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(54) **PROCESS AND APPARATUS FOR IMPROVED RECOVERY OF ARGON**

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(58) **Field of Classification Search**
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,688,238 A 9/1954 Shilling
4,022,030 A 5/1977 Brugerolle
4,822,935 A 4/1989 Scott
5,305,611 A 4/1994 Howard
5,682,764 A * 11/1997 Agrawal F25J 3/04206 62/646
5,893,276 A * 4/1999 Higginbotham F25J 3/04296 62/651
6,196,024 B1 3/2001 Ha
6,397,632 B1 * 6/2002 Meagher F25J 3/04303 62/648
6,543,253 B1 * 4/2003 Schaub F25J 3/04345 62/646

(Continued)

FOREIGN PATENT DOCUMENTS

DE 4406069 A1 9/1995
EP 3614082 A1 2/2020

(Continued)

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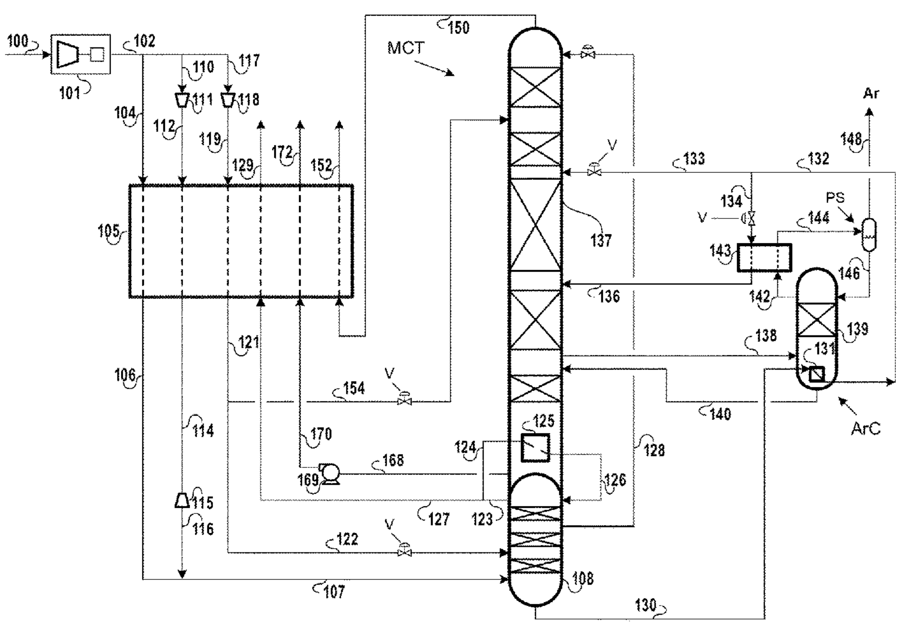
(57) **ABSTRACT**

A process and apparatus for recovering at least argon from a feed gas that can provide an improved recovery of argon as well as an improvement in operational efficiency. Some embodiments can be adapted so that the improved argon recovery can also be obtained with improved condenser operation for an argon column without requiring an increase in power for the recovery of the argon. Some embodiments can utilize a reboiler positioned near or at the bottom of argon recovery column to increase boil-up therein and/or provide added heat duty to drive a condenser of the argon recovery column to provide improved argon recovery.

17 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

11,512,897	B2	11/2022	Herron et al.	
2007/0283719	A1*	12/2007	Howard	F25J 3/04284 62/646
2014/0109614	A1*	4/2014	Tachibana	F25J 3/04303 62/643
2019/0331417	A1	10/2019	Kromer et al.	
2019/0331418	A1	10/2019	Prosser et al.	
2019/0331419	A1	10/2019	Handley et al.	
2022/0221221	A1	7/2022	Herron et al.	
2024/0035740	A1*	2/2024	Prosser	F25J 3/04709

FOREIGN PATENT DOCUMENTS

FR	2839548	A1	11/2003
JP	H07318241	A	12/1995
JP	2414947	A2	6/2003
WO	14099848	A2	6/2014
WO	2020244801	A1	12/2020
WO	2021078405	A1	4/2021

