gas treatment system (FGTS) III, according to aspects of this disclosure; FIG. 1C is a schematic of a FGPS II operable to produce a flash gas, according to aspects of this disclosure; and FIG. 1D is a schematic of a polymerization system I', according to aspects of this disclosure;

[0020] Referring to FIG. 1A, a polymer (e.g., polyethylene) production system (PPS) I is disclosed. PPS system I generally comprises a flash gas production system (FGPS) II and a flash gas treatment system (FGTS) III. PPS I can comprise a purifier **102**, polymerization reactor or reactor system **110**, one or more (e.g., flash-line) heaters **120**, a flash chamber **130**, a first column **145**, a gas/liquid separator (e.g., an accumulator) **160**, a second column **170**, a vent column **185**, or a combination thereof. In aspects disclosed herein, various such system components can be in fluid communication via one or more conduits (e.g., pipes, tubing, flow lines, etc.) suitable for the conveyance of a particular stream, for example as shown in FIGS. 1A-2 by the streams which are conveyed via such conduits. In alternative aspects, the same or similar equipment and/or processes can be employed for the production of a variety of polymeric materials, for example, polyethylene, polypropylene, polybutylene, polyvinylchloride, or the like.

[0021] With reference to FIG. 1A, PPS I comprises: a FGPS II comprising one or more polymerization reactor(s)/system **110** (also referred to as a polymerization reactors **110** or polymerization system **110**) configured to produce a polymerization reactor effluent stream **111**; and flash apparatus **100** (also referred to herein as a flash system **100**) configured for flashing the

polymerization reactor(s)/system effluent stream **111** (also referred to simply as a “polymerization reactor effluent stream **111**”) to form a flash gas stream **140**; and a FGTS III comprising a first column **145** configured to separate the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146** (also referred to as a “hexene recycle stream **146**” or simply “side stream **146**”), and a first column bottoms stream **147**; a liquid/vapor separator **160** configured for separating the first column overhead stream **148** into a gas/vapor stream **161** and a liquid stream **162**; and a second column **170** configured to receive a feed **165** (via one or more feed inlets **166**) comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** and separate the feed **165** to produce a second column overhead stream **173**, a second column side stream **171** (also referred to herein as a recycle isobutane or RIC4 stream **171**, and a second column bottoms stream **172** (also referred to herein as an olefin-free isobutane or OFIC4 stream **172**).

[0022] FGPS II can include a polymerization feed purifier **102** (also referred to simply as a “feed purifier **102**” or a “feed stream purifier **102**”) operable to purify a polymerization feed stream **101** (also referred to simply as a “feed stream **101**”), thus providing a purified feed **103** (also referred to herein as a “feed stream **103**” or a “polymerization feed stream **103**”) for introduction into polymerization system **110**. In aspects, the purifier **102** can comprise a device or apparatus suitable for the purification of one or more reactant gases in a feed stream which can comprise a plurality of potentially unwanted gaseous compounds, elements, contaminants, or the like. Non-limiting examples of a suitable feed purifier **102** can comprise a filter, a membrane, a reactor, an absorbent, a molecular sieve, one or more distillation columns, fractionation columns, or combinations thereof. The purifier **102** can be configured to separate ethylene from a feed stream **101** comprising ethylene and further comprising methane, ethane, acetylene, propane, propylene, water, oxygen, other gaseous hydrocarbons, various contaminants, and/or combinations thereof. The purified polymerization feed **103** can comprise substantially pure monomers (e.g., ethylene monomers), as will be described herein. A portion **104'** of feed stream **103** can be combined with flash gas **131**, in embodiments.

[0023] Flash apparatus **100** of FGPS II can comprise one or more heaters **120** and a flash chamber **130**. One or more heaters **120** can be utilized to heat the polymerization system effluent stream **111**. The heated effluent stream **121** from the one or more heaters **120** can be introduced into flash chamber **130**. Within flash chamber **130**, flash gas **140** can be separated from polymer product **135** (also referred to herein as “polymer fluff **135**” or simply “polymer **135**”). The polymer product **135** can comprise, for example, polyethylene (PE), polypropylene (PP), polybutylene (PB), polyvinylchloride (PVC), or the like.

[0024] The FGTS III can generally comprise a three-column fractionation train to meet the demands of (1) rejecting heavy and light impurities, (2) recycling 1-hexene (e.g., via first column side stream **146**, described hereinbelow), and (3) providing recycle isobutane (in second column side stream **171**, which is also referred to herein as RIC4 **171**) and substantially olefin free isobutane (in second column bottoms stream **172**, which is also referred to herein as OFIC4 **172**). The three columns in the fractionation train of FGTS III can comprise: (1) first column **145** (e.g., a dehexanizer column), configured for taking upstream fluids (e.g., primarily flash gas **140**) to reject heavies (e.g., in first column bottoms stream **147**), recycle 1-hexene (e.g., via first column side stream **146**) and provide feed **165** to second (e.g., deethanizer) column **170**; (2) second column **170** (e.g., a deethanizer column), configured to provide RIC4 **171** and OFIC4 **172**, provide feed (e.g., second column overhead stream **173**) to the third column (e.g., vent column) **185**; and (3) the third column (e.g., vent column) **185**, to recover components (e.g., isobutane, ethylene) from the vent column feed (e.g., second column overhead stream **173**) from deethanizer second column **170** and reject lights **186**.

[0025] PPS I (and FGTS III) comprises no compressor between the first column **145** and the second column **170**. Second column **170** can be configured for operation at a pressure within about 10% of a pressure at which the first column **145** is operated. First column **145**, second column **170**,

or both can comprise a fractionation/distillation column. In aspects, polymer product **135** comprises polyethylene (PE), and first column **145** comprises a dehexanizer column configured to separate hexane and heavier components from the flash gas stream **140** to provide the first column overhead stream **148**.

[0026] The first column overhead stream **148** can comprise less than or equal to about 10, 5, 4, 3, 2, 1 or 0.5 ppmv C6+ (e.g., compounds containing 6 or more carbon atoms). In aspects, first column overhead stream **148** comprises from about 85 to about 100, from about 80 to about 90, or from about 85 to about 90 vol. % isobutane, from about 0 to about 2, from greater than 0 to about 3, or from 0.001 to about 2 vol % hydrogen, from about 2 to about 15, from about 0 to about 15, from greater than 0 to 15, or from greater than 0 to 10 vol % ethylene. For example, in aspects, first column overhead stream **148** can comprise, from about 3 to about 4 ppm vol. C6+, from about 85.6 to about 87.2 vol % isobutane, from about 0.04 to about 1.3 vol % H₂, and/or from about 6.1 to about 10.1 vol % ethylene.

[0027] The first column side stream **146** can comprise from about 85, 90, or 95 to about 95, 98, or 99 vol. % hexene. In aspects, the first column side stream **146** can comprise from about 80 to 100 vol % hexene and from about 0 to about 20 vol % C6+. For example, in aspects, first column side stream **146** can comprise from about 94.6 to about 96.2 wt % 1-hexene, from about 2.6 to about 4.2 wt % N-hexane, and/or less than about 1 wt % isobutane. All or a portion of first column side stream **146** can be recycled. For example, all or a portion of first column side stream **146** can be recycled to first column **145** (e.g., via an inlet line **141**), all or a portion of first column side stream **146** can be recycled to polymerization reactor/system **110** (e.g., to first polymerization reactor **110A** of an advanced dual loop reactor, such as described hereinbelow with reference to FIG. 1C), or a combination thereof. Accordingly, PPS I can include recycle line or path fluidly connecting first column side stream **146** with (e.g., inlet line **141** of) first column **145**, (e.g., a polymerization reactor **110A**, **110B** of (discussed hereinbelow with reference to FIG. 2)) polymerization system **110**, or both. One or more inlet lines **141** can be configured to introduce one or more additional components to first column **145**. For example, an inlet line **141** can be configured/utilized to introduce fresh or recycle hexene to first column **145**, an inlet line **141** can be configured/utilized to introduce fresh or recycle isobutane to first column **145**, or a combination thereof. As discussed hereinbelow, in aspects, recycled isobutane in second column side stream **171** is recycled to first column **145** via one or more inlet lines **141**.

[0028] The first column bottoms stream **147** can comprise primarily C6+ (e.g., compounds containing six or more carbon atoms; such as hexane, oils, oligomers, or a combination thereof). For example, in aspects, first column bottoms stream **147** can comprise from about 0 to about 50 vol % hexane, from about 0 to about 25 vol % oligomers, from about 0 to about 25 vol % oils, from about 0 to about 90 vol % hexene, or a combination thereof. In aspects, first column bottoms stream **147** can comprise from about 5 to about 12 wt % hexane, from about 1 to about 30 wt % oligomers, or a combination thereof. A portion **147B** of first column bottoms stream **147** can be returned to first column **145** via first column reboiler R1, and a portion **147A** of first column bottoms stream **147** not returned to first column **145**.

[0029] With reference to FIG. 1B, which is a schematic of the FGTS III, according to aspects of this disclosure, FGTS III comprises first column **145**, gas/liquid separator **160**, and second column **170**. FGTS III can further include a condenser **150** upstream of gas/liquid separator **160**. The condenser **150** can be configured to cool the first column overhead stream **148** to provide cooled first column overhead stream **148'**, to further condense components therein for separation in gas/liquid separator **160**. The liquid/vapor separator **160** can comprise an overhead accumulator (also referred to simply as “an accumulator **160**” or “gas/liquid separator **160**”) configured to separate the cooled first column overhead stream **148'** into a gas stream **161** (also referred to herein as a “gas/vapor stream **161**”) and a liquid **162** (also referred to herein as a “liquid stream **162**”). Liquid **162** from accumulator **160** can be divided into portion of liquid stream **164** that can be

pumped (e.g., via pump P1) to second column **170** as a component of second column feed **165** (also referred to herein simply as “feed stream **165**”), and liquid reflux stream **163** returned to first column **145**.

[0030] In aspects, polymer product **135** comprises polyethylene (PE), and second column **170** comprises a deethanizer column configured to separate ethane and lighter components in second column overhead stream **173** from the feed **165** to produce second column side stream **171** and second column bottoms stream **172**. The second column bottoms stream **172** can comprise less than or equal to about 5, 4, 3, 2, or 1 ppmw C₂–, (e.g., compounds having two or fewer carbon atoms). In aspects, a second column bottoms stream **172** outlet line can be configured for a second column bottoms stream **172** flow rate of isobutane and a second column side stream **171** outlet line is configured for a second column side stream **171** flow rate of isobutane, a total flow rate of isobutane comprises the bottoms stream **172** flow rate and the side stream **171** flow rate, and the bottoms stream **172** flow rate comprises less than or equal to about 15, 20, or 25 volume percent (vol. %) of the total flow rate and the side stream **171** flow rate comprises greater than or equal to about 85, 80, or 75 vol. % of the total flow rate.

[0031] In aspects, second column bottoms stream **172** can comprise from about 95 to about 96 wt % isobutane, from about 5 to about 10 ppmw (e.g., about 8 ppmw) olefins (such as 1 ppm ethylene, 7 ppm 1-hexene), and essentially no hydrogen. Second column bottoms stream **172** can comprise up to 5 ppmw ethylene and/or 500 ppmw hexene, in aspects. In aspects, the second column side stream **171** can comprise from about 50, 60, 70, 80, or 90 to about 80, 90, or 95 vol. % isobutane (e.g., from 90 to 95 vol % isobutane), from about 0, 5, or 8 to about 5, 6, 7, 8, 9, or 10 vol % olefins (e.g., from 2 to 5 vol % ethylene), and from about 1, 2, 3, 4, or 5 to about 10, 9, 8, 7, or 6 vol % hydrogen (e.g., less than about 1 ppb hydrogen). For example, in aspects second column side stream **171** can comprise from about 91-93 wt % isobutane, from about 2 to about 4 wt % ethylene, and less than about 1 ppb hydrogen. In aspects, second column overhead stream **173** can comprise from about 45, 50, or 55 to about 55, 50, or 45 vol %, or less than or equal to about 55, 50, or 45 vol % isobutane, from about 20, 25, or 30 to about 35, 40, or 45 vol %, or less than or equal to about 45, 40, or 35 vol % ethylene, and/or from about 0, 5, or 10 to about 20, 15, or 10 vol %, or less than or equal to about 15, 14, 13, 12, 11, or 10 vol % hydrogen, from about 0.1, 0.5, or 1 to about 5, 4, 3, 2, or 1 vol %, or less than or equal to about 5, 4, 3, 2, or 1 vol % ethane. For example, in aspects, second column overhead stream **173** can comprise from about 0.5 to about 14.5 vol % hydrogen, from about 23 to about 45 vol % ethylene, from about 0.5 to about 4.5 vol % ethane, and/or from about 52 to about 56 vol % isobutane. In aspects, second column overhead stream **173** can comprise from about 50 to about 90 vol % isobutane, from about 0 to 10 vol % ethylene, up to 10 vol % hydrogen and up to 15 vol % ethane.

[0032] As noted above, FGTS III/PPS I can include a recycle path for recycling at least a portion **171'** (also referred to herein as “recycle isobutane **171**” or “recycle RIC4”) of the second column side stream **171**. For example, such a recycle path can be configured to introduce the at least the portion of the second column side stream **171** to at least one of the one or more polymerization reactors/polymerization system **110** as a recycle isobutane stream. As noted hereinabove, the recycle isobutane stream (RIC4, e.g., second column side stream **171**) can comprise greater than or equal to about 90 volume percent (vol %) (e.g., from about 90 to about 93 wt %) isobutane, greater than or equal to about 5 ppmw olefins (e.g., 2 to 4 wt % ethylene, 4-5 ppmw 1-hexene), less than or equal to about 0.1 vol % hydrogen (e.g., less than 1 ppbw hydrogen), less than about 5 wt % n-butane (e.g., about 3 wt % n-butane), less than about 0.5 wt % C₃ (e.g., 0.1 to about 0.2 wt % C₃s), less than about 1 wt % ethane (e.g., 0.1 to 0.7 wt % ethane), or a combination thereof. The olefins can comprise ethylene, hexene, or a combination thereof.

[0033] In aspects, second column bottoms stream **172** is a substantially olefin-free isobutane stream (OFIC4) comprising greater than or equal to about 90 volume percent (vol %), or from about 90, 91, 92, 93, or 94 to about 93, 94, 95, 96 vol % isobutane (e.g., from about 95 to about 96

wt % isobutane), less than or equal to about 5, 4, 3, 2, or 1 ppmw olefins (e.g., less than or equal to about 1 ppmw ethylene, less than or equal to about 7 ppmw hexene), less than or equal to about 5, 4, 3, 2, or 1 ppmw other paraffins (e.g., less than or equal to about 5 wt % n-butane, less than 3 ppmw ethane), substantially no (e.g., less than about 0.1 ppmw) hydrogen, less than 0.1 wt % C3s (e.g., 0.03 to 0.06 wt % C3s), or a combination thereof, wherein the olefins comprise ethylene, hexene, or a combination thereof.

[0034] With reference to FIG. 1C, which is a schematic of a flash gas production system (FGPS) II operable to produce a flash gas **140**, according to aspects of this disclosure, and which will be described in further detail hereinbelow, PPS I can further comprise a catalyst pretreater **106'** upstream of the one or more polymerization reactor(s)/system **110**. PPS I can further include a recycle path for recycling at least a portion **172'** of the substantially olefins-free isobutane stream (e.g., second column bottoms stream **172**) from the second column **170** as a recycle olefins-free isobutane stream **172'** to the catalyst pretreater **106'**. The catalyst pretreater **106'** can be configured to produce (and provide via a pump P3) a catalyst slurry **106** comprising a polymerization catalyst **107** and the recycle olefins-free isobutane stream **172'/191'**. Polymerization catalyst **107** from catalyst hopper **160''** can be combined olefin-free diluent (e.g., with recycle olefin-free isobutane **172'** from second column bottoms stream **172** and/or recycle substantially olefin-free isobutane **191'** from an olefin-free isobutane storage tank **190**). Portion **172'** is also referred to herein as "recycle olefin-free isobutane **172''**")

[0035] As noted hereinabove, second column **170** can be in operation at a second column pressure and the first column **145** can be in operation at a first column pressure; the second column pressure can be within about 10% of the first column pressure. In aspects, the second column pressure is from about 110 psig to about 160 psig. For example, the second column **170** pressure can be about 110, 120, 130, 140, 150, or 160 psig, in aspects.

[0036] As best seen in FIG. 2, which is a schematic of a portion IV of a flash gas treatment system (FGTS), according to aspects of this disclosure, FGTS III can further include a second column reboiler R2 associated with the second column **170**. A portion of second column bottoms stream **172** can be returned to second column **170** via second column reboiler R2. Heating fluid (e.g., steam) **174** can be introduced to second column reboiler R2, and spent (e.g., cooled) heating fluid removed from second column reboiler R2 via condensate line **175**. A reboiler duty of the second column reboiler R2 associated with the second column **170** can be less than a reboiler duty of a reboiler associated with a second column in a same system designed to effect a same separation of isobutane in second column side stream **171** and second column bottoms stream **172** except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure. A diameter of the second column **170** can be less than a diameter of the second column utilized to provide the same separation in the same system operated at the second column pressure that is not within about 10% of the first column pressure.

[0037] As depicted in FIGS. 1A-1D, and noted above, PPS I and FGTS III do not comprise any compressor for compressing of the first column overhead stream **148**, the gas stream **161**, or the at least the portion **164** of the liquid stream **162** prior to introduction of the gas stream **161** and the at least the portion **164** of the liquid stream **162** as feed **165** to the second column **170**. In aspects, PPS I and FGTS III also comprise no preheater for preheating of the feed **165** or components thereof (e.g., the gas stream **161**, the liquid stream **162**, the portion **164** of the liquid stream **162**) between the second column **170** and the first column **145**.

[0038] With reference back to FIG. 2, which provides the schematic of the portion IV of flash gas treatment system III comprising second column **170** and vent column **185**, a liquid side draw stage SDS is a stage from which or tray from immediately above which the second column side stream **171** is withdrawn, and a feed stage FS is a stage to which or a tray immediately above which the second column feed **165** is introduced to the second column **170**. The stages can be numbered from the top. The bottom stage BS is located closer to a bottom of the second column **170** than the feed

stage FS. According to aspects of this disclosure, the liquid side draw stage SDS of the second column **170** can be separated from the feed stage FS of the second column **170** by more than 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 theoretical or actual stages (trays), or by from about 3 to about 20, from about 5 to about 18, or from about 10 to about 15 theoretical or actual stages (trays).

[0039] In aspects, PPS I and/or FGTS III is configured to produce the second column side stream **171** comprising less than or equal to about 0.1 vol % hydrogen, greater than or equal to about 0.5 vol % ethylene, greater than or equal to about 90 vol % isobutane, or a combination thereof. In aspects, a desired composition of the second column side stream **171** and/or the second column bottom stream **172** can be obtained by utilizing a PPS I.

[0040] PPS I and/or FGTS III can be configured for maximizing an amount of ethylene in the second column side stream **171** (e.g., for recycle, for example, to polymerization system **110**), while maintaining a concentration of hydrogen in the second column side stream **171** below a tolerance of the one or more polymerization reactor(s)/system **110** (e.g., at less than about 0.1, 0.5 or 1% ppmw volume percent (vol %) H.sub.2), and comprising a recycle path for recycling at least a portion **171'** of the second column side stream **171** to at least one of the one or more polymerization reactor(s)/system **110**.

[0041] With reference to FIG. 1C, the one or more polymerization reactors/polymerization system **110** can comprise an advanced dual loop (ADL) polymerization reactor(s)/system **110** comprising a first polymerization reactor **110A** upstream of a second polymerization reactor **110B** and optionally downstream of a catalyst pretreater **106'**. Catalyst slurry **106** and feed stream **103** (e.g., olefin, such as ethylene), and additional reactants **105** (e.g., hydrogen) can be introduced into ADL polymerization reaction system **110**. First polymerization reactor **110A** can be configured to produce a higher molecular weight polymer of a bimodal polymer, and second polymerization reactor **110B** can be configured to produce a lower molecular weight polymer of the bimodal polymer. The higher molecular weight polymer has a higher average molecular weight than the lower molecular weight polymer. At least a portion **171'** of the second column side stream **171** can be recycled to the first polymerization reactor **110A**, the second polymerization reactor **110B**, or both.

[0042] The polymerization reactor effluent stream **111** from the ADL reactor **110** can be introduced (e.g., via valve V1) into flash apparatus **100** to produce the polymer product **135** and the flash gas **140** to be treated in downstream FGTS III. In aspects, second polymerization reactor **110B** tolerates a higher hydrogen concentration than first polymerization reactor **110A**. In aspects, the system and method of this disclosure provide for a second column side stream **171** that comprises a level of hydrogen low enough for introduction into first polymerization reactor **110A**, second polymerization reactor **110B**, or both, with approximately 85% or more of the total diluent (e.g., isobutane) flow (further comprising unreacted ethylene and a low level of hydrogen) exiting second column **170** with second column side stream **171** and less than or equal to about 15 volume percent of the diluent exiting second column **170** as recycle OFIC4 via second column bottoms stream **172**.

[0043] The one or more polymerization reactors **110** (e.g., first polymerization reactor **110A**, second polymerization reactor **110B**) contain a polymerization catalyst **107**, which is further described hereinbelow.

[0044] The FGTS III/PPS I can further include one or more overhead treaters **180**, with a first overhead treater **180A** and a second overhead treater **180B** depicted in the aspect of FIG. 2. The one or more overhead treaters **180** can be configured to remove one or more components from second column overhead stream **173** prior to introduction of treated second column overhead stream **181** (e.g., comprising first overhead treater outlet stream **181A** and second overhead treater outlet stream **181B**) into vent column **185**. The overhead treaters **180** can be configured to remove moisture (e.g., water) and prevent hydrates from forming in the vent condenser. The two treaters can be operated in parallel, with one online while the other is standing by and/or being regenerated. Vent column **185** can include a condenser/condensing section **182** for condensing the treated

second column overhead stream **181**, and can separate the treated second column overhead stream **181** into a vent column overhead gas **186** and a vent column bottom liquid **187**. A reflux pump P2 can be operable to return at least a portion of the vent column bottom liquid **187** to the second column **170** as reflux, and a vent or outlet for venting at least a portion of the vent column overhead gas **186** (e.g., to a cracker). Refrigerant (e.g., propane) **188** can be introduced into condenser/condensing section **182** of vent column **185**, and spent refrigerant **189** removed therefrom.

[0045] With continued reference to FIG. 2, second column side stream **171** can be cooled in recycle isobutane cooler **195**. Cooled second column side stream **196** can be stored in a recycle diluent tank **197**. Relatively cold coolant can be introduced into recycle isobutane cooler **195** via line **176** and relatively warm coolant removed therefrom via line **177**. Recycle diluent (e.g., a portion of cooled second column side stream **196**) can be recycled, for example, to the one or more polymerization reactor(s)/system **110** via second column bottom stream **172**, cooled second column side stream **196**, and/or recycle diluent tank outlet line **198**.

[0046] In aspects, the second column **170** is operating/operated at a second column operating pressure, and the first column **145** is operating/operated at a first column operating pressure, the second column operating pressure is within about 10% of the first column operating pressure, and an amount of ethylene in the vent column overhead gas **186** being vented is less than or equal to an amount of ethylene vented in a same system configured for a same separation of isobutane between the second column side stream **171** and the second column bottoms stream **172** except without having the second column pressure within about 10% of the first column pressure.

[0047] With reference to FIG. 1D, which is a schematic of a PPS I', according to aspects of this disclosure, FGPS II can include polymerization system or reactor(s) **110** configured for the production of polymerization effluent stream **111** comprising polymer (e.g., PE), unreacted reactants, diluent, etc. Olefin-free diluent (e.g., olefin-free isobutane) **172'/191'** from second column bottoms stream **172** and/or olefin-free diluent storage tank **190**/olefin-free storage tank outlet line **191**, respectively, can be combined with polymerization catalyst and/or co-catalyst **107** to form catalyst slurry **106** for introduction into the polymerization reactor(s)/system **110**. Olefin (e.g., hexene, ethylene) can be introduced into polymerization reactor(s)/system **110** via, for example, one or more feedstream(s) **103**. Diluent (e.g., recycle isobutane **171'**) can also be introduced into polymerization reactor(s)/system **110**.

[0048] Flash apparatus **100** can include one or more flash line heaters (FLHs) **120**, with five (**120A**, **120B**, **120C**, **120D**, **120E**) depicted in the aspect of FIG. 1D. Heated effluent stream **121** can be introduced into flash gas cyclone **122** of flash apparatus **100**. Gas **131** separated from the polymer product in flash gas cyclone can be removed from flash gas cyclone **122**. Polymer from flash gas cyclone **122** can be introduced into surge tank **123**. From surge tank **123**, solids including polymer product can be metered (e.g., via valve V2) to a purge column **124**. Purge column **124** can be configured to remove additional gas from the polymer fluff. Gas **125** extracted from the polymer fluff in purge column **124** can be introduced into an isobutane nitrogen recovery unit (INRU) **126**, configured to separate nitrogen **128** for recycle to purge column **124** from INRU liquid **127**. The INRU liquid **127** can be combined with the flash gas **131** to provide flash gas **140** for introduction to FGTS III. Polymer product **135** from purge column **124** can be sent for further processing, for example to an extruder **136**. Transport gas **129** (e.g., nitrogen) and one or more metering valves (e.g., rotary valve V3, rotary valve V4) can be utilized to flow polymer fluff **135** from purge column **124** to extruder **136**. Other FGPS II can be utilized to produce the flash gas **140** for introduction into FGTS III; the FGPS II and flash apparatus **100** of FIGS. 1A, 1C, and 1D are provided by way of examples.

[0049] In aspects, a polymerization system of this disclosure comprises: one or more polymerization reactors **110** configured to produce a polymerization reactor effluent stream **111**; flash apparatus **100** (e.g., a flash chamber **130**) configured for flashing the polymerization reactor

effluent stream **111** to form a flash gas stream **140**; a first column **145** configured to separate the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**; a liquid/vapor separator **160** configured for separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**; and a second column **170** configured to receive a feed **165** comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** and separate the feed **165** to produce a second column overhead stream **173**, a second column side stream **171**, and a second column bottoms stream **172**, wherein the second column **170** is operating at a second column pressure, and wherein the first column **145** is operating at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

[0050] In aspects, a polymerization system of this disclosure comprises: one or more polymerization reactors **110** configured to produce a polymerization reactor effluent stream **111**; flash apparatus **100** (e.g., a flash chamber **130**) configured for flashing the polymerization reactor effluent stream **111** to form a flash gas stream **140**; a first column **145** configured to separate the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**; a liquid/vapor separator **160** configured for separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**; a second column **170** configured to receive a feed **165** comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** and separate the feed **165** to produce a second column overhead stream **173**, a second column side stream **171**, and a second column bottoms stream **172**, and a recycle path (e.g., a recycle line(s)) for recycling at least a portion **171'** of the second column side stream **171** to at least one of the one or more polymerization reactors **110**. The system I can be configured such that an amount of ethylene in the second column side stream **171** is maximized, while a concentration of hydrogen in the second column side stream **171** is below a tolerance of the one or more polymerization reactors **110** (e.g., at less than about 0.1, 0.5, or 1% ppmw H.sub.2).

[0051] In aspects, the PPS I/FGTS III of this disclosure comprises no dehexanizer overhead compressor or associated suction drum and pump, no deethanizer column feed economizer, no deethanizer feed preheater, no deethanizer overhead condenser, no deethanizer accumulator, or a reduced number of deethanizer reflux pumps, or a combination thereof.

[0052] Various aspects of suitable PPS systems having been disclosed, aspects of a flash gas treatment process will now be disclosed. One or more of the aspects of a flash gas treatment process can be described with reference to PPS I. Although a given flash gas treatment process may be described with reference to one or more aspects of a PPS, such a disclosure should not be construed as limiting. Although the various steps of the processes disclosed herein may be disclosed or illustrated in a particular order, such should not be construed as limiting the performance of these processes to any particular order unless otherwise indicated.

[0053] Also disclosed herein are methods of treating a polymerization reactor effluent stream **111** and/or a flash gas **140**. The method can include producing polymerization reactor effluent stream **111** via a PPS, such as PPS I/I' as described hereinabove with reference to FIGS. **1A** and **1D**; producing the flash gas **140** via a FGPS, such as FGPS II described hereinabove with reference to FIGS. **1A-1D**, and treating the flash gas **140** via a FGTS, such as FGTS III described hereinabove with reference to FIG. **1A**, FIG. **1B**, and FIG. **1D**. A method of this disclosure can comprise: recovering a polymerization reactor effluent stream **111** from one or more polymerization reactors **110**; flashing the polymerization reactor effluent stream **111** (e.g., in flash system or apparatus **100**) to form a flash gas stream **140**; separating, in a first column **145**, the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**; separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**; and introducing a feed **165** comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** to a second column **170** to produce a second column overhead stream **173**, a second column side stream **171**, and a second column bottoms stream **172**. The second column

bottoms stream **172** can have a second column bottoms stream **172** flow rate of diluent (e.g., isobutane) and the second column side stream **171** can have a second column side stream **171** flow rate of diluent (e.g., isobutane). A total flow rate of diluent (e.g., isobutane) from second column **170** can comprise the second column bottoms stream **172** flow rate and the second column side stream **171** flow rate. The second column bottoms stream **172** flow rate can comprise less than or equal to about 15 volume percent (vol. %) of the total flow rate of diluent and the second column side stream **171** flow rate can comprise greater than or equal to about 85 vol. % of the total flow rate of diluent.

[0054] The method can further comprise purifying a polymerization feed stream **101** to provide a purified polymerization feed stream **103** and polymerizing monomers of the purified feed stream **103** in one or more polymerization reactors **110** to provide the polymerization reactor effluent stream **111**. In aspects, a polymerization feed stream **101** is purified. Purifying the feed stream **101** can comprise separating unwanted compounds and elements from a feed stream comprising ethylene to form a purified polymerization feed stream **103**. In aspects illustrated by FIG. 1A, purifying the feed stream **101** can comprise routing the feed stream **101** to a feed stream purifier **102**, such as described hereinabove.

[0055] In aspects, purifying a feed stream **101** can yield a purified feed stream **103** comprising substantially pure ethylene. In aspects, the purified feed stream **103** can comprise less than 25% by weight, alternatively, less than about 10%, alternatively, less than about 1.0% of any one or more of nitrogen, oxygen, methane, ethane, propane, other hydrocarbons, or combinations thereof. As used herein “substantially pure ethylene” refers to a fluid stream comprising at least about 60% ethylene, alternatively, at least about 70% ethylene, alternatively, at least about 80% ethylene, alternatively, at least about 90% ethylene, alternatively, at least about 95% ethylene, alternatively, at least about 99% ethylene by weight, alternatively, at least about 99.5% ethylene by weight. In aspects, the purified feed stream **103** can further comprise trace amounts of ethane.

[0056] The method can further include polymerizing monomers of the purified stream **103** in the polymerization reactor(s)/system **110** to yield a polymerization system effluent stream **111** generally comprising unreacted monomers (e.g., ethylene), ethane, diluent (e.g., one or more of propane, propylene, isobutane, n-butane, etc.), and a polymerization product (e.g., polyethylene).

[0057] In aspects, monomers of the purified feed stream **103** are polymerized. Polymerizing monomers of the purified feed stream **103** can comprise allowing a polymerization reaction between a plurality of monomers by contacting a monomer or monomers with a catalyst system under conditions suitable for the formation of a polymer. A suitable catalyst system/polymerization catalyst **107** can comprise a catalyst and, optionally, a co-catalyst and/or promoter. Non-limiting examples of suitable catalyst systems include Ziegler-Natta catalysts, Ziegler catalysts, chromium catalysts, chromium oxide catalysts, chromocene catalysts, metallocene catalysts, nickel catalysts, or combinations thereof. Catalyst systems suitable for use in this disclosure have been described, for example, in U.S. Pat. No. 7,619,047 and U.S. Patent Application Publication Nos.

2007/0197374, 2009/0004417, 2010/0029872, 2006/0094590, and 2010/0041842, each of which is incorporated by reference herein in its entirety. In aspects, any suitable catalyst system can be employed, as may be appropriate for a given process or product need or desire.