* cited by examiner

FIG. 1

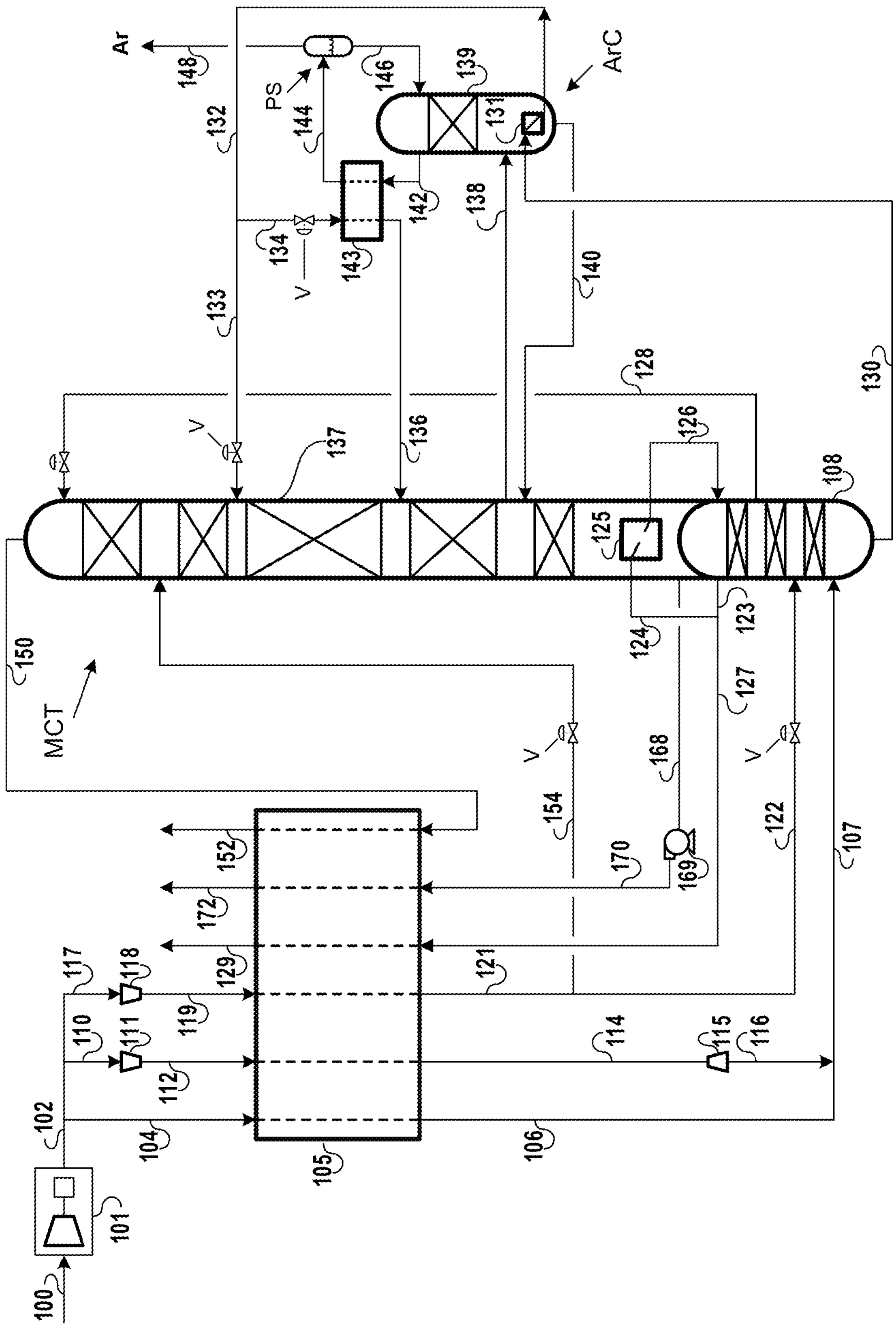

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FIG. 2

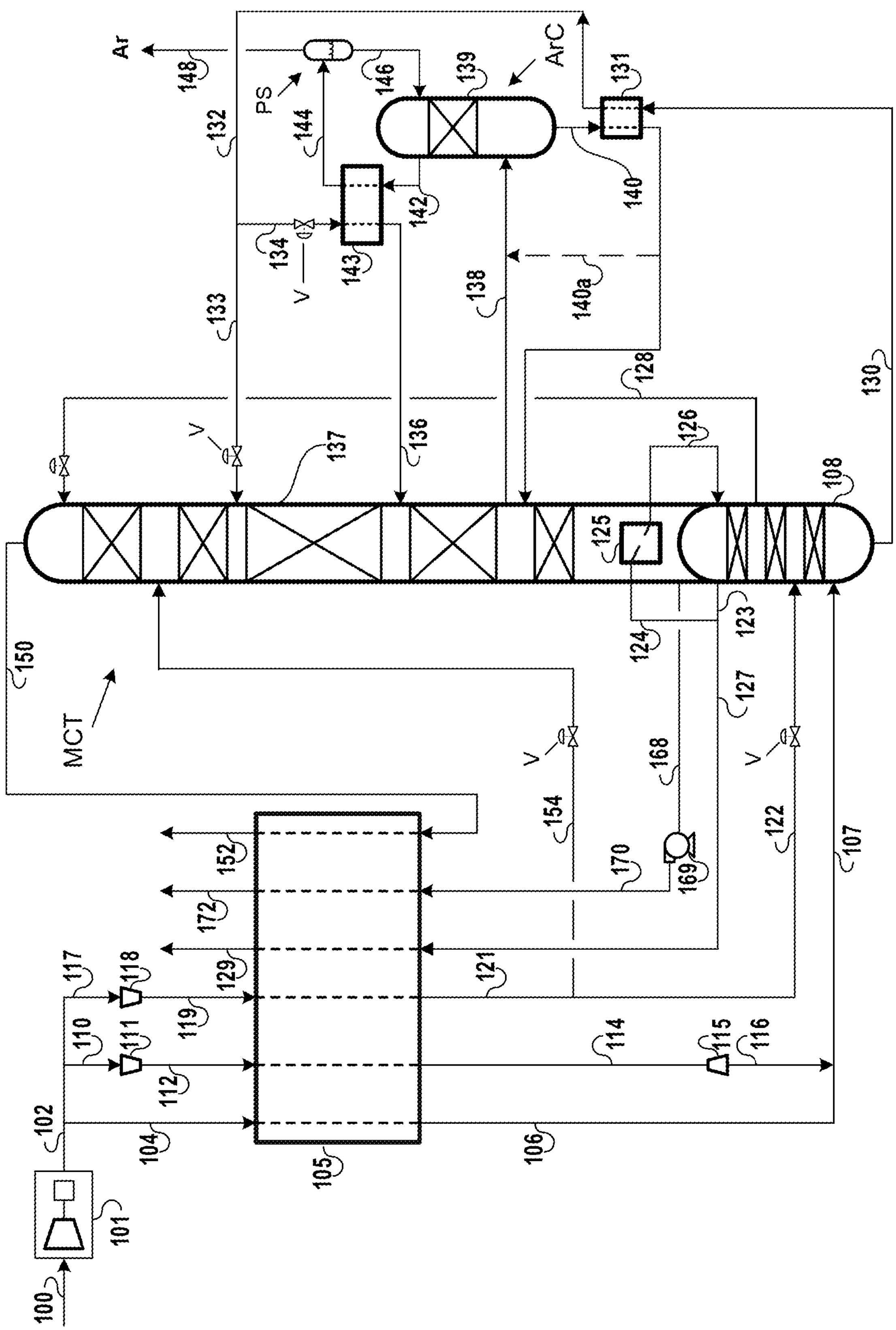
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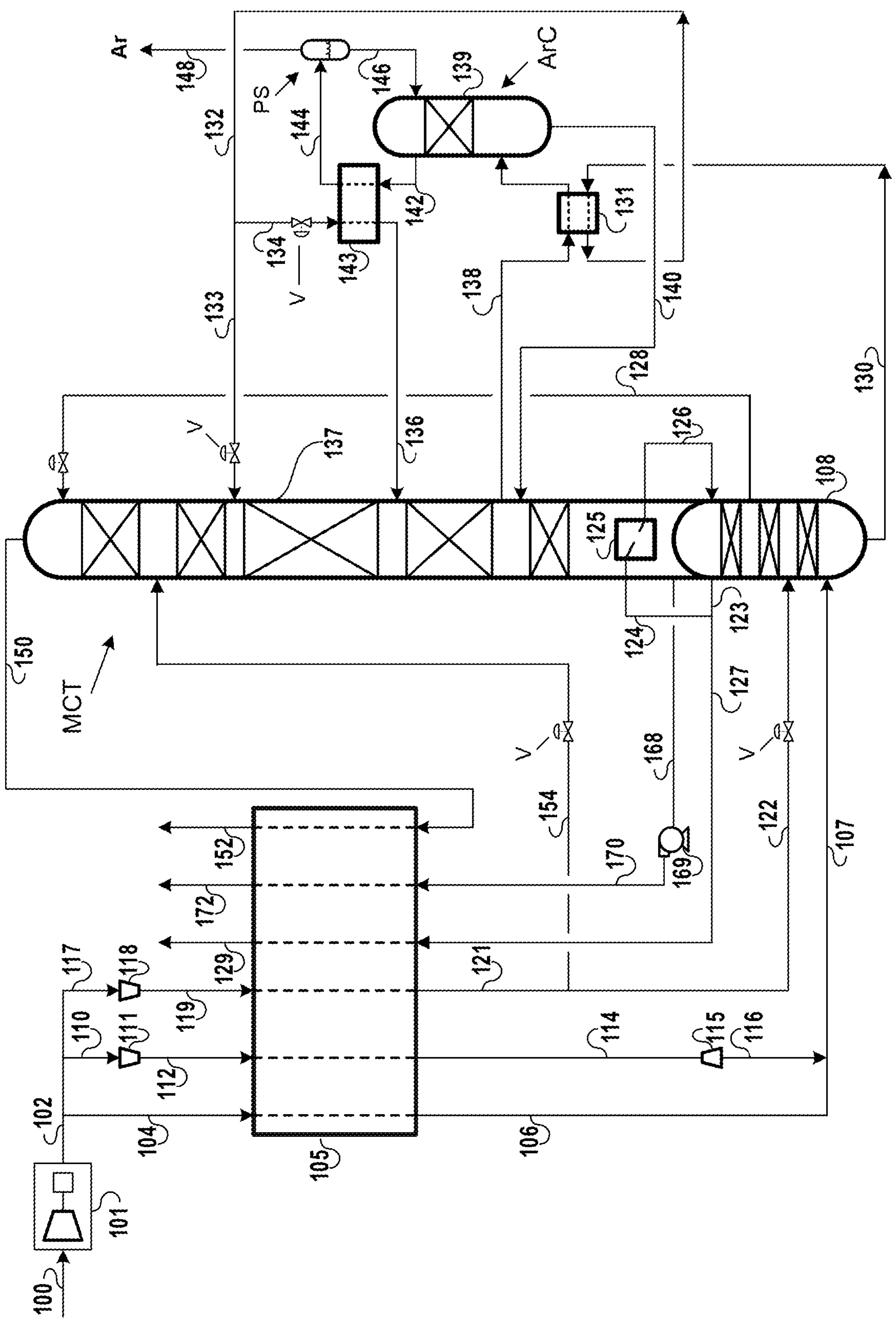
FIG. 3



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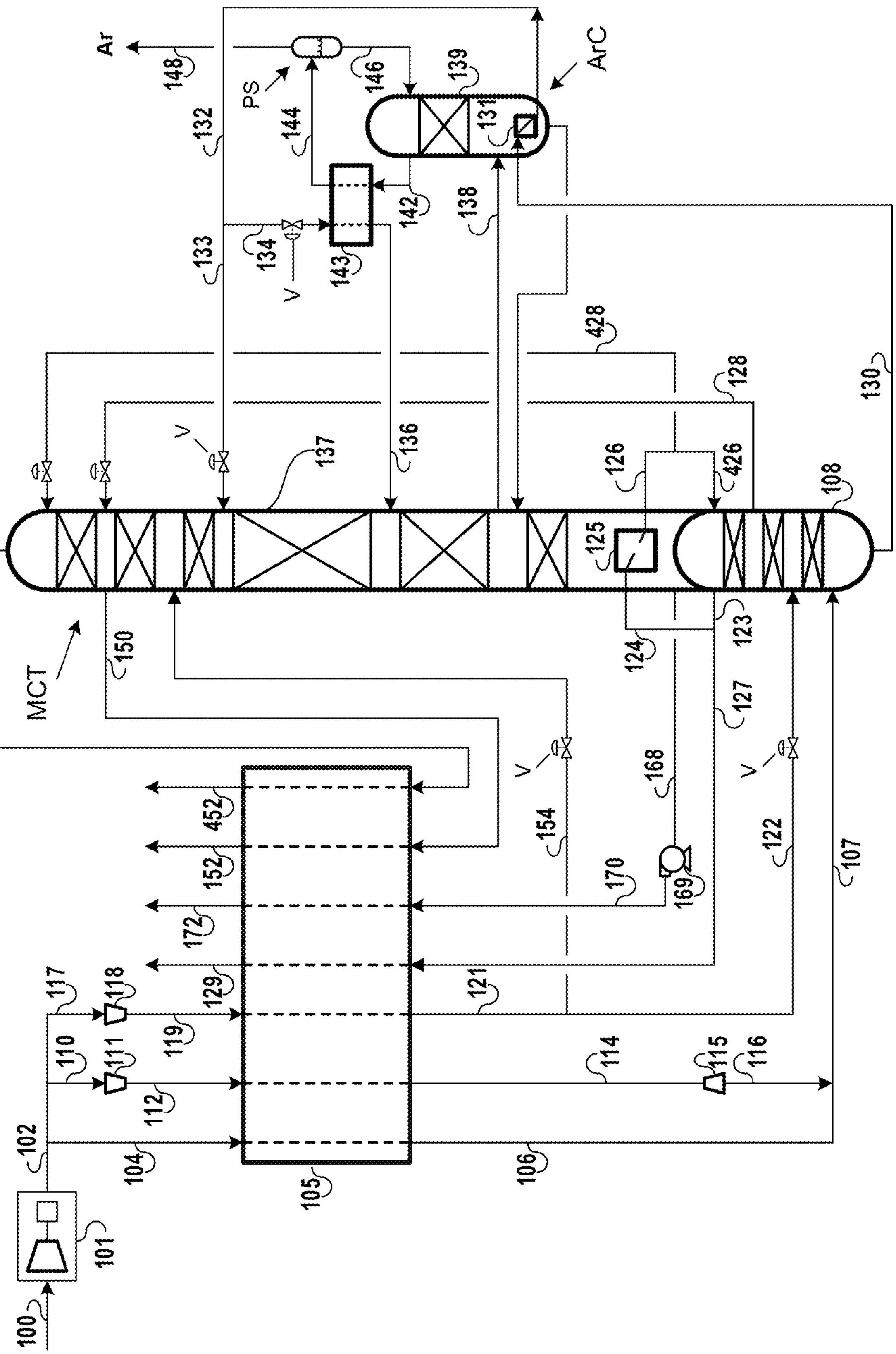
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FIG. 4

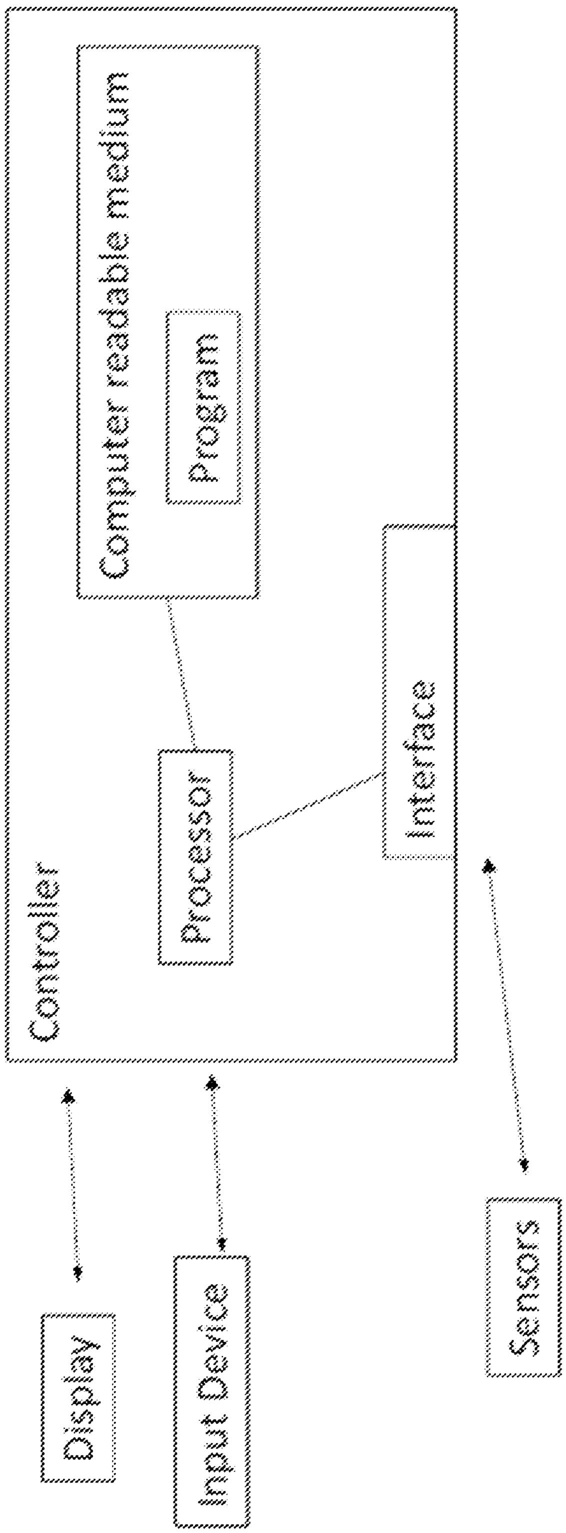
Controller
Computer readable medium
Program
Processor
Interface
Display
Input Device
Sensors