[0058] In the aspect illustrated in FIG. 1A, polymerizing monomers of the purified feed **103** can comprise routing the purified feed stream **103** to the polymerization reactor(s)/polymerization system **110**. In aspects disclosed herein, the polymerization reactor(s)/system **110** can comprise any vessel or combination of vessels suitably configured to provide an environment for a chemical reaction (e.g., a contact zone) between monomers (e.g., ethylene) and/or polymers (e.g., an active or growing polymer chain) in the presence of a polymerization catalyst **107** to yield a polymer **135** (e.g., a polyethylene polymer). Although the aspects of FIG. 1A and FIG. 1D illustrate a PPS I/T' having one polymerization reactor, one of skill in the art viewing this disclosure will recognize that two or more reactors arranged in any suitable configuration (e.g., in series and/or in parallel) can be

employed. For example, FIG. 1B, described hereinabove, depicts an advanced dual loop polymerization reactor system **110** comprising two polymerization reactors, including first polymerization reactor **110A** and second polymerization reactor **110B**.

[0059] As used herein, the terms “polymerization reactor” or “reactor” include any polymerization reactor (e.g., a vessel) capable of polymerizing olefin monomers to produce homopolymers or copolymers. Such homopolymers and copolymers may be referred to as resins or polymers. The various types of reactors include those that may be referred to as batch, slurry, gas-phase, solution, high pressure, tubular, or autoclave reactors. Gas phase reactors may comprise fluidized bed reactors or staged horizontal reactors. Slurry reactors may comprise vertical or horizontal loops. High pressure reactors may comprise autoclave or tubular reactors. Reactor types can include batch and/or continuous processes. Continuous processes may use intermittent or continuous product discharge. Processes may also include partial or full direct recycle of un-reacted monomer, un-reacted comonomer, and/or diluent.

[0060] Polymerization reactor systems of the present disclosure can comprise one type of reactor in a system. Alternatively, in aspects where multiple reactors are employed, two or more reactors of the same or different type can be employed. Production of polymers in multiple reactors may include several stages in at least two separate polymerization reactors interconnected by a transfer device or conduit making it possible to transfer the polymers resulting from the first polymerization reactor into the second reactor. The desired polymerization conditions in one of the reactors may be different from the operating conditions of the other reactors. Alternatively, polymerization in multiple reactors may include the transfer of polymer from a first reactor to a subsequent reactor(s) for continued polymerization. Multiple reactor systems may include any combination including, but not limited to, multiple loop reactors, multiple gas reactors, a combination of loop and gas reactors, multiple high pressure reactors or a combination of high pressure with loop and/or gas reactors. The multiple reactors may be operated in series or in parallel, or any combination thereof.

[0061] According to aspects of this disclosure, the polymerization reactor may comprise at least one gas phase reactor. In an alternative aspect, the polymerization reactor may comprise at least one gas phase reactor in combination with at least one other reactor, which may be a slurry loop reactor or a solution polymerization reactor. Such systems may employ a continuous recycle stream containing one or more monomers continuously cycled through a fluidized bed in the presence of the catalyst under polymerization conditions. A recycle stream may be withdrawn from the fluidized bed and recycled back into the reactor. Simultaneously, polymer product may be withdrawn from the reactor and new or fresh monomer may be added to replace the polymerized monomer. Such gas phase reactors may comprise a process for multi-step gas-phase polymerization of olefins, in which olefins are polymerized in the gaseous phase in at least two independent gas-phase polymerization zones while feeding a catalyst-containing polymer formed in a first polymerization zone to a second polymerization zone. One type of gas phase reactor is disclosed in U.S. Pat. Nos. 5,352,749, 4,588,790 and 5,436,304, each of which is incorporated by reference in its entirety herein.

[0062] According to another aspect of the disclosure, the polymerization reactor system may additionally comprise at least one loop slurry reactor comprising vertical or horizontal loops. Monomer, diluent, catalyst, and optionally any comonomer may be continuously fed to a loop reactor where polymerization may occur. Generally, continuous processes may comprise the continuous introduction of a monomer, a catalyst, and a diluent into a polymerization reactor and the continuous removal from this reactor of a suspension comprising polymer particles and the diluent. Suitable diluents used in slurry polymerization include, but are not limited to, the monomer being polymerized and hydrocarbons that are liquids under reaction conditions. Examples of suitable diluents include, but are not limited to, hydrocarbons such as propane, cyclohexane, isobutane, n-butane, n-pentane, isopentane, neopentane, and n-hexane. Some loop polymerization reactions can occur under bulk conditions where no diluent is used. An example of polymerization

of propylene monomer is disclosed in U.S. Pat. No. 5,455,314, which is incorporated by reference herein in its entirety. A typical slurry polymerization process (also known as the particle form process), is disclosed, for example, in U.S. Pat. Nos. 3,248,179, 4,501,885, 5,565,175, 5,575,979, 6,239,235, 6,262,191 and 6,833,415, each of which is incorporated by reference in its entirety herein. In aspects, any suitable type, form, style, or combination of polymerization reactor or reactors may be employed in a given application.

[0063] According to yet another aspect of the disclosure, the polymerization reactor may comprise a solution polymerization reactor wherein the monomer is contacted with the catalyst composition by suitable stirring or other means. A carrier comprising an inert organic diluent or excess monomer may be employed. If desired, the monomer may be brought in the vapor phase into contact with the catalytic reaction product, in the presence or absence of liquid material. The polymerization zone may be maintained at temperatures and pressures that result in the formation of a solution of the polymer in a reaction medium. Agitation may be employed to obtain better temperature control and to maintain uniform polymerization mixtures throughout the polymerization zone. Adequate means may be utilized for dissipating the heat of polymerization.

[0064] Polymerization reactors suitable for the present disclosure may further comprise any combination of at least one raw material feed system, at least one feed system for catalyst or catalyst components, at least one recycle system, and/or at least one polymer recovery system. Suitable reactor systems for the present disclosure may further comprise systems for feedstock purification, catalyst storage and preparation, extrusion, reactor cooling, polymer recovery, fractionation, recycle, storage, load-out, laboratory analysis, process control, and/or other systems.

[0065] Conditions that may be controlled for polymerization efficiency and to provide desired resin properties include time, temperature, pressure and the concentrations of various reactants. Polymerization temperature can affect catalyst productivity, polymer molecular weight and molecular weight distribution. Suitable polymerization temperature may be any temperature below the de-polymerization temperature according to the Gibbs Free energy equation. Typically this includes from about 60° C. to about 280° C., for example, and from about 70° C. to about 110° C., depending upon the type of polymerization reaction.

[0066] Suitable contact time of the components of the polymerization process may vary, as may be appropriate for a given process or product need or desire. In addition to contact time for the polymerization reaction itself, any/all times for pre-contacting, pre-activation, activation, aging, conditioning, or other process relating to the polymerization step may be varied, as may be necessary or desired to achieve an appropriate outcome.

[0067] Suitable pressures will also vary according to the reactor and polymerization type. The pressure for liquid phase polymerizations in a loop reactor is typically less than 1000 psig. Pressure for gas phase polymerization is usually at about 200 to 500 psig. High pressure polymerization in tubular or autoclave reactors is generally run at about 20,000 to 75,000 psig. Polymerization reactors can also be operated in a supercritical region occurring at generally higher temperatures and pressures. Operation above the critical point of a pressure/temperature diagram (supercritical phase) may offer advantages. In aspects, polymerization may occur in an environment having a suitable combination of temperature and pressure. For example, polymerization may occur at a pressure in a range from about 425 psi to about 900 psi, alternatively, about 450 psi to about 675 psi, and a temperature in a range from about 60° C. to about 280° C., alternatively, from about 70° C. to about 110° C.

[0068] The concentration of various reactants can be controlled to produce resins with certain physical and mechanical properties. The proposed end-use product that will be formed by the resin and the method of forming that product determines the desired resin properties. Mechanical properties include tensile, flexural, impact, creep, stress relaxation and hardness tests. Physical properties include density, molecular weight, molecular weight distribution, melting temperature, glass transition temperature, temperature melt of crystallization, density, stereoregularity, crack

growth, long chain branching and rheological measurements.

[0069] The concentrations and/or partial pressures of monomer, co-monomer, hydrogen, co-catalyst, modifiers, and electron donors are important in producing these resin properties. Comonomer may be used to control product density. Hydrogen may be used to control product molecular weight. Co-catalysts can be used to alkylate, scavenge poisons and control molecular weight. Modifiers can be used to control product properties and electron donors affect stereoregularity, the molecular weight distribution, or molecular weight. In addition, the concentration of poisons is minimized because poisons impact the reactions and product properties.

[0070] In aspects, polymerizing monomers of the purified feed may comprise introducing a suitable catalyst system **107** into the reactor(s) **110**, so as to form a catalyst slurry **106**. Alternatively, a suitable catalyst system may reside in the polymerization reactor(s)/system **110**.

[0071] As explained above, polymerizing monomers of the purified feed **103** may comprise selectively manipulating one or more polymerization reaction conditions to yield a given polymer product **135**, to yield a polymer product **135** having one or more desirable properties, to achieve a desired efficiency, to achieve a desired yield, the like, or combinations thereof. Non-limiting examples of such parameters include time, temperature, pressure, type and/or quantity of catalyst or co-catalyst, the concentrations and/or partial pressures of various reactants, or other process parameters. In aspects, polymerizing monomers of the purified feed **103** may comprise adjusting one or more polymerization reaction conditions.

[0072] In aspects, polymerizing monomers of the purified feed **103** may comprise maintaining a suitable temperature, pressure, and/or partial pressure(s) during the polymerization reaction, alternatively, cycling between a series of suitable temperatures, pressures, and/or partials pressure(s) during the polymerization reaction.

[0073] In aspects, polymerizing monomers of the purified feed **103** may comprise circulating, flowing, cycling, mixing, agitating, or combinations thereof, the monomers, catalyst system, and/or the slurry within the polymerization reactor(s)/system **110**. In aspects where the monomers, catalyst system, and/or slurry are circulated, circulation may be at a velocity (e.g., fluid velocity) of from about 1 m/s to about 30 m/s, alternatively, from about 2 m/s to about 17 m/s, alternatively, from about 3 m/s to about 15 m/s.

[0074] In aspects, polymerizing monomers of the purified feed **103** may comprise configuring the polymerization reactor(s)/system **110** to yield a multimodal (e.g., a bimodal) polymer (e.g., polyethylene). For example, the resultant polymer **135** may comprise both a relatively high molecular weight, low density (HMWLD) polyethylene polymer and a relatively low molecular weight, high density (LMWHD) polyethylene polymer. For example, various types of suitable polymers may be characterized as having different densities. For example, a Type I may be characterized as having a density in a range of from about 0.910 g/cm.^{sup.3} to about 0.925 g/cm.^{sup.3}, alternatively, a Type II may be characterized as having a density from about 0.926 g/cm.^{sup.3} to about 0.940 g/cm.^{sup.3}, alternatively, a Type III may be characterized as having a density from about 0.941 g/cm.^{sup.3} to about 0.959 g/cm.^{sup.3}, alternatively, a Type IV may be characterized as having a density of greater than about 0.960 g/cm.^{sup.3}.

[0075] Polymerizing monomers of the purified feed **103** in polymerization reactor(s)/system **110** may yield an effluent stream **111**, which may generally comprise various solids, semi-solids, volatile and nonvolatile liquids, gases and/or combinations thereof. For example, the polymerization reactor effluent stream **111** may comprise unreacted reactant monomers (e.g., unreacted ethylene monomers) liquids, diluents, waste products, other gases, and/or contaminants. In aspects, the effluent stream **111** may comprise hydrogen, nitrogen, methane, ethylene, ethane, propylene, propane, butane, isobutane, pentane, hexane, hexene-1 and heavier hydrocarbons and polymer product (e.g., polyethylene). In aspects, ethylene may be present in a range of from about 0.1% to about 15%, alternatively, from about 1.0% to about 10%, by weight. Ethane may be present in a range of from about 0.001% to about 4%, alternatively, from about 0.2% to about 2%

by weight. Isobutane may be present in a range from about 70% to about 99%, alternatively, from about 80% to about 98%, alternatively, about 83% to about 97% by weight. The solids and/or liquids may comprise a polymer product (e.g., a polyethylene polymer), often referred to at this stage of the process as “polymer fluff”, or simply “fluff.”

[0076] The method can include heating the polymerization reactor effluent stream **111** in heater **120** to yield a heated effluent stream **121**. The method can further include separating the heated effluent stream **121** in flash chamber **130** to provide a polymer product stream **135** and a flash gas stream **140**. In aspects, heat may be added to effluent stream **111**. For example, energy (e.g. heat) may be added to effluent stream **111** to facilitate processing (separation of the components of effluent stream **111**, as will be discussed herein). In aspects, heating the effluent stream **111** can be accomplished by any suitable device, apparatus, or process as will yield component states and/or phases, increases in effluent stream temperature, or combinations thereof as may be desired for a given application. In shown in the aspects of FIG. 1A and FIG. 1D, heating the effluent stream **111** can comprise routing the effluent stream **111** through a suitable heater **120**, for example, flash-line heater. As used herein, the term “flash-line heater” may refer to a device or apparatus configured and arranged to add heat to a stream (e.g., effluent stream **111**, which may comprise solids, liquids, and/or gases). Suitable flash-line heaters as may be employed herein are disclosed in U.S. Pat. Nos. 3,152,872; 5,183,866; and 5,207,929, each of which is incorporated herein in its entirety. An example of a suitable flash-line heater is a heat exchanger. Such a heat exchanger may comprise a double-walled pipe in which the substance to be heated (e.g., effluent stream **111**) flows through an inner pipe while steam is injected in an outer or surrounding pipe. In aspects, the flash-line heater may operate intermittently. Generally, the volume of material flowing through a heat exchanger and the speed at which it flows determine the amount of heat that will be added. In aspects, heating the effluent stream **111** may yield a heated effluent stream **121**.

[0077] In alternative aspects, heat is not be added to effluent stream **111**. For example, in aspects, the polymerization reaction may occur at temperatures, pressures, and/or other operating parameters as may provide sufficient energy to make unnecessary the addition of heat or energy to the effluent stream **111**.

[0078] In aspects, the heated effluent stream **121** (alternatively, in aspects where the effluent stream has not been heated, the effluent stream **111**) may be separated into a polymer product stream **135** and a flash gas stream **140**. In aspects, separating the heated effluent stream **121** into a polymer product stream **135** and a flash gas stream **140** can be by any suitable device, apparatus, or process. For example, in aspects, separating an effluent stream (such as heated effluent stream **121** or effluent stream **111**) into a polymer product stream **135** and a flash gas stream **140** can comprise flashing the effluent stream. Not intending to be bound by theory, “flashing” a stream generally refers to causing a phase change in which liquid phase components of a stream (e.g., the heated effluent stream **121**) are converted into gas phase components (e.g. vaporizing/gasifying the liquid components of the stream), for example, as by a reduction of the pressure of the stream. In aspects, flashing may be accomplished by adding heat to a stream, reducing the pressure of the stream, adding other forms of energy to the stream (e.g. ultrasonic energy), or combinations thereof. For example, flashing a stream may comprise rapidly (e.g., instantaneously or nearly instantaneously) allowing the volume of the stream to increase such that the pressure of the stream falls and the liquid components of the stream enter a vapor or gas phase. As such, a stream that has been flashed can comprise gaseous phase components (e.g., the flash gas) and solid phase components (e.g., the polymer product). For example, in aspects, substantially all (e.g., at least 98%, alternatively 99%, alternatively 99.5%, alternatively 99.9%) by total weight of the heated effluent stream **121** of non-polymer components (e.g., liquids and gases) present in stream **121** are recovered as gases via flash gas stream **140**.

[0079] In aspects, separating polymerization effluent stream **111** (e.g., the heated effluent stream **121**) into a polymer product stream **135** and a flash gas stream **140** can generally comprise

segregating the gas phase components from the solid phase components. Segregating the gas phase components and the solid phase components may be by any suitable device, apparatus, or process. For example, as depicted in the aspect of FIG. 1D, in aspects where a stream has been flashed, the solid phase components (e.g., the polymer product **135**) and the vapor phase components (e.g., the flash gas **140**) can be separated by cyclonic separation. Generally speaking, cyclonic or vortex separation refers to a method of separating solid, and/or particulate materials from gaseous materials, for example, via a high speed rotating flow established within a cylindrical or conical container (e.g., a cyclonic chamber or cyclone, such as flash gas cyclone **122**). Material flows in a spiral pattern, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow) end before exiting the cyclone. Not intending to be bound by theory, solid and/or particulate material (e.g. the polymer fluff) entrained within a rotating, gaseous stream within the cyclone have too much inertia to follow the tight curve of the rotating, gaseous stream and, thus, strike the outside wall of the cyclone, and fall toward the bottom of the cyclone. In such a conical system, as the rotation flow moves towards the narrow end of the cyclone the rotational radius of the stream is reduced, separating smaller and smaller particles. The cyclone geometry, together with flow rate, defines the “cut point” of the cyclone; that is, the size of particle that will be removed from the stream with 50% efficiency. Generally, particles having a size larger than the cut point will be removed with a greater efficiency, and smaller particles with a lower efficiency.

[0080] In an alternative aspect, the solid phase components may be sufficiently segregated from the gaseous components upon flashing (e.g., vaporization) of the stream and without the need to subject the solid phase components and the gaseous components to any further segregating process. For example, the solid materials that had been entrained within the stream may “fall out” when the liquid components of the stream undergo a phase change to vapor.

[0081] In the aspect of FIG. 1A, separating the heated effluent stream **111** comprises routing the heated effluent stream **121** into the flash chamber **130**. Flash chamber **130** may comprise a single vessel or multiple vessels, as suitable, and may comprise additional flash compartments or chambers, cyclonic separators, flush/surge chambers, various valves, inlets, outlets, filters (such as bag filters), or other suitable equipment. Not seeking to be bound by theory, as the heated effluent stream **121** is introduced into the flash chamber **130**, the volume of the stream entering the flash chamber **130** may expand rapidly, resulting in a decrease in the pressure of the stream and the vaporization of the liquid components of the heated effluent stream **121**. As such, in aspects, introduction of the heated effluent stream **121** into the flash chamber **130** (e.g., flashing the heated effluent stream **121**) may yield solid components (e.g., polymer product or polymer fluff) and gaseous or vaporous components (e.g., flash gases). Also in the aspect of FIG. 1D, the polymer product **135** may be segregated from the flash gases **140** by cyclonic separation as described above.

[0082] In the aspect of FIG. 1A, the solid components of the heated effluent stream **121** can exit the flash chamber **130** as a polymer product stream **135** and the gaseous or vaporous components as flash gas stream **140**. In aspects, the polymer product stream **135** may comprise polymer fluff comprising oligomers and/or larger polymers, as produced in the polymerization reaction or reactions described previously (e.g., polyethylene). In aspects, the flash gas stream **140** may comprise the non-solid components of the effluent stream **111** in the vapor phase (e.g., hydrogen, nitrogen, methane, ethylene, ethane, propylene, propane, butane, isobutane, pentane, hexane, hexene-1 and heavier hydrocarbons).

[0083] In aspects, the flash gas stream **140** can exit the flash chamber **130** at a suitable pressure. For example, the pressure of flash gas stream **140** as it exits flash chamber **130** may be within a pressure range of from about 14.7 psia to about 527.9 psia, alternatively, from about 15.7 psia to about 348 psia, alternatively, from about 85 psia to about 290 psia.

[0084] In aspects, separating the heated effluent stream **121** (alternatively, in aspects where the effluent stream has not been heated, the effluent stream **111**) into a polymer product stream **135** and a gaseous stream (e.g. flash gas stream **140**) may be by filtration, membrane separation, various

forms of centrifugal separation, or other suitable device, apparatus, or process of separation as will be appreciated by one of ordinary skill in the art with the aid of this disclosure.

[0085] The method can further comprise returning at least a portion **146'** of the first column side stream **146** (e.g., comprising hexene) to at least one of the one or more polymerization reactors **110**. The first column **145**, the second column **170**, or both can comprise a fractionation/distillation column.

[0086] In aspects, as noted above, the first column **145** comprises a dehexanizer column configured to separate hexane and heavier components from the flash gas stream **140** to provide the first column overhead stream **148**. The first column **145** can be operated to produce the first column overhead stream **148** comprising less than or equal to about 5 ppmw C6+. In aspects, the first column **145** can be operated to produce first column overhead stream **148** comprising greater than or equal to about 90 vol % isobutane, from about 0 to about 3 vol % hydrogen, from about 0 to about 15 vol % ethylene, or a combination thereof. For example, in aspects, first column overhead stream **148** comprises from about 3 to about 4 ppm vol. C6+, from about 85 to about 90 vol. % isobutane, from about 0.04 to about 1.5 vol % hydrogen, from about 5 to about 10 vol % ethylene, or a combination thereof.

[0087] In aspects, first column **145** can be operated to produce the first column side stream **146** comprising from about 0 to about 5 vol % hexene. For example, in aspects, first column side stream **146** comprises from about 94 to about 96 wt % 1-hexene, from about 2.5 to about 4.5 wt % n-hexane, and less than about 1 wt % isobutane.

[0088] In aspects, the first column **145** can be operated to produce first column bottoms stream **147** comprising primarily C6+ (e.g., hexane, oils, oligomers, or a combination thereof). One or more additional components (e.g., hexene, such as recycled from first column side stream **146**, and/or isobutane (e.g., recycled from second column side stream **171**)) can be introduced into first column **145** via one or more inlets **141**.

[0089] A portion **147B** of first column bottoms stream **147** can be returned to first column **145** via first column reboiler R1. A portion (e.g., liquid reflux stream **163**) of liquid **162** can be returned as reflux to first column **145** via pump P1.

[0090] The method can thus include separating the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**. In aspects, separating the flash gas stream **140** may generally comprise segregating parts of the flash gas stream **140** on the basis of various differences in physical or chemical properties between those parts. In aspects, separating the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147** can generally comprise separating the flash gas stream **140** into a first column overhead stream **148** comprising C.sub.4 and lighter hydrocarbons and any other gases (e.g., hydrogen or nitrogen), a first column bottom stream **147** comprising C.sub.6 and heavier compounds such as alkanes, and a first column side stream **146** comprising hexene.

[0091] In aspects, separating the flash gas stream **140** into first column overhead stream **148**, first column side stream **146**, and a first column bottom stream **147** can occur by any suitable device, apparatus, or process. Nonlimiting examples of such a suitable process include fractionation, distillation, and the like. Not intending to be bound by theory, fractionation refers to a separation process in which a mixture is separated into a number of parts based on differences in a given property of those parts. In aspects, it may be possible to separate components of a mixture in a single run via fractionation. Not intending to be bound by theory, distillation refers to a separation process in which a mixture is separated based on differences in the volatilities of the components of the mixture. Generally speaking, distillation involves adding heat to a mixture, allowing the various components of the mixture to volatilize into the vapor phase, and then collecting the individual components as they condense at different points within the distillation column.

[0092] In the aspect of FIG. 1A, separating the flash gas stream **140** into first column overhead

stream **148**, first column side stream **146**, and first column bottom stream **147** comprises routing the flash gas stream **140** to the first column **145**. In aspects, the first column **145** can comprise a fractionation tower (or fractionation column). In an alternative aspect, the first column **145** can comprise a distillation column (or distillation tower). In aspects, first column **145**, can be provided with one or more inlets and at least three outlets. The first column **145** can be operated at suitable temperature and pressure, for example as may be suitable to achieve separation of the components of the flash gas stream **140**. For example, the first column **145** can be operated at a temperature in a range of from about 15° C. to about 233° C., alternatively, from about 20° C. to about 200° C., alternatively, from about 20° C. to about 180° C., and/or a pressure in a range of from about 14.7 psi to about 527.9 psi, alternatively, from about 15.7 psi to about 348 psi, alternatively, from about 85 psi to about 290 psi. The first column **145** may be configured and/or sized provide for separation of a suitable volume of gases (e.g., the flash gas stream **140**). As will be appreciated by one of skill in the art viewing this disclosure, the flash gas stream **140** may remain and/or reside within first column **145** for any suitable amount of time, for example an amount of time as may be necessary to provide sufficient separation of the components of flash gas stream **140**.

[0093] In aspects, the flash gas stream **140** can be introduced into the first column **145** without a compressive step, that is, without compression of the flash gas stream after it is emitted from the flash apparatus **100**/flash chamber **130** and before it is introduced into the first column **145**. In another aspect, the flash gas stream **140** may be introduced into the first column **145** at substantially the same pressure as the outlet pressure of flash chamber **130** (e.g., a pressure of from about 14.7 psia to about 527.9 psia, alternatively, from about 15.7 psia to about 348 psia, alternatively, from about 85 psia to about 290 psia at the outlet of the flash chamber **130**). In another aspect, the flash gas stream **140** may be introduced into the first column **145** without a significant compressive step. In aspects, flash gas stream **140** may be introduced into first column at a pressure in a range of from about 25 psi less than the pressure at which the flash gas stream was emitted from the flash chamber to about 25 psi greater than the pressure at which the flash gas stream was emitted from the flash chamber, alternatively, from about 15 psi less than the pressure at which the flash gas stream was emitted from the flash chamber to about 15 psi greater than the pressure at which the flash gas stream was emitted from the flash chamber, alternatively, from about 5 psi less than the pressure at which the flash gas stream was emitted from the flash chamber to about 5 psi greater than the pressure at which the flash gas stream was emitted from the flash chamber. In aspects, the flash gas stream **140** may be introduced into the first column **145** at a pressure in a range of from about 14.7 psia to about 527.8 psia, alternatively, from about 15.7 psia to about 348 psia, from about 85 psia to about 290 psia.

[0094] In aspects, the first column **145** can be configured and/or operated such that each of the first column overhead stream **148**, the first column bottom stream **147**, and the first column side stream **146** can comprise a desired portion, part, or subset of components of the flash gas stream **140**. For example, as will be appreciated by one of skill in the art with the aid of this disclosure, the location of a particular stream outlet, the operating parameters of the first column **145**, the composition of the flash gas stream **140**, or combinations thereof may be manipulated such that a given stream may comprise a particular one or more components of the flash gas stream **140**.

[0095] In aspects, first column overhead stream **148** can be characterized as comprising C.sub.4 and lighter hydrocarbons (e.g., butane, isobutane, propane, ethane, or methane) and any light gases e.g., hydrogen or nitrogen). For example, C.sub.4 and lighter hydrocarbons and gases may be present in the first column overhead stream **148** in an amount of from about 80% to about 100% by total weight of the first column overhead stream **148**, alternatively from about 90% to about 99.999999%, alternatively from about 99% to about 99.9999%, alternatively, C.sub.5 and heavier hydrocarbons may be present in the first column overhead stream **148** in an amount from 0% to about 20% by total weight of the first column overhead stream **148**, alternatively from about 10% to about 0.000001%, alternatively from about 1.0% to about 0.0001%. Also, for example, at least

90% by weight of the flash gas stream **140** of the C.sub.4 and lighter hydrocarbons and gases may be present in the first column overhead stream **148**, alternatively, at least 98%, alternatively, at least 99%.

[0096] In aspects, the first column bottom stream **147** can be characterized as comprising C.sub.6 and heavier components such as alkanes, that is, alkanes larger than hexane (e.g., heptane and/or other large alkanes). In aspects, hydrocarbons other than C.sub.6 and heavier alkanes may be present in the first column bottom stream **147** in an amount less than about 15%, alternatively, less than about 10%, alternatively, less than about 5% by total weight of the first bottom stream **147**. In aspects, the first column bottom stream **147** can be directed to additional processing steps or methods, or alternatively they may be disposed of, as appropriate. In aspects, first column bottom stream **147** can be directed to a flare for disposal.

[0097] In aspects, first column side stream **146** can be characterized as comprising hexene. For example, hexene may be present in first column side stream **146** in an amount of from about 20% to about 98% by total weight of the first column side stream **146**, alternatively from about 40% hexene to about 95%, alternatively from about 50% hexene to about 95% hexene.

[0098] In aspects, at least a portion of the first column bottom stream **147** can be returned to the first column **145**. For example, in the example of FIG. 1A, a portion of the first column bottom stream **147** is routed, via a first column reboiler R1, to the first column **145** for additional processing.

[0099] In aspects, at least a portion **146'** of the first column side stream **146** can be recycled. In the aspect of FIG. 1A, recycling the first column side stream **146** can comprise routing, for example, via a suitable pump or compressor, the first column side stream **146** back to and/or introducing the side stream **146** into the PPS I, for example, for reuse in a polymerization reaction. Recycling the first column side stream **146** (e.g., comprising hexene) may provide an efficient and/or cost-effective means of supplying hexene for operation of the polymerization reaction process. In aspects, the hexene of side stream **146** can be employed in the polymerization reaction as, for example, a comonomer in the reaction. In alternative or additional aspects, first column side stream **146** can be routed to storage for subsequent use in a polymerization reaction or employed in any other suitable process.

[0100] In aspects, the method comprises separating the flash gas stream **140** in first column **145** to provide a first column overhead stream **148** generally comprising C.sub.4 and smaller/lighter hydrocarbons, a first column bottom stream **147** generally comprising C.sub.6 and larger/heavier hydrocarbons, and a first column side stream **146** generally comprising hexene. The method can further comprise separating the first column overhead stream **148** in a gas/liquid separator (e.g., an accumulator) **160** to yield a gas stream **161** generally comprising light gases (e.g., hydrogen, nitrogen), isobutane, ethylene, ethane, and/or other light hydrocarbons, and a liquid stream **162** generally comprising isobutane, ethylene, ethane, and/or other hydrocarbons. The method can further include separating the gas stream **161** in second column **170** to yield a second column overhead stream **173** comprising substantially ethylene, a second column side stream generally comprising isobutane and ethylene and a low level of hydrogen and a second column bottoms stream **172** generally comprising olefin-free isobutane.

[0101] In aspects, the first column overhead stream **148** can thus be separated into a gas stream **161** and a liquid stream **162**. Separating the first column overhead stream **148** into the gas stream **161** and the liquid stream **162** can generally comprise separating the first column overhead stream **148** into a gas stream **161** comprising butane and lighter hydrocarbons and any other gases (e.g., hydrogen or nitrogen) and a liquid stream **162** comprising isobutane.

[0102] In aspects, the first column overhead stream **148** can be separated by any suitable device apparatus, or process. Nonlimiting examples of suitable means of separation include accumulation, settling, condensation, membrane separation, flashing, distillation, fractionation, or the like. Not intending to be bound by theory, accumulation refers to a separation process in which components

of a mixture are separated on the basis of weight and/or density. For example, the mixture may be introduced into a vessel (an accumulating vessel or accumulator) in which the lighter (less dense) components are allowed to rise toward the top of the vessel while the heavier (more dense) are allowed to fall toward the bottom of the vessel. In aspects, the first column overhead stream **148** can comprise gaseous or vaporous components, liquid components (e.g., such components having cooled and/or condensed, for example, via flow through a condenser **150**) or combinations thereof. In such aspects, the liquid components may be separated from the gaseous components in an accumulator.

[0103] As noted above, the method can comprise separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**. Separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162** can be effected by condensing the first column overhead stream **148** in a condenser **150** to produce a cooled first column overhead stream **148'**, introducing the cooled first column overhead stream **148'** into an accumulator **160**, and extracting a gas stream **161** and a liquid **162** from the accumulator **160**.

[0104] With reference to the aspect of FIG. 1A, separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162** can comprise routing the first column overhead stream **148** into accumulator **160**. As illustrated in the aspect of FIG. 1A, the first column overhead stream **148** can be routed to the accumulator **160** via a condenser **150**, for example to remove heat from the stream and/or allow at least a portion of the stream to condense into a liquid phase. In aspects, the accumulator **160** can generally comprise any suitable vessel as will allow for the separation of the components of the first column overhead stream **148** (e.g., as disclosed above). The accumulator **160** can comprise one or more compartments or chambers, valves, at least one inlet, and two or more outlets. In aspects, the accumulator **160** can permit the lighter components of first column overhead stream **148** to rise to the top of accumulator **160** and the heavier components to fall to the bottom of the accumulator **160**. For example, in aspects where the first column overhead stream **148** comprises both liquid and gaseous phases, the vapor phase components may rise toward the top and the liquid phase components may fall to the bottom of the accumulator **160**. In aspects, the lighter components (e.g., the vapor phase components) may be emitted from the accumulator as the gas stream **161** and the heavier components (e.g., the liquid phase components) may be emitted as the liquid stream **162**. The accumulator **160** may be operated at a suitable temperature and pressure, for example, as may be suitable to cause condensation of at least one component of the first column overhead stream **148**. For example, the accumulator **160** may be operated at a temperature in a range of from about 10° C. to about 100° C., alternatively, from about 15° C. to about 60° C., alternatively, from about 20° C. to about 50° C., and a pressure in a range of from about 14.7 psia to about 527.9 psia, alternatively, from about 15.7 psia to about 348 psia, alternatively, from about 85 psia to about 290 psia.