FIG. 5

PROCESS AND APPARATUS FOR IMPROVED RECOVERY OF ARGON

FIELD OF THE INVENTION

The present innovation relates to processes utilized to recover fluids from air that can include an argon column for recovery of argon that can be configured to utilize a reboiler for cooling crude liquid oxygen. The present innovation also relates to air separation units for separation of at least argon from air or other feed gas, gas separation plants configured to recover at least nitrogen or oxygen, and argon from at least one feed gas, air separation plants, air separation systems, systems utilizing multiple columns to recover nitrogen, argon, and oxygen fluids, and methods of making and using the same.

BACKGROUND OF THE INVENTION

Air separation processing has been utilized to separate air into different constituent flows of fluid (e.g. nitrogen, oxygen, etc.). Examples of systems that were developed in conjunction with air separation processing include U.S. Pat. Nos. 4,022,030, 4,822,395, International Patent Publication Nos. WO2020/169257, WO2020/244801, WO 2021/078405 and U.S. Pat. App. Pub. Nos. 2019/0331417, 2019/0331418, and 2019/0331419.

Some manufacturers may require the air separation plant in their facility to supply high purity argon as well as nitrogen. Some examples of argon stream processing can be appreciated from U.S. Pat. No. 5,305,611, International Patent Publication No. 2014/099848, French Patent Publication No. FR 2839548, and Japanese Patent No. JP 3414947.

SUMMARY

We have determined that some air separation processes designed to provide high-purity argon fluid for use by a manufacturing facility or other type of facility that may utilize or produce such argon can incur substantial cost in terms of power needed for processing to obtain incremental recovery of argon from air. We have determined that an improved process can be provided that can increase argon recovery without significantly increasing power needed for operation of the system. For example, some embodiments can utilize a reboiler driven by crude liquid oxygen (CLOX) at or adjacent the bottom of an argon column to provide improved argon recovery by increasing boil-up in the argon column while also simultaneously providing added heat duty benefit to drive the condenser of an argon column. Other embodiments can provide improved operational efficiency by providing more condenser duty for improved recovery of argon while also not increasing power for improvement in argon recovery or not substantively increasing power for the improvement in argon recovery (e.g. providing an increase in heat input for operation of the reboiler that cools the CLOX that can be offset by an increase in heat removal/rejection for operation of the condenser resulting in the improved argon recovery). Embodiments can be employed relatively simply and, in many cases, with relatively small changes to pre-existing process flows for pre-existing plants to permit pre-existing conventional systems to be retrofit to an embodiment of this new process and/or apparatus so that improved argon recovery can be obtained without large capital costs or requiring a new plant to be built.

In a first aspect, a process for separation of a feed gas comprising oxygen, nitrogen, and argon can include compressing the feed gas via a compression system of a separation system having a first column and a second column. The first column can be a high pressure (HP) column operating at a pressure that is higher than the second column. The second column can be a low pressure (LP) column operating at a pressure that is lower than the first column. The process can also include feeding the compressed feed gas to a first heat exchanger to cool the compressed feed gas, feeding at least a first portion of the compressed and cooled feed gas to the HP column to produce an HP oxygen-enriched stream, passing the HP oxygen-enriched stream output from the HP column through a reboiler positioned adjacent to an argon enrichment column or within an argon enrichment column to cool the HP oxygen-enriched stream, and passing at least a portion of the HP oxygen-enriched stream output from the reboiler to a reboiler-condenser of the argon enrichment column for condensing at least a portion of an argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser.

In some implementations, the reboiler positioned adjacent to the argon enrichment column can be within a lower portion or bottom portion of the argon enrichment column. In other implementations, the reboiler can be positioned to cool the HP oxygen-enriched stream via a feed stream fed to the argon enrichment column or via an argon depleted fluid output from the argon enrichment column.

In a second aspect, the process can be configured so that the passing of the HP oxygen-enriched stream output from the HP column through the reboiler positioned adjacent to the argon enrichment column or within the argon enrichment column to cool the HP oxygen-enriched stream includes passing the HP oxygen-enriched stream to the reboiler. The reboiler can be positioned in a bottom of the argon enrichment column or within a lower portion of the argon enrichment column.

In a third aspect, the passing of the HP oxygen-enriched stream output from the HP column through the reboiler positioned adjacent to the argon enrichment column or within the argon enrichment column to cool the HP oxygen-enriched stream can include passing the HP oxygen-enriched stream to the reboiler. The reboiler can be positioned adjacent the argon enrichment column. The process can also include passing an argon depleted fluid stream output from the argon enrichment column to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the argon depleted fluid stream.

In a fourth aspect, the passing of the HP oxygen-enriched stream output from the HP column through the reboiler positioned adjacent to the argon enrichment column or within the argon enrichment column to cool the HP oxygen-enriched stream can include passing the HP oxygen-enriched stream to the reboiler where the reboiler is positioned adjacent the argon enrichment column. An LP argon-enriched stream output from the LP column can also be passed to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the LP argon-enriched stream.

In a fifth aspect, the passing of at least a portion of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column for condensing at least a portion of the argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser can include splitting the HP oxygen-enriched stream output from the reboiler to form a first oxygen-enriched stream to feed to the LP column and a second oxygen-enriched stream to feed to the reboiler-condenser of the argon enrichment column. The process can also include feeding the second oxygen-enriched stream to the reboiler-condenser of the argon enrichment column and feeding the first oxygen-enriched stream to the LP column.

In a sixth aspect, the passing of at least a portion of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column for condensing at least a portion of the argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser can include passing an entirety of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column. The process can also include passing or feeding the portion of the argon-enriched vapor output from the argon enrichment column the reboiler-condenser of the argon enrichment column. The portion of the argon-enriched vapor fed to the reboiler-condenser of the argon enrichment column can be an entirety of the argon-enriched vapor stream output from the argon enrichment column or can be a first portion of that stream. A second portion of that stream can be split from the first portion for being utilized in another element.

In a seventh aspect, the process can also include the HP column outputting a second column reflux stream to feed the second column reflux stream to the LP column.

In an eight aspect, a separation system is provided. The separation system can be configured to utilize any of the above noted aspects of the process for separation of a feed gas comprising oxygen, nitrogen, and argon.