[0105] In aspects, the accumulator **160** can be configured and/or operated such that each of the gas stream **161** and the liquid stream **162** comprise a desired portion, part, or subset of components of the first column overhead stream **148**. For example, as will be appreciated by one of skill in the art with the aid of this disclosure, the operating parameters of the accumulator **160**, the composition of the first column overhead stream **148**, or combinations thereof may be manipulated such that a given stream may comprise a particular one or more components of the first column overhead stream **148**.

[0106] In aspects, gas stream **161** can be characterized as comprising butane, lighter hydrocarbons, and non-condensable gases (e.g., butane, isobutane, propane, ethane, methane, oxygen, helium hydrogen, nitrogen, or carbon dioxide). For example, butane and lighter hydrocarbons may be present in the gas stream **161** in an amount from about 90% to about 100 by total weight of the gas stream **161**, alternatively, from about 95% to about 99.9999%, alternatively, from about 98% to about 99%. Also, for example, species heavier than butane may be present in the gas stream **161** in an amount less than about 1%, alternatively, less than about 0.01%, alternatively, less than about

0.0001%. The flow rate of gas stream **161** may be such that sufficient propane, lighter hydrocarbons, and non-condensable gases (e.g., propylene, ethane, methane, oxygen, helium hydrogen, nitrogen, or carbon dioxide) are removed overhead in vent column overhead gas stream **186** to prevent build up in the system.

[0107] In aspects the liquid stream **162** can be characterized as comprising isobutane. For example, isobutane may be present in the liquid stream **162** in an amount from about 70% to about 100% by total weight of the liquid stream **162**, alternatively, from about 75% to about 99%, alternatively, from about 80% to about 98%. Also, for example, ethylene may be present in the liquid stream **162** in an amount from about 0% to about 10 or 20% by total weight of the liquid stream **162**, alternatively, from about 0.5 or 1% to about 10 or 15%, alternatively, from about 2% to about 10 or from about 3 to about 6%.

[0108] In aspects, for example, as illustrated in FIG. **1A**, at least a portion **163** of liquid stream **162** may be introduced into first column **145** as a reflux stream. In the aspect of FIG. **1A**, the reflux stream may be taken from the accumulator **160** and routed back to the first column **145**, via a suitable pump P1 or compressor.

[0109] The method can further comprise introducing a feed comprising gas stream **161** and portion **164** of liquid **162** into second column **170**. As noted above, second column **170** can comprise a fractionation/distillation column. Second column **170** can comprise a deethanizer column configured to separate ethane and lighter components from the feed **165** to produce the second column bottoms stream **172**. As noted hereinabove, second column **170** can be operated to provide a second column bottoms stream **172** as described hereinabove, for example comprising less than or equal to about 5 ppmw C₂-. Second column **170** can be operated to provide a second column side stream **171** as described hereinabove, for example comprising from about 70 to about 99 vol % isobutane, from about 0 to about 10 vol % ethylene, and less than about 0.1 vol % hydrogen. Second column **170** can be operated to provide a second column overhead stream **173** as described hereinabove that minimizes loss of isobutane and ethylene.

[0110] The method can comprise recycling at least a portion **171'** of the second column side stream **171**. Recycling the at least the portion **171'** of the second column side stream **171** can comprise introducing the at least the portion **171'** of the second column side stream **171** to at least one of the one or more polymerization reactors **110** as a recycle diluent (e.g., isobutane) stream **171'**. The recycle isobutane stream **171'** can thus comprise greater than or equal to about 85, 90, or 95 weight percent (wt %) or from about 80, 85, or 90 to about 90, 95, or 99 vol % isobutane, greater than or equal to about 1, 5, or 10, or from about 0, 1, or 2 to about 3, 4, or 5 wt % olefins (e.g., ethylene), less than or equal to about 1, 0.1, or 0.01 ppmw or less than or equal to about 0.1 vol % hydrogen, or a combination thereof. The olefins can comprise ethylene, hexene, or a combination thereof.

[0111] The method can further comprise recycling at least a portion **172'** of the substantially olefins-free isobutane stream **172** as a recycle olefins-free isobutane stream **172'** to a catalyst pretreater **106'** upstream of the one or more polymerization reactors **110**, and using the catalyst pretreater **106'** to form a catalyst slurry **106** comprising a polymerization catalyst **107** and the recycle olefins-free isobutane stream **172'**. The second column bottoms stream **172** can be a substantially olefin-free isobutane stream **172** comprising greater than or equal to about 85, 90, or 95 weight percent (wt %), isobutane, less than or equal to about 50, 10, 5, or 1 ppmw olefins (e.g., ethylene), less than or equal to about 1, 0.1, or 0.01 ppmw, hydrogen, or a combination thereof.

[0112] Thus, in aspects, the method of this disclosure comprises separating feed **165** into a second column overhead stream **173**, a second column side stream **171**, and a second column bottom stream **172**. In aspects, separating the feed **165** can generally comprise segregating parts of the feed **165** on the basis of various differences in physical or chemical properties between those parts. In aspects, separating the feed **165** into second column overhead stream **173**, second column side stream **171**, and second column bottoms stream **172** can generally comprise separating the feed **165** into a second column overhead stream **173** comprising ethylene, a second column side stream **171**

comprising isobutane and ethylene and a low amount of hydrogen, and a second column bottom stream **172** comprising isobutane substantially free of olefins.

[0113] In aspects, separating the feed **165** into a second column overhead stream **173**, a second column side stream **171**, and a second column bottom stream **172** can be by any suitable device, apparatus, or process. Nonlimiting examples of such a suitable process include fractionation and distillation, and the like, as described herein.

[0114] In the aspect of FIG. **1A**, separating the feed **165** into a second column overhead stream **173**, a second column side stream **171**, and a second column bottom stream **172** can comprise routing the feed stream **165** to the second column **170**, which may be referred to as a lights column. The second column **170** can be similar in form and/or function to first column **145**, or may be different, as appropriate for a product or process need or desire. For example, in aspects, the second column **170** may comprise a fractionation tower (or fractionation column). In alternative aspects, the second column **170** may comprise a distillation column (or distillation tower).

[0115] The second column **170** can be configured and/or sized provide for separation of a suitable volume of feed (e.g., the feed stream **165**). For example, the second column **170** can be operated at a temperature in a range of from about 90° C. to about 15° C., alternatively, from about 80° C. to about 25° C., alternatively, from about 70 to about 35° C., and a pressure within about 10% of the pressure of first column **145**, e.g., in a range of from about 14.7 psia to about 529.7 psia, alternatively, from about 15.7 psia to about 348 psia, alternatively, from about 85 psia to about 290 psia. The second column **170** can be configured and/or sized provide for separation of a suitable volume of feed **165**. As will be appreciated by one of skill in the art viewing this disclosure, the feed **165** can remain and/or reside within second column **170** for any suitable amount of time as may be necessary to provide sufficient separation of the components of feed stream **165**. In aspects, second column **170** can be provided with at least three outlets.

[0116] In aspects, the second column **170** can be configured and/or operated such that each of the second column overhead stream **173**, the second column side stream **171**, and the second column bottom stream **172** can comprise a desired portion, part, or subset of components of the feed **165**. For example, as will be appreciated by one of skill in the art with the aid of this disclosure, the location of a particular stream outlet, the operating parameters of the second column **170**, the composition of the feed **165**, or combinations thereof may be manipulated such that a given stream may comprise a particular one or more components of the feed **165**.

[0117] In aspects, second column overhead stream **173** can be characterized as comprising ethane and lighter gases (e.g., ethylene, ethane, methane, carbon dioxide, nitrogen, or hydrogen). For example, ethylene may be present in the second column overhead stream **173** in an amount from about 5% to about 65% by total weight of the second column overhead stream **173**, alternatively from about 10% to about 55%, alternatively, from about 15% to about 45%. In aspects, the second column overhead stream **173** can be routed to further processing (e.g. catalytic cracking), routed to an ethylene plant, routed to storage, recycled (e.g., returned into the PPS I/I'), disposed of (e.g., flared), or employed in any otherwise suitable application or process.

[0118] As noted above, second column side stream **171** can be recycled. With reference to the aspect of FIGS. **1A** and **1D**, recycling the second column side stream **171** can comprise routing, for example, via a suitable pump or compressor, the second column side stream **171** back to and/or introducing the second column side stream **171** into the PPS I/I', for example, for reuse in a polymerization reaction of polymerization system **110**. For example, in aspects, the second column side stream **171** can be introduced into the polymerization reactor(s) **110**. Not intending to be bound by theory, because the second column side stream **171** can comprise ethylene, isobutane, and a low level of hydrogen, the second column side stream **171** can be introduced into polymerization reactor(s)/system **110** (e.g., a first polymerization reactor **110A**, a second polymerization reactor **110B**, or both). As such, the second column side stream **171** can serve as a source of isobutane and ethylene for a polymerization reaction. Recycling the second column side stream **171** can provide

an efficient and/or cost-effective means of supplying isobutane for operation of the polymerization reaction process. Alternatively or additionally, second column side stream **171** can be routed to storage for subsequent use in a polymerization reaction or employed in any other suitable process. [0119] In aspects, second column bottom stream **172** comprises C.sub.4. In aspects, the second column bottom stream **172** can be free of olefins, alternatively, substantially free of olefins. For example, olefins can be present in the second column bottom stream **172** in an amount less than about 1.0% by total weight of the second column bottom stream **172**, alternatively, less than about 0.5%, alternatively, less than about 0.1%.

[0120] As noted above, second column bottom stream **172** can be recycled. With reference to the aspect of FIGS. **1A** and **1D**, recycling the second column bottom stream **172** can comprise routing, for example, via a suitable pump or compressor, the second column bottom stream **172** back to and/or introducing the second column bottom stream **172** into the PPS I/I', for example, for reuse in a polymerization reaction of polymerization system **110**. For example, in aspects, the second column bottom stream **172** can be combined with various other components (catalysts, cocatalysts, etc.) to form a catalyst slurry **106** that can be introduced into the polymerization reactor(s) **110**. Not intending to be bound by theory, because the second column bottom stream **172** can comprise an olefin-free isobutane stream (alternatively, a substantially olefin-free, as disclosed above), the second column bottom stream **172** can be mixed with catalytic components (e.g., catalysts, cocatalysts, etc.) without the risk of unintended polymerization reactions (e.g., polymerization prior to introduction into the reactor). As such, the second column bottom stream **172** can serve as a source of olefin-free isobutane for a polymerization reaction. Recycling the second column bottom stream **172** (comprising olefin-free isobutane) can provide an efficient and/or cost-effective means of supplying isobutane for operation of the polymerization reaction process. Alternatively or additionally, second column bottom stream **172** can be routed to storage for subsequent use in a polymerization reaction or employed in any other suitable process.

[0121] In aspects, at least a portion of the second column bottom stream **172** can be returned to the second column **170**. For example, in the example of FIG. **1A**, a portion **172B** of the second column bottom stream **172** is routed, via a second column reboiler R2, to the second column **170** for additional processing in second column **170**, while portion **172A** can be sent, for example, to an OFIC4 tank **190**.

[0122] As discussed hereinabove with regard to the system, the method can further comprise operating the second column **170** at a second column pressure, and operating the first column **145** at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure. The second column **170** pressure can be from about 120 psig to about 160 psig, for example, about 120, 130, 140, 150, or 160 psig.

[0123] In aspects of the method, a reboiler duty of a reboiler R2 associated with the second column **170** is less than a reboiler duty of a reboiler associated with a second column in a same method except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure. In aspects, operation of the second column **170** at a pressure within about 10% of the pressure of the first column **145** enables the use of a diameter of the second column **170** to be less than a diameter of a second column utilized to provide a same separation in the same method (e.g., the same method except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure).

[0124] In aspects, the method does not include compressing of the first column overhead stream **148**, the gas stream **161**, or the at least the portion **164** of the liquid stream **162** prior to introducing the gas stream **161** and the at least the portion **164** of the liquid stream **162** as feed **165** to the second column **170**.

[0125] In aspects, the method of a disclosure does not include preheating of the feed **165** or components thereof (e.g., the gas stream **161**, the liquid stream **162**, the portion **164** of the liquid stream **162**) between the second column **170** and the first column **145**.

[0126] In aspects, the method includes extracting the second column side stream **171** at a liquid side draw stage SDS of the second column **170** that is separated from a feed stage FS of the second column **170** by more than 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 theoretical or actual stages (trays), or by from about 3 to about 20, from about 5 to about 18, or from about 10 to about 15 theoretical or actual stages (trays). As noted hereinabove, the liquid side draw stage SDS is a stage from which or tray from immediately above which the second column **170** side stream **171** is withdrawn, and the feed stage FS is a stage to which or a tray immediately above which the second column **170** feed **165** is introduced to the second column **170**.

[0127] In aspects, the method include operating the FGTS such that the second column side stream **171** as described hereinabove, for example comprising less than or equal to about 0.1 ppmw hydrogen, less than or equal to about 10 vol % ethylene, greater than or equal to about 90 vol % isobutane, or a combination thereof.

[0128] The method can comprise introducing the feed **165** to the second column **170** at subcooled or bubble point or super-heated conditions.

[0129] The method can further comprise maximizing an amount of ethylene in the second column side stream **171**, while maintaining a concentration of hydrogen in the second column side stream **171** below a tolerance of the one or more polymerization reactor(s)/system **110** (e.g., at less than about 0.1, 0.5 or 1% ppmw H.sub.2), and recycling at least a portion **171'** of the second column side stream **171** to at least one of the one or more polymerization reactor(s)/system **110**.

[0130] As noted above with reference to FIG. **1C**, the one or more polymerization reactor(s)/system **110** can comprise an advanced dual loop reactor comprising a first polymerization reactor **110A** upstream of a second polymerization reactor **110B**. The first polymerization reactor **110A** can be configured to produce a higher molecular weight polymer of a bimodal polymer, and the second polymerization reactor **110B** can be configured to produce a lower molecular weight polymer of the bimodal polymer, wherein the higher molecular weight polymer has a higher average molecular weight than the lower molecular weight polymer. The method can include recycling at least a portion of the second column side stream **171** to the first polymerization reactor **110A**, the second polymerization reactor **110B**, or both. The one or more polymerization reactor(s)/system **110** (e.g., first polymerization reactor **110A**, second polymerization reactor **110B**) contain a polymerization catalyst **107**, for example, such as described herein.

[0131] The method can further comprise condensing the second column overhead stream **173**, and separating the condensed second column overhead stream **173** into a vent column overhead gas **186** and a vent column bottom liquid **187**, returning at least a portion of the vent column bottom liquid **187** to the second column **170**, and venting at least a portion of the vent column overhead gas **186**.

[0132] The method can comprise operating the second column **170** at a second column pressure, and operating the first column **145** at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure, wherein an amount of ethylene in the vent column overhead gas **186** is less than or equal to an amount of ethylene vented in a same method except wherein the second column **170** pressure is not within about 10% of the first column **145** pressure.

[0133] In aspects, a method (e.g., of treating a polymerization reactor effluent stream **111**) comprises: recovering a polymerization reactor effluent stream **111** from one or more polymerization reactor(s)/system **110**; flashing the polymerization reactor effluent stream **111** (e.g., in flash system **100**) to form a flash gas stream **140**; separating, in a first column **145**, the flash gas stream **140** into a first column overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**; separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**; introducing a feed **165** comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** to a second column **170** to produce a second column overhead stream **173**, a second column side stream **171**, and a second column bottoms stream **172**; and operating the second column **170** at a second column pressure, and operating the first column **145** at a first column pressure, wherein the second column **170** pressure is within about 10% of the first

column **145** pressure.

[0134] In aspects, a method of this disclosure comprises: recovering a polymerization reactor effluent stream **111** from one or more polymerization reactor(s)/system **110**; flashing (e.g., in a flash system **100**) the polymerization reactor effluent stream **111** to form a flash gas stream **140**; separating, in a first column **145**, the flash gas stream **140** into a first column **145** overhead stream **148**, a first column side stream **146**, and a first column bottoms stream **147**; separating the first column overhead stream **148** into a gas stream **161** and a liquid stream **162**; introducing a feed **165** comprising the gas stream **161** and at least a portion **164** of the liquid stream **162** to a second column **170** to produce a second column overhead stream **173**, a second column side stream **171**, and a second column bottoms stream **172**; and maximizing an amount of ethylene in the second column side stream **171**, while maintaining a concentration of hydrogen in the second column side stream **171** below a tolerance of the one or more polymerization reactor(s)/system **110** (e.g., at less than about 0.1, 0.5, or 1% ppmw H₂), and recycling at least a portion **171'** of the second column side stream **171** to at least one of the one or more polymerization reactor(s)/system **110**.

[0135] In aspects, the systems and methods disclosed herein can have various advantages over prior art systems and/or processes. For example, by reducing the second column (e.g., deethanizer) operating pressure, increasing RIC4/OFIC4 ratio and using a colder and higher capacity refrigeration system **184**, the herein disclosed system and method can provide significant advantages over conventional designs by reducing capital expenses (CAPEX) and operating expenses (OPEX) and improving plant operability. This savings can be attained, in aspects described herein, by eliminating the dehexanizer overhead compressor and associated pump and drum, feed economizer, and feed preheater, deethanizer condenser and accumulator/reflux pumps. Further savings can be realized by significantly reducing the sizes of the OFIC4 tank, treaters, high head OFIC4 reactor feed pump, deethanizer diameter and reboiler size. The savings is partially offset by a larger refrigeration package, larger RIC4 tank, pump and treaters, and a larger vent column system. During normal operation, improved deethanizer energy efficiency, and reduced ethylene loss in vent can, in aspects, lead to a significant net OPEX savings. In aspects, isobutane venting is increased due to lower second column operating pressures. The reduction of equipment count provided by the herein disclosed system can improve equipment reliability, process operability, and provide an efficient process design. A particularly notable benefit is eliminating the dehexanizer overhead compressor, which can provide a significant improvement on operability and debottlenecking due to numerous issues on commissioning and startup, performance, and reliability of said compressor.

[0136] Relative to the heavies/lights column setup used in direct recycle designs and conventional fractionation designs, differences between those two designs and the system and method described herein can include: (1) relative to the heavies/lights column for direct recycle plants, which can be operated at similar pressures, the proposed system and method can utilize larger columns that handle the entire reactor diluent stream, rather than just a portion thereof. Additionally, the deethanizer lights column can have an expanded section dedicated to the removal of hydrogen; and (2) relative to conventional dehexanizer/deethanizer columns, the herein disclosed system and method operate both columns at lower pressures (e.g., 120 to 140 psi, rather than 220 psig).

[0137] The absence of a compressive step between the first column **145** and the second column **170** can improve polymerization effluent stream processing systems and methods by reducing costs associated with equipment and processing, decreasing process complexity, or combinations thereof.

[0138] In addition to the elimination of various equipment facilitated by the system and method of this disclosure, the following equipment can also be modified by the herein disclosed PPS I/FGTS III: an OFIC4 tank **190** volume can be reduced (e.g., by about 2, 3, or 3.5 times), an OFIC4 pump size and head can be reduced allowing for use of a low head centrifugal pump, an OFIC4 treater size can be reduced, the deethanizer/second column **170** diameter and its reboiler R2 size can be reduced, an RIC4 tank **197** volume can be increased (e.g., by 1.5, 2, or 2.5 times), an RIC4 high-

head pump size can be increased (e.g., by 1.5, 2, or 2.5 times), a refrigeration system **184** size can be increased (e.g., by 1.5, 2, or 2.5 times), or a combination thereof. The disclosed FGTS design can offer substantial savings on installed equipment cost comparing to conventional designs.

[0139] Furthermore, as noted herein, besides the CAPEX advantage, eliminating equipment particularly a dehexanizer overhead compressor, can provide significant improvement in operability and debottlenecking due to the challenge of operating such an overhead compressor.

[0140] In aspects, recycling the first column side stream **146** (e.g., hexene) back into the process can offset costs associated with hexene procurement, allow for optimized control of the hexene concentration at various points in the PPS (e.g., in the polymerization reaction), minimize the need to use fresh hexene, which may reduce one or more of raw material purchasing, transportation, and storage costs, avoid costs associated with hexene losses (e.g., regulatory fees), yield fewer waste products, or combinations thereof. In addition, recycling hexene (e.g., as the first column side stream **146**), which may serve as a co-monomer in the polymerization process, may allow the quality and/or quantity of hexene routed to other points in the PPS (e.g., a polymerization reactor) to be independently controlled. Such independent control of hexene may lead to improved process control, the ability to optimize the process, and/or improved process efficiency, thereby reducing process costs and helping to minimize system complexity and/or downtime.

[0141] In aspects, the systems and methods disclosed herein can also allow for the separation of isobutane from heavy hydrocarbons present in the polymerization effluent stream (e.g., butane, pentane, hexane, hexene, heptane, etc.). Isolating isobutane from such heavier hydrocarbons can allow the isobutane routed to other points in the PPS (e.g., the catalyst pretreater **106'**, the polymerization system **110**) to be independently controlled. Such independent control of the isobutane can lead to improved process control and/or process efficiency, thereby reducing process costs and helping to minimize system complexity and/or downtime.

[0142] In aspects, the systems and methods disclosed herein may allow for less energy consumption than other polymerization effluent stream treatment methods. For example, optimized process flows as disclosed herein may necessitate less energy for the process and/or may reduce the number of components, thereby leading to additional reductions in energy consumption.

[0143] In aspects, the systems and methods disclosed herein can provide a source of hexene-free isobutane (e.g., in second column bottom stream **172**), which can facilitate responding to process fouling from the inadvertent introduction of, for example, hexene into the isobutane stream. In such aspects, the introduction of hexene-free isobutane can be employed to reverse the effects of hexene fouling of the isobutane stream through flushing or other remediation methods. Such usage of the hexene-free isobutane stream may, in turn, provide reduced downtime and thereby improve system uptime.

[0144] In aspects, overall system robustness can be another unexpected benefit of the systems and/or processes disclosed herein, and can be accompanied by the related capital and/or operating overhead reductions associated therewith. For example, such overall system robustness can be the result of a simplified process flow and/or the reduction in the number and complexity of components of such systems.

[0145] In aspects, a flash gas treatment system III of this disclosure can be utilized in a retrofit/debottleneck fractionation train in existing an existing polymer production system.

[0146] While the present disclosure has been illustrated and described in terms of particular apparatus and methods of use, it is apparent that equivalent techniques, components and constituents may be substituted for those shown, and other changes can be made within the scope of the present disclosure as defined by the appended claims.

EXAMPLES

[0147] The disclosure having been generally described, the following examples are given as particular aspect of the disclosure and to demonstrate the practice and advantages thereof. It is understood that the examples are given by way of illustration and is not intended to limit the

specification or the claims in any manner.

Example 1

[0148] To demonstrate the operation of the systems and/or processes disclosed herein, a computerized commercial process simulator was employed to generate an output from a model in accordance with the systems and/or processes disclosed herein.

[0149] A Comparative System employed a second column (deethanizer column) operated at an elevated pressure relative to the first column (dehexanizer column). The higher pressures in the deethanizer column enabled its downstream vent column to operate at a relatively high pressure, which can decrease the concentration of isobutane in the overhead vent at the temperatures provided by the commonly available propane/propylene refrigerant, reducing isobutane losses.

[0150] The Comparative System design also included a liquid feed pre-heater to heat the liquid product of the upstream dehexanizer column up to its new bubble point following its increase in pressure from about 135 psig (bubble point of about 100° F.) to about 320 psig (bubble point of about 200° F.). The Comparative PPS also employed an economizing exchanger to exchange waste heat from the deethanizer column bottoms with the liquid feed, reducing the amount of external heating supplied by the liquid feed pre-heater.

[0151] The deethanizer column of the Comparative System was designed such that approximately half of the total diluent flow exited from the sidedraw (e.g., deethanizer/second column side stream **171**) containing some unreacted ethylene and potentially some hydrogen, while the remaining half exits the bottom of the column as olefin-free isobutane. The sidedraw recycle stream was recycled to the second polymerization reactor, where hydrogen could be tolerated, and the first reactor was fed olefin-free isobutane from the deethanizer bottom stream.

[0152] The comparative fractionation scheme has some drawbacks associated with the higher operating pressure of deethanizer column and 50/50 split of RIC4 and OFIC4 in the deethanizer. (1) The pressure differential between the dehexanizer and the deethanizer requires additional equipment, of which are not only to overcome the pressure differential (e.g., an intermediate compressor and pump between the dehexanizer and the deethanizer), but also to provide extra energy requirement associated with higher operating pressure (e.g., pre-heater and economizing exchanger). (2) Higher operating pressures in the deethanizer demands more duty from a deethanizer column reboiler due to the accompanying lower relative volatilities between components. (3) Producing a 50/50 split of RIC4 and OFIC4 in the deethanizer requires increasing storage vessel, pump, and treaters associated with OFIC4 in size to accommodate the large increase in flow, relative to systems in which olefin-free IC4 comprises less than 15 or 10% of the total diluent. (4) The 50/50 split of RIC4 and OFIC4 and bubble-point feed pre-heating also attribute to poor olefin efficiency.

[0153] The PPS I/I' of this disclosure provides recycle RIC4 **171'** that can be effectively used in polymerization reactor(s)/system **110** (e.g., first polymerization reactor **110A** and/or second polymerization reactor **110B**) via feed hydrogen metering and techniques used for analysis of hydrogen in the recycle isobutane stream **171'**. Relative to the conventional Comparative System, deethanizer second column **170** operating pressure was reduced and the RIC4/OFIC4 ratio (e.g., the ratio of second column side draw stream **171** to second column bottoms stream **172**) increased by the PPS of this disclosure.

[0154] In this example, Resin 1 was selected as one representative case because of its popularity, high H.sub.2 feed requirements and ethane generation and high isobutane loss in vent, and Resin 2 was selected as another representative case because of its popularity, low H.sub.2 feed requirements and ethane generation and low isobutane loss in vent.

[0155] A fractionation system, as depicted in FIG. **1B** was selected for comparison with the Comparative System.

[0156] In Table 1 and Table 2, the proposed fractionation train design of FIG. **1B** is compared to the results obtained for the comparative fractionation train design of the Comparative System

described above, for Resin 1 at a common capacity.

TABLE-US-00001 TABLE 1 Comparisons Between PPS I and Comparative System on Deethanizer Second Column 170 for Resin 1 1 ppmw C2 = in OFIC4 <0.01 ppmw H2 in RIC4 (Disclosed Design) <0.4 ppmw H2 in RIC4 Deethanizer Column (Comparative Design) Disclosed System Comparative System No. of theoretical stages 25 28 Feed stage #1 #2 Liquid sidedraw stage #16 #6 Pressure (psig) 132.sup.1/Na/137 320/323/329 (top/condenser/bottom) Required feed preheater duty 0 1.6 (MM Btu/h) Required economizer duty 0 5.0 (MM Btu/h) Required condenser duty 0 4.2 (MM Btu/h) Required reboiler duty (MM 2.1 5.9 Btu/h) Min. dia. (ft) 3.7 5.5 RIC4/OFIC4 (kg/h) 46,267/7,565 27,622/26,115 .sup.1Deethanizer pressure was determined by dehexanizer pressure and reasonable dP (3 psi) between dehexanizer/first column 145 and deethanizer/second column 170.

[0157] As shown in Table 1, in the FGTS III of this disclosure, operating pressure of the deethanizer column is reduced to 132 psig from 320 psig, and the ratio of RIC4/OFIC4 (e.g., second column side stream **171** to second column bottom stream **172**) is increased to about 85/15 from about 50/50 in the Comparative System. These two changes enable (1) a more compact deethanizer second column **170** (e.g., 8 ft. shorter in deethanizer column height, 1.8 ft reduction in deethanizer column diameter); (2) less required equipment (eliminating compressor, feed preheater, economizing exchanger, condenser, condenser accumulator, and reflux pump); and (3) increased energy efficiency (e.g., eliminating cooling, 65% reduction in heating).

[0158] As shown in Table 2, in the disclosed system design, the operating pressure of vent column **185** is reduced to 117 psig from 305 psig, due to the decrease in the upstream (deethanizer second column **170**) operating pressure. To counter the isobutane loss caused by lower operating pressure in deethanizer second column **170**, a colder and higher capacity refrigeration system **184** can be included. The refrigeration system **184** temperature can be reduced (e.g., to about to -34° C.), and its duty a little more than doubled to reduce/minimize isobutane losses in vent column overhead gas stream **186**.

[0159] The ethane (inert) venting rates are the same for both the disclosed FGTS III and the Comparative Design. In the disclosed design, the vent column **185** has a reduction in ethylene venting by about 140 kg/h, relative to that of the Comparative Design; however, an increase of isobutane venting of about 40 kg/h is seen with the disclosed FGTS III.

TABLE-US-00002 TABLE 2 Comparisons between PPS I and Comparative System on Vent Column 185 for Resin 1 Vent Column 185 Disclosed System Comparative System No. of theoretical stages 3 3 Feed stage #4 #4 Pressure (psig) 117/120/121 305/308/309 (top/condenser/bottom) Required condenser duty 1.2 @-34° C. 0.5 @-25° C. (MM Btu/h) Min. dia. (ft) 2.1 1.3 Ethane venting rate (kg/h) 121 121 C2 = loss to vent (kg/h) 686 825 IC4 loss to vent (kg/h) 82 39

[0160] In Table 3 and Table 4, the proposed new fractionation train design FGTS III is compared to the Comparative System fractionation train design for Resin 2 at a common capacity. As shown in Table 3, the proposed deethanizer second column **170** design offers very similar benefits for Resin 2 as for Resin 1.

[0161] Lower operating pressure of deethanizer second column **170** and higher RIC4/OFIC4 ratio (e.g., ratio of second column side stream **171** to second column bottom stream **172**) enable (1) a more compact deethanizer second column **170** (e.g., 8 ft shorter in deethanizer second column **170** height, 2.2 ft reduction in deethanizer second column **170** diameter), (2) less required equipment (e.g., elimination of compressor, feed preheater, economizing exchanger, condenser, condenser accumulator, and reflux pump), and (3) increased energy efficiency (e.g., eliminating cooling, 64% reduction in heating).

TABLE-US-00003 TABLE 3 Comparisons Between PPS I and Comparative System on Deethanizer Second Column 170 for Resin 2 1 ppmw C2 = in OFIC4 <0.01 ppmw H2 in RIC4 (Disclosed Design) <0.4 ppmw H2 in RIC4 Deethanizer Column (Comparative Design) Disclosed

System Comparative System No. of theoretical stages 25 28 Feed stage #1 #2 Liquid sidedraw stage #16 #6 Pressure (psig) 132/Na/137 320/323/329 (top/condenser/bottom) Required feed preheater duty 0 1.8 (MM Btu/h) Required economizer duty 0 5.6 (MM Btu/h) Required condenser duty 0 4.9 (MM Btu/h) Required reboiler duty (MM 2.5 6.9 Btu/h) Min. dia. (ft) 3.9 6.1 RIC4/OFIC4 (kg/h) 50,514/7,910 28,949/29,329

[0162] As shown in Table 4, similar to the Resin 1 case, the operating pressure of vent column **185** is reduced, a colder and higher capacity refrigeration system **184** can be included in the proposed design to counter the isobutane loss caused by lower operating pressure in deethanizer second column **170**, the refrigeration system **184** temperature was reduced to -36°C . for this Resin 2 Example, and its duty was doubled, the ethane (inert) venting rates are the same for both Disclosed System (PPS I) and the Comparative System. The vent column **185** of the herein disclosed PPS I has a reduction in ethylene venting by about 200 kg/h, however, an increase of isobutane venting by about 50 kg/h was seen in the Disclosed System relative to the Comparative System.

TABLE-US-00004 TABLE 4 Comparisons between PPS I and Comparative System on Vent Column 185 for Resin 2 Vent Column 185 Disclosed System Comparative System No. of theoretical stages 3 3 Feed stage #4 #4 Pressure (psig) 117/120/121 305/308/309 (top/condenser/bottom) Required condenser duty 1.1 @ -36°C . 0.6 @ -25°C . (MM Btu/h) Min. dia. (ft) 2.1 1.5 Ethane venting rate (kg/h) 18 18 C2 = loss to vent (kg/h) 1196 1395 IC4 loss to vent (kg/h) 54 5

Example 2

[0163] Deethanizer second column **170** temperature profiles are shown in FIG. 3 and FIG. 4 for Resin 1 and Resin 2, respectively. For each resin, four lines were modeled to depict one on-spec case (e.g., 1 ppmw ethylene (C2=) in OFIC4), one deviation case (e.g., 0.5 ppmw C2= in OFIC4), and two off-spec cases (e.g., 2 ppmw and 5 ppmw C2= in OFIC4). The sidedraw location is determined such that H2 in RIC4 on-spec (e.g., less than or equal to 1% ppmw) is guaranteed when C2= in OFIC4 specification is met (e.g., 1 ppmw).