In some embodiments, the separation system can include a first column and a second column. The first column can be a high pressure (HP) column operating at a pressure that is higher than the second column and the second column can be a low pressure (LP) column operating at a pressure that is lower than the first column. The HP column can be connected to the LP column. The system can also include an argon enrichment column and a reboiler positioned adjacent to the argon enrichment column or within a lower portion of the argon enrichment column. The HP column can be connected to the reboiler so that an HP oxygen-enriched stream output from the HP column is feedable to the reboiler for cooling of the HP oxygen-enriched stream. The reboiler can be connected to a reboiler-condenser of the argon enrichment column so that at least a portion of the HP oxygen-enriched stream output from the reboiler is feedable to the reboiler-condenser for condensing at least a portion of an argon-enriched vapor output from the argon enrichment column that is feedable to the reboiler-condenser.

In a ninth aspect, the system can be configured so that the reboiler is positioned in a bottom of the argon enrichment column.

In a tenth aspect, the reboiler can be positioned to receive an argon depleted fluid stream output from the argon enrichment column so that the HP oxygen-enriched stream is coolable via heat transfer with the argon depleted fluid stream.

In an eleventh aspect, the separation system can be configured so that the reboiler is positioned to receive an LP argon-enriched stream output from the LP column so that the HP oxygen-enriched stream is coolable via heat transfer with the LP argon-enriched stream.

In a twelfth aspect, the separation system can be arranged and configured so that the HP column is connected to the LP column such that a second column reflux stream outputtable from the HP column is feedable to the second column reflux stream to the LP column.

In a thirteenth aspect, the reboiler can be connected to the reboiler-condenser of the argon enrichment column and the LP column such that the HP oxygen-enriched stream outputtable from the reboiler is splittable into a first oxygen-enriched stream to feed to the LP column and a second oxygen-enriched stream to feed to the reboiler-condenser of the argon enrichment column.

In a fourteenth aspect, the separation system can be configured and arranged so that the reboiler is connected to the reboiler-condenser of the argon enrichment column such than an entirety of the HP oxygen-enriched stream outputtable from the reboiler is feedable to the reboiler-condenser of the argon enrichment column.

In a fifteenth aspect, a method of retrofitting an air separation unit can be provided. The retrofitting can be provided to facilitate formation or utilization of an embodiment of the separation system or an embodiment of the process for process for separation of a feed gas comprising oxygen, nitrogen, and argon. Embodiments of the method of retrofitting an air separation unit can include positioning a reboiler adjacent to or within an argon enrichment column so that a high pressure (HP) oxygen-enriched stream output from an HP column is feedable to the reboiler to cool the HP oxygen-enriched stream. The method can also include connecting the reboiler to a reboiler-condenser of the argon enrichment column so that at least a portion of the HP oxygen enriched stream output from the reboiler is feedable to the reboiler-condenser for condensing at least a portion of an argon-enriched vapor outputtable from the argon enrichment column that is feedable to the reboiler-condenser.

In a sixteenth aspect, the retrofitting method can be implemented so that the reboiler is positioned in a bottom of the argon enrichment column or within a lower portion of the argon enrichment column.

In a seventeenth aspect, the retrofitting method can be implemented so that the reboiler is positioned adjacent to the argon enrichment column so that an argon depleted fluid stream output from the argon enrichment column is feedable to the reboiler so that the HP oxygen-enriched stream feedable to the reboiler is coolable via heat transfer with the argon depleted fluid stream.

In an eighteenth aspect, the retrofitting method can be implemented so that the reboiler is positioned adjacent to the argon enrichment column so that a low pressure (LP) argon-enriched stream output from a second column is feedable to the reboiler so that the HP oxygen-enriched stream is coolable via heat transfer with the LP argon-enriched stream.

In a nineteenth aspect of the retrofitting method, the positioning of the reboiler adjacent to or within an argon enrichment column can include adjusting conduits to accommodate the use of the reboiler. Other types of adjustments or modifications to an air separation system configuration can also be implemented to facilitate the retrofitting method.

In a twentieth aspect, embodiments of the process for separation of a feed gas, the separation system, or the retrofitting method can be adapted for separation systems that can be arranged and configured as shown in the exemplary embodiments of FIGS. **1-4** or as discussed in the text of the below detailed description section.

It should be appreciated that different streams of fluid that can be utilized in the above discussed embodiments can include vapor, liquid, or a combination of vapor and liquid. Fluid streams that include vapor can include vapor, or gas.

It should also be appreciated that embodiments of the process and/or the system can use a series of conduits for interconnection of different units so that different streams can be conveyed between different units. Such conduits can include piping, valves, and other conduit elements. The system can also utilize sensors, detectors, and at least one controller to monitor operation of the system and/or provide automated or at least partially automated control of the system. Various different sensors (e.g. temperature sensors, pressure sensors, flow sensors, level controllers, etc.) can be connected to different conduits or system elements.

Other elements can also be included in embodiments of the system that may be provided to utilize an embodiment of our process. For instance, one or more pumps, compressors, fans, vessels, pre-treatment units, heat exchangers, expanders, adsorbers, or other units can also be utilized in embodiments of the system. It should be appreciated that embodiments of the system or apparatus can be structured and configured to utilize at least one embodiment of the process.

Other details, objects, and advantages of our processes utilized to recover at least one fluid (e.g. argon, argon and nitrogen, argon, nitrogen, and oxygen, etc.) from air, gas separation plants configured to recover argon from at least one feed gas, air separation plants, air separation systems, systems utilizing multiple columns to recover argon and also optionally nitrogen and/or oxygen fluids, plants utilizing such systems or processes, and methods of making and using the same will become apparent as the following description of certain exemplary embodiments thereof proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to FIGS. **1-5**, a plant can include an air separation unit that includes a compression system **101** that can compress a feed gas **100** to output a compressed feed gas stream **102** at a pre-selected feed pressure or at a pressure within a pre-selected feed pressure range. The feed gas **100** that is compressed can be air or a gas stream from a plant process unit that can be fed to the compression system **101**. The feed gas that is compressed by the compression system can include argon (Ar), nitrogen (N2) and oxygen (O2), as well as other constituents (e.g. carbon dioxide (CO2), water (H2O), etc.).

The compression system **101** can also include a purification unit for purification of the feed after it is compressed. The purification unit can remove undesired feed constituents that may have undesired boiling points or present other undesired processing difficulties. The purification unit can remove, for example, CO2, carbon monoxide (CO), hydrogen (H2), methane (CH4) and/or water (H2O) from the feed, for example.

The compressed feed gas stream **102** output from the compression system **101** can be a purified feed gas stream that has impurities removed from the feed gas so that the impurities are below pre-selected constituent thresholds or are entirely removed from the compressed feed gas before the compressed feed gas stream **102** is passed to a first heat exchanger **105**. In some embodiments, the compressed feed gas stream **102** can include nitrogen (N2) within a pre-selected nitrogen concentration range, argon (Ar) within a pre-selected argon concentration range, and O2 within a pre-selected oxygen concentration range. The pre-selected N2 concentration range can be, for example, 75-80 volume percent (vol %) of the feed gas stream **102**, the pre-selected argon concentration range can be 0.7-3.1 vol % of the feed gas stream **102**, and the pre-selected O2 concentration range can be 19-23 vol % of the feed gas stream **102**, example.