[0164] The sidedraw location (SDS, FIG. 2) was determined by case with high H2 presence, e.g., Resin 1. The sidedraw location becomes very conservative for case with low H2 presence, e.g., Resin 2. As shown in FIG. 4 for Resin 2, with this conservative sidedraw location, even with C2= in OFIC4 off-spec, H2 in RIC4 is still well below spec value.

[0165] The control objective was to maintain (1) temperatures of sidedraw stage and the two stages right below hot enough to reject C2= from liquid, and (2) temperatures of the stages above second column side stream **171** sidedraw hot enough to reject H2 from liquid; the control handle is the reboiler R2 steam **174**.

[0166] The temperature deltas are greatest at sidedraw location (stage #16), and the 1 stage above and below the SDS. With the higher deltas at these stages, these locations can be best for tray tower control. As C2= and H2 make their way down the tower, the tray temperature TI can sense the change with respect to time and the temperature controller (TC) can adjust reboiler R2 steam **174** as required.

[0167] Based on the temperature profile and control loop timing, one TI can be placed at stage #17 (the second actual tray below the sidedraw tray) for column temperature control of OFIC4 for both Resin 1 and Resin 2. On the other hand, if the sidedraw stage (stage #16) temperature were utilized as the control temperature of RIC4, timing may be an issue for this control loop. The moment the temperature difference is sensed, and the reboiler R2 steam **174** adjusted, H2 has already made it to RIC4. For better control loop timing, one TI can be placed at stage #4 or stage #5 (e.g., the #7 or #8 actual tray from top) for column temperature control of RIC4 for Resin 1.

[0168] As shown in FIG. 4, for Resin 2, no/limited temperature delta exists at stages above sidedraw location SDS, because H2 in RIC4 concentrations are always well below spec value for all cases. RIC4 is more likely off-spec in Resin 1 case, and highly unlikely off-spec in Resin 2 case, as noted above.

[0169] For Resin 1, as shown in FIG. 3, low temperature (bottom, diamond line) in deethanizer second column **170** top section leads to high (off-spec) H₂ concentration in RIC4 stream **171**. In operation, such a low temperature profile can be caused by feed temperature deviation (colder). In FIG. 5, with a colder feed (92° F.) to deethanizer second column **170**, top section temperatures become lower for all cases (square, diamond, triangle lines) compared to reference case (circles line, Feed@ 102° F.). As shown in triangles line, although OFIC4 is on-spec, the H₂ in RIC4 is off-spec (8 ppmw). To reduce the H₂ in RIC4, top section temperature profiles can be lifted (squares and triangles lines) by increasing reboiler R2 duty, which also results in reduction C₂= in OFIC4 **172**.

[0170] Based on characteristics of FIG. 3 and FIG. 5, besides direct temperature control of RIC4 **171** for Resin 1, alternatively differential temperature control strategy can be utilized to control RIC4 **171** for Resin 1. For one differential temperature control scheme, the feed temperature to the column (T_{sub.feed}) and the temperature at stage #4 (T₄) can be measured. The delta between these two ($dT = T_4 - T_{\text{sub.feed}}$) can be calculated. This dT value could be controlled at a constant value, e.g., 10° F. to fix the location of the upper wave and result in the <0.01 ppmw H₂ in RIC4 **171**, as shown in squares/circles/triangles lines in FIG. 3 and squares line in FIG. 5. This control strategy can provide a quicker and more responsive control for feed temperature deviation, in aspects.

[0171] For another differential temperature control scheme, the temperature at stage #24 (T₂₄) and the temperature at stage #5 (T₅) can be measured. The delta between these two ($dT = T_{24} - T_5$) can then be calculated. This dT value could be controlled in a certain range, e.g., 40-50° F. to fix the location of the upper wave and result in the <0.01 ppmw H₂ in RIC4 **171**, as shown in squares/circles/triangles lines in FIG. 3 and squares line in FIG. 5. This control strategy can provide a pressure-compensated temperature control. The temperature near the bottom (e.g., T₂₄) can be chosen as a reference because temperature is relatively constant and insensitive to composition near the bottom of deethanizer second column **170**, as shown in FIG. 3 and FIG. 5.

ADDITIONAL DISCLOSURE

[0172] The particular aspects disclosed above are illustrative only, as the present disclosure can be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative aspects disclosed above can be altered or modified and all such variations are considered within the scope and spirit of the present disclosure. Alternative aspects that result from combining, integrating, and/or omitting features of the aspect(s) are also within the scope of the disclosure. While compositions and methods are described in broader terms of “having”, “comprising”, “containing”, or “including” various components or steps, the compositions and methods can also “consist essentially of” or “consist of” the various components and steps. Use of the term “optionally” with respect to any element of a claim means that the element is required, or alternatively, the element is not required, both alternatives being within the scope of the claim.

[0173] Numbers and ranges disclosed above can vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range are specifically disclosed. In particular, every range of values (of the form, “from about a to about b,” or, equivalently, “from approximately a to b,” or, equivalently, “from approximately a-b”) disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles “a” or “an”, as used in the claims, are defined herein to mean one or more than one of the element that it introduces. If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents, the definitions that are consistent with this specification should be adopted. The term “about” (e.g., “about 10”) can indicate $\pm 10\%$ (e.g., 9

to 11), and includes equal to (e.g., equal to 10), in aspects. “Substantially” equal to a value can include within 5, 4, 3, 2, or 1% or equal to the value, in aspects.

[0174] The following are non-limiting, specific aspects in accordance with the present disclosure:

[0175] In a first aspect, method (of treating a polymerization reactor effluent) comprises:

recovering a polymerization reactor effluent stream from one or more polymerization reactors; flashing the polymerization reactor effluent stream to form a flash gas stream; separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; separating the first column overhead stream into a gas stream and a liquid stream; and introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, wherein the second column bottoms stream has a second column bottoms flow rate of isobutane and the second column side stream has a second column side stream flow rate of isobutane, wherein a total flow rate of isobutane comprises the second column bottoms stream flow rate and the second column side stream flow rate, and wherein the second column bottoms stream flow rate comprises less than or equal to about 15, 20, or 25 volume percent (vol %) of the total flow rate and the second column side stream flow rate comprises greater than or equal to about 85, 80, or 75 vol % of the total flow rate.

[0176] A second aspect can comprise the method of the first aspect further comprising returning at least a portion of the first column side stream to at least one of the one or more polymerization reactors.

[0177] A third aspect can include the method of the first or the second aspect, wherein the first column comprises a fractionation/distillation column.

[0178] A fourth aspect can comprise the method of the third aspect, wherein the first column comprises a dehexanizer column configured to separate hexane and heavier components from the flash gas stream to provide the first column overhead stream, wherein the first column overhead stream comprises less than or equal to about 10, 5, or 1 ppmw C6+, wherein the first column side stream comprises from about 80, 85, or 90 to about 95, 98, 99, or 100 vol. % hexene (e.g., from about 60 to 100 vol % hexene), and wherein the first column bottoms stream comprises primarily C6+ (e.g., hexane, oils, oligomers, or a combination thereof).

[0179] A fifth aspect can include the method of any one of the first to fourth aspects, wherein separating the first column top stream is effected in an accumulator.

[0180] A sixth aspect can include the method of any one of the first to fifth aspects, wherein the second column comprises a fractionation/distillation column.

[0181] A seventh aspect can include the method of the sixth aspect, wherein the second column comprises a deethanizer column configured to separate ethane and lighter components from the feed to produce the second column bottoms stream, wherein the second column bottoms stream comprises less than or equal to about 10, 5, or 1 ppmw C2–, wherein the second column side stream comprises from about 85, 90, or 92 to about 95, 98, or 99 wt % isobutane, from about 1, 2, or 3 to about 4, 5, 6, 7, 8, 9, or 10 vol. % ethylene, and less than or equal to about 0.1 ppmw hydrogen, and wherein the second column overhead stream maximizes ethylene and isobutane losses.

[0182] An eighth aspect can include the method of any one of the first to seventh aspects further comprising recycling at least a portion of the second column side stream.

[0183] A ninth aspect can include the method of the eighth aspect, wherein recycling the at least the portion of the second column side stream further comprises introducing the at least the portion of the second column side stream to at least one of the one or more polymerization reactors as a recycle isobutane stream.

[0184] A tenth aspect can include the method of the ninth aspect, wherein the recycle isobutane stream comprises greater than or equal to about 10 volume percent (vol %) isobutane, less than or equal to about 10 vol % olefins (e.g., ethylene), less than or equal to about 0.1 ppmw hydrogen, or

a combination thereof.

[0185] An eleventh aspect can include the method of the tenth aspect, wherein the olefins comprise ethylene, hexene, or a combination thereof.

[0186] A twelfth aspect can include the method of any one of the first to eleventh aspects, wherein the second column bottoms stream is a substantially olefin-free isobutane stream comprising greater than or equal to about 95, 96, 97, 98, or 99 volume percent (vol %), less than or equal to about 50 ppmw olefins (e.g., ethylene), less than or equal to about 0.1 ppmw hydrogen, or a combination thereof.

[0187] A thirteenth aspect can include the method of the twelfth aspect, wherein the olefins comprise ethylene, hexene, or a combination thereof.

[0188] A fourteenth aspect can include the method of the twelfth or thirteenth aspect further comprising recycling at least a portion of the substantially olefins-free isobutane stream as a recycle olefins-free isobutane stream to a catalyst pretreater upstream of the one or more polymerization reactors, and using the catalyst pretreater to form a catalyst slurry comprising a polymerization catalyst and the recycle olefins-free isobutane stream.

[0189] A fifteenth aspect can include the method of any one of the first to fourteenth aspects further comprising operating the second column at a second column pressure, and operating the first column at a first column pressure, wherein the second column pressure is within about 10, 15, or 20% of the first column pressure.

[0190] A sixteenth aspect can include the method of the fifteenth aspect, wherein the second column pressure is from about 110 psig to about 160 psig.

[0191] A seventeenth aspect can include the method of the sixteenth aspect, wherein the second column pressure is about 120 psig.

[0192] An eighteenth aspect can include the method of the seventeenth aspect, wherein a reboiler duty of a reboiler associated with the second column is less than a reboiler duty of a reboiler associated with a second column in a same method except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure.

[0193] A nineteenth aspect can include the method of the seventeenth or eighteenth aspect, wherein a diameter of the second column is less than a diameter of the second column utilized to provide a same separation in the same method.

[0194] A twentieth aspect can include the method of any one of the first to nineteenth aspects, comprising no compressing of the first column overhead stream, the gas stream, or the at least the portion of the liquid stream prior to introducing the gas stream and the at least the portion of the liquid stream as feed to the second column.

[0195] A twenty first aspect can include the method of any one of the first to twentieth aspects, comprising no preheating of the feed or components thereof (e.g., the gas stream, the liquid stream) between the second column and the first column.

[0196] A twenty second aspect can include the method of any one of the first to twenty first aspects, wherein a liquid side draw stage of the second column is separated from a feed stage of the second column by more than 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 theoretical or actual stages (trays), or by from about 3 to about 20, from about 5 to about 18, or from about 10 to about 15 theoretical or actual stages (trays), wherein the liquid side draw stage is a stage from which or tray from immediately above which the second column side stream is withdrawn, and wherein the feed stage is a stage to which or a tray immediately above which the second column feed is introduced to the second column.

[0197] A twenty third aspect can include the method of any one of the first to twenty second aspects, wherein the second column side stream comprises less than or equal to about 1, 0.1, or 0.01 ppmw, less than or equal to about 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 weight percent (wt %) ethylene, greater than or equal to about 80, 85, or 90 weight percent (wt %) isobutane, or a combination thereof.

[0198] A twenty fourth aspect can include the method of any one of the first to twenty third aspects further comprising maximizing an amount of ethylene in the second column side stream, while maintaining a concentration of hydrogen in the second column side stream below a tolerance of the one or more polymerization reactors (e.g., at less than about 1, 0.1, or 0.01 ppmw H₂), and recycling at least a portion of the second column side stream to at least one of the one or more polymerization reactors.

[0199] A twenty fifth aspect can include the method of any one of the first to twenty fourth aspects, wherein the one or more polymerization reactors comprise an advanced dual loop reactor comprising a first polymerization reactor upstream of a second polymerization reactor.

[0200] A twenty sixth aspect can include the method of the twenty fifth aspect, wherein the first polymerization reactor is configured to produce a higher molecular weight polymer of a bimodal polymer, and wherein the second polymerization reactor is configured to produce a lower molecular weight polymer of the bimodal polymer, wherein the higher molecular weight polymer has a higher average molecular weight than the lower molecular weight polymer.

[0201] A twenty seventh aspect can include the method of the twenty fifth or twenty sixth aspect further comprising recycling at least a portion of the second column side stream to the first polymerization reactor, the second polymerization reactor, or both.

[0202] A twenty eighth aspect can include the method of any one of the first to twenty seventh aspects, wherein the one or more polymerization reactors contain a polymerization catalyst.

[0203] A twenty ninth aspect can include the method of any one of the first to twenty eighth aspects further comprising condensing the second column overhead stream, and separating the condensed second column overhead stream into a second column overhead gas and a second column overhead liquid, returning at least a portion of the second column overhead liquid to the second column, and venting at least a portion of the second column overhead gas.

[0204] A thirtieth aspect can include the method of the twenty ninth aspect further comprising operating the second column at a second column pressure, and operating the first column at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure, wherein an amount of ethylene in the second column overhead gas is less than or equal to an amount of ethylene vented in a same method except wherein the second column pressure is not within about 10% of the first column pressure.

[0205] In a thirty first aspect, a method (of treating a polymerization reactor effluent) comprises: recovering a polymerization reactor effluent stream from one or more polymerization reactors; flashing the polymerization reactor effluent stream to form a flash gas stream; separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; separating the first column overhead stream into a gas stream and a liquid stream; introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream; and operating the second column at a second column pressure, and operating the first column at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

[0206] In a thirty second aspect, a method (of treating a polymerization reactor effluent) comprises: recovering a polymerization reactor effluent stream from one or more polymerization reactors; flashing the polymerization reactor effluent stream to form a flash gas stream; separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; separating the first column overhead stream into a gas stream and a liquid stream; introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream; and maximizing an amount of ethylene in the second column side stream, while maintaining a concentration of hydrogen in the second column side stream below a tolerance of the one or more polymerization reactors (e.g., at less than about 1, 0.1,

or 0.01 ppmw H.sub.2), and recycling at least a portion of the second column side stream to at least one of the one or more polymerization reactors.

[0207] In a thirty third aspect, a system (of treating a polymerization reactor effluent, the system) comprises: one or more polymerization reactors configured to produce a polymerization reactor effluent stream; flash apparatus configured for flashing the polymerization reactor effluent stream to form a flash gas stream; a first column configured to separate the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; a liquid/vapor separator configured for separating the first column overhead stream into a gas stream and a liquid stream; and a second column configured to receive a feed comprising the gas stream and at least a portion of the liquid stream and separate the feed to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, wherein a second column bottoms outlet line is configured for a second column bottoms stream flow rate of isobutane and a second column side stream is configured for a second column side stream flow rate of isobutane, wherein a total flow rate of isobutane comprises the bottoms stream flow rate and the side stream flow rate, and wherein the bottoms stream flow rate comprises less than or equal to about 15 volume percent (vol. %) of the total flow rate and the side stream flow rate comprises greater than or equal to about 85 vol. % of the total flow rate.

[0208] A thirty fourth aspect can include the system of the thirty third aspect, comprising no compressor between the first column and the second column.

[0209] A thirty fifth aspect can include the system of the thirty third or thirty fourth aspect, configured for operation of the second column at a pressure within about 10% of a pressure at which the first column is operated.

[0210] A thirty sixth aspect can include the system of any one of the thirty third to thirty fifth aspects, wherein the first column, the second column, or both comprise a fractionation/distillation column.

[0211] A thirty seventh aspect can include the system of the thirty sixth aspect, wherein the first column comprises a dehexanizer column configured to separate hexane and heavier components from the flash gas stream to provide the first column overhead stream, wherein the first column overhead stream comprises less than or equal to about 10, 5, or 1 ppmw C6+ (e.g., compounds containing 6 or more carbon atoms), wherein the first column side stream comprises from about 85, 90, or 95 to about 95, 98, 99, or 100 wt % hexene, and wherein the first column bottoms stream comprises primarily C6+ (e.g., compounds containing six or more carbon atoms; such as hexane, oils, oligomers, or a combination thereof).

[0212] A thirty eighth aspect can include the system of any one of the thirty third to thirty seventh aspects, wherein the liquid/vapor separator comprises an accumulator.

[0213] A thirty ninth aspect can include the system of any one of the thirty third to thirty eighth aspects, wherein the second column comprises a deethanizer column configured to separate ethane and lighter components from the feed to produce the second column bottoms stream, wherein the second column bottoms stream comprises less than or equal to about 10, 5, or 1 ppmw C2-, (e.g., compounds having two or fewer carbon atoms) wherein the second column side stream comprises from about 85, 90, or 92 to about 95, 98, 99, or 100 wt % isobutane, from about 1, 2, 3, 4, or 5 to about 4, 5, 6, 7, 8, 9, or 10 wt % ethylene, and from about 1, 0.1, or 0.01 to about 0.1, 0.01, or 0.001 ppmw hydrogen, and wherein the second column overhead stream comprises from about 70, 65, or 60 to about 45, 50, or 55 wt %, or less than or equal to about 70, 65, or 60 wt % isobutane, from about 10, 15, or 20 to about 55, 50, or 45 wt. %, or less than or equal to about 55, 50, or 45 wt. % ethylene.

[0214] A fortieth aspect can include the system of any one of the thirty third to thirty ninth aspects further comprising a recycle path for recycling at least a portion of the second column side stream.

[0215] A forty first aspect can include the system of the fortieth aspect, wherein the recycle path introduces the at least the portion of the second column side stream to at least one of the one or

more polymerization reactors as a recycle isobutane stream.

[0216] A forty second aspect can include the system of the forty first aspect, configured such that the recycle isobutane stream comprises greater than or equal to about 80, 85, or 90 weight percent (wt %) or from about 85, 90, or 92 to about 95, 98, or 99 isobutane, greater than or equal to about 1, 2, 3, 4, or 5, or from about 11, 2, 3, 4, or 5 to about 10, 9, 8, 7, or 6 wt % olefins (e.g., ethylene), less than or equal to about 1, 0.1, or 0.01 ppmw, or from about 1, 0.1, or 0.01 to about 0.1, 0.01, or 0.001 ppmw hydrogen, or a combination thereof.

[0217] A forty third aspect can include the system of the forty second aspect, wherein the olefins comprise ethylene, hexene, or a combination thereof.

[0218] A forty fourth aspect can include the system of any one of the thirty third to forty third aspects, wherein the second column bottoms stream is a substantially olefin-free isobutane stream comprising greater than or equal to about 85, 90, or 95 weight percent (wt %), or from about 85, 90, or 95 to about 97, 98, or 99 wt % isobutane, less than or equal to about 50, 10, or 1 wt %, or from about 50, 10, or 1 to about 5, 1, or 0.1 ppmw olefins (e.g., ethylene), less than or equal to about 0.1, 0.01, or 0.001 ppmw hydrogen, or a combination thereof.

[0219] A forty fifth aspect can include the system of the forty fourth aspect, wherein the olefins comprise ethylene, hexene, or a combination thereof.

[0220] A forty sixth aspect can include the system of the forty fourth or forty fifth aspect further comprising a catalyst pretreater upstream of the one or more polymerization reactors, and a recycle path for recycling at least a portion of the substantially olefins-free isobutane stream from the second column as a recycle olefins-free isobutane stream to the catalyst pretreater, wherein the catalyst pretreater is configured to produce a catalyst slurry comprising a polymerization catalyst and the recycle olefins-free isobutane stream.

[0221] A forty seventh aspect can include the system of any one of the thirty third to forty sixth aspects, wherein the second column is in operation at a second column pressure and the first column is in operation at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

[0222] A forty eighth aspect can include the system of the forty seventh aspect, wherein the second column pressure is from about 110 psig to about 160 psig.

[0223] A forty ninth aspect can include the system of the forty eighth aspect, wherein the second column pressure is about 120 psig.

[0224] A fiftieth aspect can include the system of any one of the forty seventh to forty ninth aspects further comprising a reboiler associated with the second column, wherein a reboiler duty of the reboiler associated with the second column is less than a reboiler duty of a reboiler associated with a second column in a same system except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure.

[0225] A fifty first aspect can include the system of the fiftieth aspect, wherein a diameter of the second column is less than a diameter of the second column utilized to provide a same separation in the same system.

[0226] A fifty second aspect can include the system of any one of the thirty third to fifty first aspects, comprising no compressor for compressing of the first column overhead stream, the gas stream, or the at least the portion of the liquid stream prior to introduction of the gas stream and the at least the portion of the liquid stream as feed to the second column.

[0227] A fifty third aspect can include the system of any one of the thirty third to fifty second aspects, comprising no preheater for preheating of the feed or components thereof (e.g., the gas stream, the liquid stream) between the second column and the first column.

[0228] A fifty fourth aspect can include the system of any one of the thirty third to fifty third aspects, wherein a liquid side draw stage of the second column is separated from a feed stage of the second column by more than 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 theoretical or actual stages (trays), or by from about 3 to about 20, from about 5 to about 18, or from about 10 to about 15

theoretical or actual stages (trays), wherein the liquid side draw stage is a stage from which or tray from immediately above which the second column side stream is withdrawn, and wherein the feed stage is a stage to which or a tray immediately above which the second column feed is introduced to the second column.

[0229] A fifty fifth aspect can include the system of any one of the thirty third to fifty fourth aspects, configured to produce the second column side stream comprising less than or equal to about 1, 0.1, or 0.01 ppmw, or from about 1, 0.1, or 0.01 to about 0.1, 0.01, or 0.001 ppmw hydrogen, greater than or equal to about 1, 2, or 3 wt percent (wt %), or from about 1, 2, 3, 4, or 5 to about 5, 6, 7, 8, 9, or 10 weight percent (wt %) ethylene, greater than or equal to about 80, 85, or 90 wt %, or from about 80, 85, or 90 to about 95, 97, or 99 weight percent (wt %) isobutane, or a combination thereof.

[0230] A fifty sixth aspect can include the system of anyone of the thirty third to fifty fifth aspects configured for introducing the feed (e.g., having one or more feed inlets **166**) to the second column at a feed location to minimize ethylene and isobutane losses.

[0231] A fifty seventh aspect can include the system of any one of the thirty third to fifty sixth aspects configured for maximizing an amount of ethylene in the second column side stream, while maintaining a concentration of hydrogen in the second column side stream below a tolerance of the one or more polymerization reactors (e.g., at less than about 10.1, 0.1, or 0.01 ppmw H.sub.2), and further comprising a recycle path for recycling at least a portion of the second column side stream to at least one of the one or more polymerization reactors.

[0232] A fifty eighth aspect can include the system of any one of the thirty third to fifty seventh aspects, wherein the one or more polymerization reactors comprise an advanced dual loop reactor comprising a first polymerization reactor upstream of a second polymerization reactor.

[0233] A fifty ninth aspect can include the system of the fifty eighth aspect, wherein the first polymerization reactor is configured to produce a higher molecular weight polymer of a bimodal polymer, and wherein the second polymerization reactor is configured to produce a lower molecular weight polymer of the bimodal polymer, wherein the higher molecular weight polymer has a higher average molecular weight than the lower molecular weight polymer.

[0234] A sixtieth aspect can include the system of the fifty eighth or fifty ninth aspect further comprising a recycle path for recycling at least a portion of the second column side stream to the first polymerization reactor, the second polymerization reactor, or both.

[0235] A sixty first aspect can include the system of any one of the thirty third to sixtieth aspects, wherein the one or more polymerization reactors contain a polymerization catalyst.

[0236] A sixty second aspect can include the system of any one of the thirty third to sixty first aspects further comprising a condenser for condensing the second column overhead stream, and a separating the condensed second column overhead stream into a second column overhead gas and a second column overhead liquid, a reflux line for returning at least a portion of the second column overhead liquid to the second column, and a vent for venting at least a portion of the second column overhead gas.

[0237] A sixty third aspect can include the system of the sixty second aspect, wherein the second column is operating at a second column operating pressure, and the first column is operating at a first column operating pressure, wherein the second column operating pressure is within about 10% of the first column operating pressure, and wherein an amount of ethylene in the second column overhead gas being vented is less than or equal to an amount of ethylene vented in a same system configured for a same separation of isobutane between the second column side stream and the second column bottoms stream except wherein the second column pressure is not within about 10% of the first column pressure.

[0238] In a sixty fourth aspect, a system (of treating a polymerization reactor effluent, the system) comprises: one or more polymerization reactors configured to produce a polymerization reactor effluent stream; flash apparatus configured for flashing the polymerization reactor effluent stream

to form a flash gas stream; a first column configured to separate the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; a liquid/vapor separator configured for separating the first column overhead stream into a gas stream and a liquid stream; and a second column configured to receive a feed comprising the gas stream and at least a portion of the liquid stream and separate the feed to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, wherein the second column is operating at a second column pressure, and wherein the first column is operating at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

[0239] In a sixty fifth aspect, a system (of treating a polymerization reactor effluent, the system) comprises: one or more polymerization reactors configured to produce a polymerization reactor effluent stream; flash apparatus configured for flashing the polymerization reactor effluent stream to form a flash gas stream; a first column configured to separate the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; a liquid/vapor separator configured for separating the first column overhead stream into a gas stream and a liquid stream; a second column configured to receive a feed comprising the gas stream and at least a portion of the liquid stream and separate the feed to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, and a recycle path (e.g., a recycle line(s)) for recycling at least a portion of the second column side stream to at least one of the one or more polymerization reactors, wherein an amount of ethylene in the second column side stream is maximized, while a concentration of hydrogen in the second column side stream is below a tolerance of the one or more polymerization reactors (e.g., at less than about 10, 0.1, or 0.01 ppmw H₂).

[0240] While preferred aspects of the invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the teachings of this disclosure. The aspects described herein are exemplary only, and are not intended to be limiting. Many variations and modifications of the invention disclosed herein are possible and are within the scope of the invention.

[0241] Numerous other modifications, equivalents, and alternatives, will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such modifications, equivalents, and alternatives where applicable. Accordingly, the scope of protection is not limited by the description set out above but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated into the specification as an aspect of the present invention. Thus, the claims are a further description and are an addition to the detailed description of the present invention. The disclosures of all patents, patent applications, and publications cited herein are hereby incorporated by reference.

Claims

1. A method comprising: recovering a polymerization reactor effluent stream from one or more polymerization reactors; flashing the polymerization reactor effluent stream to form a flash gas stream; separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; separating the first column overhead stream into a gas stream and a liquid stream; and introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, wherein the second column bottoms stream has a second column bottoms stream flow rate of isobutane and the second column side stream has a second column side stream flow rate of isobutane, wherein a total flow rate of isobutane comprises the second column bottoms stream flow rate and the second column

side stream flow rate, and wherein the second column bottoms stream flow rate comprises less than or equal to about 25 volume percent (vol %) of the total flow rate and the second column side stream flow rate comprises greater than or equal to about 75 vol % of the total flow rate.

2. The method of claim 1, further comprising returning at least a portion of the first column side stream to at least one of the one or more polymerization reactors.

3. The method of claim 1 further comprising recycling at least a portion of the second column side stream.

4. The method of claim 1, wherein the second column bottoms stream is a substantially olefin-free isobutane stream comprising greater than or equal to about 95 weight percent (wt %) isobutane, less than or equal to about 50 ppmw olefins, less than or equal to about 0.1 ppmw hydrogen, or a combination thereof.

5. The method of claim 1 further comprising operating the second column at a second column pressure, and operating the first column at a first column pressure, wherein the second column pressure is within about 20% of the first column pressure.

6. The method of claim 1, wherein a reboiler duty of a reboiler associated with the second column is less than a reboiler duty of a reboiler associated with a second column in a same method except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure, and wherein a diameter of the second column is less than a diameter of the second column utilized to provide a same separation in the same method.

7. The method of claim 1, comprising no compressing of the first column overhead stream, the gas stream, or the at least the portion of the liquid stream prior to introducing the gas stream and the at least the portion of the liquid stream in the feed to the second column.

8. The method of claim 1, comprising no preheating of the feed or components thereof between the second column and the first column.

9. The method of claim 1, wherein the second column side stream comprises less than or equal to about 0.1 ppmw, less than or equal to about 10 weight percent (wt %) ethylene, greater than or equal to about 80 wt % isobutane, or a combination thereof.

10. The method of claim 1 further comprising maximizing an amount of ethylene in the second column side stream, while maintaining a concentration of hydrogen in the second column side stream below a tolerance of the one or more polymerization reactors, and recycling at least a portion of the second column side stream to at least one of the one or more polymerization reactors.

11. A method comprising: recovering a polymerization reactor effluent stream from one or more polymerization reactors; flashing the polymerization reactor effluent stream to form a flash gas stream; separating, in a first column, the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; separating the first column overhead stream into a gas stream and a liquid stream; introducing a feed comprising the gas stream and at least a portion of the liquid stream to a second column to produce a second column overhead stream, a second column side stream, and a second column bottoms stream; and operating the second column at a second column pressure, and operating the first column at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

12. A system comprising: one or more polymerization reactors configured to produce a polymerization reactor effluent stream; flash apparatus configured for flashing the polymerization reactor effluent stream to form a flash gas stream; a first column configured to separate the flash gas stream into a first column overhead stream, a first column side stream, and a first column bottoms stream; a liquid/vapor separator configured for separating the first column overhead stream into a gas stream and a liquid stream; and a second column configured to receive a feed comprising the gas stream and at least a portion of the liquid stream and separate the feed to produce a second column overhead stream, a second column side stream, and a second column bottoms stream, wherein a second column bottoms outlet line is configured for a second column bottoms stream flow rate of isobutane and a second column side stream is configured for a second column side

stream flow rate of isobutane, wherein a total flow rate of isobutane comprises the second column bottoms stream flow rate and the second column side stream flow rate, and wherein the bottoms stream flow rate comprises less than or equal to about 15 volume percent (vol. %) of the total flow rate and the side stream flow rate comprises greater than or equal to about 85 vol. % of the total flow rate.

13. The system of claim 12 comprising no compressor between the first column and the second column.

14. The system of claim 12, configured for operation of the second column at a pressure within about 10% of a pressure at which the first column is operated.

15. The system of claim 12, wherein the second column bottoms stream is a substantially olefin-free isobutane stream comprising greater than or equal to about 85 weight percent (wt %), or from about 85 to about 99 wt % isobutane, less than or equal to about 50 wt %, or from about 50, to about 0.1 ppmw olefins, less than or equal to about 0.1 ppmw hydrogen, or a combination thereof.

16. The system of claim 12, wherein the second column is in operation at a second column pressure and the first column is in operation at a first column pressure, wherein the second column pressure is within about 10% of the first column pressure.

17. The system of claim 12, wherein a reboiler duty of a reboiler associated with the second column is less than a reboiler duty of a reboiler associated with a second column in a same method except wherein the second column is not operated at a second column pressure that is within about 10% of the first column pressure, and wherein a diameter of the second column is less than a diameter of the second column utilized to provide a same separation in the same system.

18. The system of claim 12, comprising no compressor for compressing of the first column overhead stream, the gas stream, or the at least the portion of the liquid stream prior to introduction of the gas stream and the at least the portion of the liquid stream in the feed to the second column.

19. The system of claim 12, comprising no preheater for preheating of the feed or components thereof between the second column and the first column.

20. The system of claim 12, wherein a liquid side draw stage of the second column is separated from a feed stage of the second column by more than 5 theoretical or actual stages, or by from about 3 to about 20 theoretical or actual stages, wherein the liquid side draw stage is a stage from which or tray from immediately above which the second column side stream is withdrawn, and wherein the feed stage is a stage to which or a tray immediately above which the feed is introduced to the second column.