The compressed feed gas stream **102** can be fed to the first heat exchanger **105** via at least one heat exchanger feed conduit positioned between the compression system **101** and the first heat exchanger **105**. As shown in FIGS. **1-4**, the feed gas stream **102** can be split into multiple streams before it is fed to the first heat exchanger **105**. At least one valve or other splitting mechanism can be utilized to split the compressed feed gas stream **102** into multiple streams, for example. The multiple streams that are formed can include a first feed stream portion **104**, a second feed stream portion **110**, and a third feed stream portion **117** for feeding to the first heat exchanger **105**.

Alternatively, the feed gas stream **102** can be fed to the first heat exchanger **105** as a single stream. In yet other embodiments, the feed gas stream may only be split into two feed streams instead of three feed streams or more than two feed streams.

In embodiments where the compressed feed gas stream **102** is split or is splittable, the first feed stream portion **104** can be between 30% and 100% of the entire compressed feed gas stream **102** and the second feed stream portion **110** can be up to 70% of the entire compressed feed gas stream **102** (e.g. greater than 0% to 70% of the feed stream **102**). A third feed stream portion **117** can be up to 50% of the entire compressed feed gas stream **102** (e.g. greater than 0% to 50% of feed stream **102**).

The first heat exchanger **105** can cool the one or more feed gas streams to output the one or more compressed feed gas streams at temperatures within pre-selected temperature ranges for the one or cooled more feed streams. For instance, as can be appreciated from FIGS. **1-4**, the compressed feed gas stream **102** can be split into a first feed stream portion **104**, a second feed stream portion **110** and a third feed stream portion **117**. The first feed stream portion **104** can undergo cooling in the first heat exchanger **105** and be subsequently output as a first cooled compressed feed stream **106** for being fed to a first column **108** of a multiple column tower MCT that is upstream of a second column **137** of the multiple column tower MCT.

The second feed stream portion **110** can be fed to a second feed stream compressor **111** to increase its pressure to form a further compressed second feed stream **112** that is subsequently fed to the first heat exchanger **105** to undergo cooling therein. The cooled further compressed second feed stream **114** output from the first heat exchanger **105** can be fed to a first expander **115** so that the second feed stream **116** output from the first expander **115** can be mixed with the first cooled compressed feed stream **106** to form a first column feed stream **107** for feeding that feed stream to the first column **108** of the multiple column tower MCT.

The first column **108** can be a high pressure (HP) column **108** of the multiple column tower MCT that is positioned below or otherwise upstream of the second column **137**. The second column **137** can be a low pressure (LP) column of the multiple column tower MCT that can operate at a pressure that is lower than the operational pressure of the HP column **108**.

The third feed stream portion **117** can also be compressed via a third feed stream compressor **118** to increase its pressure to form a further compressed third feed stream **119** that is subsequently fed to the first heat exchanger **105** to undergo cooling therein. The cooled further compressed third feed stream **119** can be output from the first heat exchanger **105** as a substantially liquefied third feed stream **121** (e.g. third feed stream **121** is entirely liquid, is between 60 vol % to 100 vol % liquid, is mostly liquid with some vapor mixed therein, is sufficiently liquefied so that the stream has properties of a liquid. etc.). The third feed stream **121** output from the first heat exchanger **105** can be fed to the first column **108** as a second first column feed stream **122** or can be fed to the second column **137** as a second column feed stream **154**. In situations where the second first column feed stream **122** is fed to the first column **108**, the first column feed stream **107** can be considered a first first column feed stream **107**.

In some embodiments or operational cycles utilized during operation of an embodiment, the third feed stream **121** can be split to form the second first column feed stream **122** for feeding to the first column **108** as well as the first second column feed stream **154** for feeding to the second column **137**. At least one valve V positioned in the second first column feed stream conduit extending between the first heat exchanger **105** and the first column **108** and at least one valve V positioned in the first second column feed stream conduit extending between the first heat exchanger **105** and the second column **137** can be adjusted to control the splitting of the third feed stream **121**. The valves V can also (or alternatively) be controlled to adjust the flow of the third feed stream **121** from the entirety of this stream being fed as the second first column feed stream **122** to the first column **108** to an entirety of the third feed stream **121** being fed as the first second column feed stream **154** for feeding to the second column **137** and vice versa.

In some embodiments, the first column feed stream **107** can be provided so it is at an HP column feeding pressure within a pre-selected HP column feeding pressure range (e.g. 4-30 atm, greater than 5 atm and less than 20 atm, etc.) for feeding the first column feed stream **107** to the first column **108**. The cooling via heat exchanger **105** and optional expansion of the second cooled compressed feed stream **114** can be performed so that the first column feed stream **107** is also at a pre-selected HP column feeding temperature that is within a pre-selected HP column feeding temperature range as well as being at a pressure that is within a pre-selected HP column feeding pressure range.

The third feed stream **121** can be formed and compressed to be at the HP feeding pressure within a pre-selected HP feeding pressure range (e.g. 4-100 atm, greater than 5 atm and less than 85 atm, etc.) and also at the a pre-selected HP column feeding temperature that is within a pre-selected HP column feeding temperature range for being fed to the first column **108** as the second first column feed stream **122**. The third stream **121** can also, or alternatively, be further compressed and cooled via the heat exchanger **105** and third stream compressor **118** to be at a pre-selected feeding pressure range (e.g. 4-100 atm) so as to substantially condense and also at a pre-selected LP column feeding temperature that is within a pre-selected LP column feeding temperature range for being fed to the second column **137** as the first second column feed stream **154** for feeding to the second column **137**. Splitting of the initial compressed feed stream **102** and compression of the third feed stream portion **117** can be performed to facilitate providing the third feed stream **121** at the desired temperature and pressure for substantially condensing the fluid of that stream and feeding it to the first column **108**, second column **137**, or being split for feeding different portions to each column based on the operational cycle of operation and particular parameter needs for operation in that cycle of operation.

The first second column feed stream conduit can include a pressure reduction mechanism (e.g. a valve) to lower the pressure of the portion of the third feed stream **121** that may be split to feed to the second column **137** so that the pressure of that portion of the stream is within a pre-selected LP pressure range for feeding to the second column **137**. It should also be appreciated that in a situation where the entirety of the third stream **121** is to be fed to the second column **137**, the third feed stream compressor **118** may not be utilized to further increase the pressure of the third feed stream portion **117**.

The first column **108** can be positioned and configured to process the first column feed stream **107** as well as the as the second first column feed stream **122** that can also be fed to the first column **108**. As discussed above, in some embodiments or some operational cycles, the first column **108** may only process the first column feed stream **107** (e.g. when the third stream **121** is fed in its entirety to the second column **137** as the first second column feed stream **154**). In such situations, the first column feed stream **107** may be the only feed stream fed to the first column **108**.

The first column **108** can receive the first column feed stream **107** at or adjacent the bottom of the first column **108**. The first column **108** can also receive the second first column feed stream **122** (when provided) at or adjacent the bottom of the first column **108** or at a position that is several stages above the bottom of the first column **108**. The first column **108** can operate a pre-selected HP pressure within a pre-selected HP pressure range (e.g. 4.0 atm to 30 atm, 4.5 atm to 16 atm, 4.5 atm to 8 atm, etc.) and can output a HP nitrogen-rich vapor stream **123**, a first HP nitrogen-enriched LP feed stream **128** and an HP oxygen-enriched stream **130**.

The HP oxygen-enriched stream **130** can be considered a crude liquid oxygen (CLOX) stream that can include liquid oxygen (**02**) or a combination of liquid O2 and vapor O2. The HP oxygen-enriched stream **130** can have an oxygen concentration in a range of 25 vol % to 50 vol %, an argon concentration of 0.5 vol % to 3.5 vol %, and a nitrogen concentration in the range of 46.5 vol % to 74.5 vol % or the HP oxygen-enriched stream **130** can include 30 vol % oxygen to 50 vol % oxygen, 1 vol % argon to 3 vol % argon, and have the balance be nitrogen (e.g. 47 vol % nitrogen to 69 vol % nitrogen).

The first HP nitrogen-enriched LP feed stream **128** can have an oxygen concentration in a range of 0 vol % to 10 vol %, an argon concentration of 0 vol % to 3.5 vol %, and balance nitrogen (e.g. nitrogen in 100 vol % to 86.5 vol %) or the first HP nitrogen-enriched stream **128** can include 0 vol % oxygen to 5 vol % oxygen, 1 ppm argon to 3 vol % argon, and have the balance be nitrogen (e.g. be about 100 vol % nitrogen to 92 vol % nitrogen).

The HP nitrogen-rich vapor stream **123** can be a stream that includes gas or vapor that has a nitrogen concentration in the range of 100 vol % nitrogen to 98 vol % nitrogen (e.g. 99 vol % nitrogen, 99.5 vol % nitrogen, etc.). At least a portion of the HP nitrogen-rich vapor stream **123** (e.g. an entirety of the stream or a portion of the stream that is a substantial portion of the stream, etc.) can be fed to a first reboiler-condenser **125** as a first reboiler-condenser feed **124** that is split from the HP nitrogen-rich vapor stream **123**. A remaining portion of the HP nitrogen-rich vapor stream **123** can be fed to the first heat exchanger **105** as a nitrogen-rich cooling medium stream **127** to undergo warming in the first heat exchanger **105** and cool the portions of the feed stream **102** fed to the first heat exchanger **105**. The warmed HP nitrogen-rich vapor stream can be output from the first heat exchanger as a first HP nitrogen-rich vapor product stream **129**. This stream can be fed to a plant process that may use the nitrogen stream.

The first reboiler-condenser **125** can be an HP reboiler-condenser **125**. The first reboiler-condenser **125** can form an HP condensate stream **126**. The HP condensate stream **126** (e.g. an entirety of this stream or less than an entirety of this stream) can be recycled back to the first column **108** as reflux. For instance, at least a portion of the HP condensate stream **126** can be output from the first reboiler-condenser **125** back to the first column **108** as a reflux stream. An entirety of the stream can be provided to the first column or a first portion of this HP condensate stream **126** can be provided back to the first column **108** and a second portion of the HP condensate stream **126** (not shown) can be a HP condensate stream that is feedable to another plant unit.

The first column **108** can be connected to the second column **137** via an LP column feed conduit through which the first HP nitrogen-enriched LP feed stream **128** can be fed to the second column **137**. The LP column feed conduit through which the first HP nitrogen-enriched LP feed stream **128** is passed can include a pressure reduction mechanism (e.g. a valve, an expander, other type of pressure reduction mechanism, etc.) to adjust a pressure of the first HP nitrogen-enriched LP feed stream **128** so it is at a suitable pressure for feeding to the second column **137**.

The second column **137** can be the LP column of the multiple column tower MCT. The second column **137** can operate at a pressure that is below the pressure at which the first column **108** operates. For example, the second column **137** can operate at a pressure of between 1.1 atm and 4 atm, 1.1 atm and 3 atm, or 1.1 and 2.8 atm.

Reflux for the second column **137** can be provided at a top of the LP column, adjacent the top of the LP column **137**, or at another position of the LP column via a suitable reflux stream that includes a suitable concentration of nitrogen. The reflux can include, for example, the first HP nitrogen-enriched LP feed stream **128**.

The second column **137** can be positioned so that rising vapor or column boil-up for the second column **137** is provided by the first reboiler-condenser **125**. Such rising vapor or boil-up can be generated by the first reboiler-condenser **125** and fed to the second column **137** so that this vapor or boil-up flows in counter-current flow with the liquid fed to the second column **137** (e.g. the fluid of the first HP nitrogen-enriched LP feed stream **128** can be liquid that flows downwardly while the vapor or boil-up flows upwardly in the second column **137**, etc.).

The second column **137** can be operated to output multiple flows of fluid during operation. For example, the second column **137** can output at least an LP nitrogen-enriched stream **150**, an oxygen-rich stream **168**, and an LP argon-enriched stream **138**. These streams can each be output from the second column **137** via conduits for feeding those streams to other plant units. The LP nitrogen-enriched stream **150** can be a nitrogen-enriched vapor stream that includes nitrogen in a concentration range of 50 vol % to 70 vol %, a range of 70 vol % to 99.9 vol % nitrogen, or may be entirely nitrogen (e.g. 100 vol % nitrogen or about 100 vol % nitrogen). The LP nitrogen-enriched stream **150** can be output from the second column **137** and fed to the first heat exchanger for cooling therein to form product stream **152**, which can be a nitrogen-rich or nitrogen-enriched product stream.

The oxygen-rich stream **168** can be an impurities containing stream that includes enriched, but relatively low, concentrations of xenon, krypton, CO2, methane, and other hydrocarbons with the balance of the stream being oxygen (e.g. 99-99.99 vol % oxygen, or at least 97 vol % oxygen to 99.99 vol % oxygen). The concentration of the trace impurities within the oxygen-rich stream **168** can be highly variable and can depend on a number of factors including the quantity of the flow. In some embodiments, the oxygen-rich stream **168** can include 0.01 vol % to 3 vol % argon, trace amounts of nitrogen, and the balance oxygen (e.g. 97-99.99 vol % oxygen) and be considered an oxygen-rich or oxygen-enriched product stream.

The oxygen-rich stream **168** can be fed to a pump **169** so a compressed oxygen-rich stream **170** can be fed to the first heat exchanger **105** as a cooling medium therein so that it can be warmed therein while cooling the feed stream **102**. The warmed oxygen-rich stream can be output from the first heat exchanger **105** as an oxygen-enriched product stream **172** or oxygen-rich product stream **172** for subsequent use by another plant process (use as a regeneration gas, directed to another type of device for producing a krypton-enriched product stream and/or a xenon-enriched product stream, etc.). Alternatively, the compressed and warmed oxygen-rich stream can be considered a waste stream and can be output from the heat exchanger **105** as an oxygen-enriched or oxygen-rich waste stream **172** that can be emitted to the atmosphere. In situations where the oxygen-rich stream **168** is to be considered a waste stream or the oxygen-rich stream **168** does not need to undergo an increase in pressure for further use of that stream, the pump **169** may not be utilized to increase the pressure of the stream before it is fed to the first heat exchange **105**.

The LP nitrogen-enriched stream **150** can be output from the second column **137** and fed to the first heat exchanger **105** for functioning as a cooling medium therein to help cool the compressed feed gas fed therein. The warmed LP nitrogen-enriched stream **152** can be output from the first heat exchanger **105** for being emitted as waste gas to atmosphere or used in another plant unit (e.g. used as a product gas, regeneration gas, fed to another plant unit or other use, etc.).

The LP argon-enriched stream **138** can include 5 vol % to 25 vol % argon, 0 to 1000 ppm nitrogen, and the balance oxygen (about 74.9 vol % oxygen to 95 vol % oxygen). The LP argon-enriched stream **138** can be a flow of fluid that includes vapor. The LP argon-enriched stream **138** can be output from the second column **137** and fed to a third column **139**. The third column **139** can be considered an argon enrichment column ArC. The argon enrichment column ArC can also be considered an argon column.

An LP argon-enriched feed conduit can be connected between the second column **137** and the argon enrichment column ArC for feeding the LP argon-enriched stream **138** to the argon enrichment column ArC. The LP argon-enriched stream **138** can be fed to a lower portion of the argon enrichment column ArC (e.g. at a bottom of the column or adjacent a bottom of the column). LP argon-enriched stream **138** can ascend within the argon enrichment column ArC to exit the top of the column or exit adjacent the top of the column as an argon-rich vapor stream **142**. The argon-rich vapor stream can have a concentration of argon that is higher than the concentration of argon within the LP argon-enriched stream **138** fed to the argon enrichment column ArC. For instance, the argon-rich vapor stream **142** can include 100 vol % to 95 vol % argon (e.g. the argon-rich vapor stream **142** can include 0 vol % to 4 vol % oxygen, 0 vol % to 1 vol % nitrogen, and the balance argon).

The argon-rich vapor stream **142** can be output from the argon enrichment column ArC and fed to a second reboiler-condenser **143** via an argon vapor reboiler-condenser feed conduit positioned between the argon enrichment column ArC and the second reboiler-condenser **143**. The second reboiler-condenser **143** can substantially condense the argon-rich vapor of the argon-rich vapor stream **142** to a liquid (e.g. condense an entirety of the argon-rich vapor to a liquid or condense at least 90% of the vapor to a liquid, condense at least 95% of the vapor to a liquid, condense enough of the argon-rich vapor so that it acts as a liquid or the condensed stream output from the second reboiler-condenser has the properties of a liquid, etc.). The substantially condensed or entirely condensed argon-rich stream **144** output from the second reboiler-condenser **143** can be fed to a phase separator PS that can output an argon vapor product stream **148** that includes argon (Ar) at high concentrations (e.g. 100 vol % Ar to 95 vol % Ar, between 100 vol % Ar and 99 vol % Ar, etc.). A liquid argon reflux stream **146** can be output from the phase separator PS and fed back to the argon enrichment column ArC.

The liquid argon reflux stream **146** can be output from the separator PS or as a fluid portion of argon-rich fluid stream **144** for feeding as reflux to the argon enrichment column ArC via an argon enrichment column reflux conduit connected between the argon enrichment column ArC and the phase separator PS. The argon enrichment column ArC can receive the liquid argon reflux stream **146** adjacent an upper portion of the argon enrichment column ArC (e.g. at its top or near its top) so that the liquid argon reflux is passed downwardly through the argon enrichment column ArC in counter-current flow with the uprising argon vapor of the argon-enriched stream **138** fed to the argon enrichment column ArC.

In some embodiments, the condensed argon-rich fluid of the argon-rich vapor stream **142** fed to the second reboiler-condenser **143** can be output from the second reboiler-condenser **143** as an argon-rich fluid stream **144** which is entirely liquid. In such a case a phase separator PS in not necessary and the argon product stream **148** can be split off from argon-rich fluid stream **144** and the remaining flow of the argon-rich fluid stream **144** not split off to form the product stream can be used as the liquid argon reflux stream **146**.

The argon enrichment column ArC can also output an argon depleted fluid stream **140** for feeding to the second column **137** via an argon depleted fluid feed conduit connected between the second column **137** and the argon enrichment column ArC. The argon depleted fluid stream **140** can be output at a lower portion of the argon enrichment column ArC (e.g. at its bottom or adjacent its bottom) for feeding to a location that is below the location at which the LP argon-enriched stream **138** is output from the second column **137** or can be located at a position at or near the position at which the LP argon-enriched stream **138** is output from the second column **137**.

The argon enrichment column ArC can also utilize a reboiler **131** (e.g. have the reboiler **131** positioned adjacent the column and/or within the column, etc.). The reboiler **131** can be included within a lower portion (e.g. a bottom) of the argon enrichment column ArC as shown in FIG. **1**, for example. This reboiler would be referred to as an internal reboiler. Alternatively reboiler **131** can be physically located outside the argon enrichment column ArC and connected to the argon enrichment column ArC so that the reboiler **131** can receive a liquid feed from the argon enrichment column ArC and return a partially boiled stream back to the argon enrichment column ArC. This reboiler would be referred to as an external reboiler. The thermodynamic effect of these two reboilers is the same.

The reboiler **131** can be positioned adjacent the argon enrichment column ArC by being positioned for subcooling the HP oxygen-enriched stream **130** while warming the argon depleted fluid stream **140** after the argon depleted fluid stream **140** is output from the argon enrichment column ArC and before it is fed to the second column **137** as shown in FIG. **2**. Alternatively, the argon depleted fluid stream **140** output from the reboiler **131** can be recycled directly to the argon enrichment column ArC by being fed to the LP argon-enriched stream **138** for mixing therewith before that stream is fed to the argon enrichment column ArC as shown in broken line **140***a* in FIG. **2**. As yet another alternative, the argon depleted fluid stream **140** output from the reboiler **131** can be recycled more directly to the argon enrichment column ArC by being fed directly back to the argon enrichment column ArC via a heated argon depleted fluid stream recycle conduit connected between the reboiler **131** and the argon enrichment column ArC.

As yet another option, the reboiler **131** can alternatively be positioned adjacent the argon enrichment column ArC by being positioned for subcooling the HP oxygen-enriched stream **130** while heating the LP argon-enriched stream **138** before the LP argon-enriched stream **138** is fed to the argon enrichment column ArC as shown in FIG. **3**.

In the embodiments of FIGS. **2** and **3**, the reboiler **131** can be configured as a heat exchanger configured for cooling the HP oxygen-enriched stream **130** output from the first column **108** while also warming the LP argon-enriched stream **138** or the argon depleted fluid stream **140** for vaporizing some of that stream and/or increasing the temperature of that stream. Such warming and cooling can be provided via a heat exchanger, or heat transfer between the streams received by the reboiler **131**.

In the embodiments discussed above concerning FIGS. **1-3**, the plant **1** can be configured to produce a HP nitrogen-rich vapor stream **123** which can be fed to the first heat exchanger **105** and output from the first heat exchanger as a first HP nitrogen-rich vapor product stream **129**. The plant **1** can also produce an LP nitrogen-enriched stream **150** which can be fed to the first heat exchanger **105** and output from the first heat exchanger as a nitrogen-rich or nitrogen-enriched product stream. An additional nitrogen-rich product stream may also be recovered from the second column **137** as stream **450**, an example of which is shown in FIG. **4**. It should be appreciated that the embodiment of FIG. **4** is a modification of the embodiment of FIG. **1**. The utilization of this additional nitrogen-rich product stream **450** (an example of which is shown in FIG. **4**) can be utilized in other embodiments as well (e.g. embodiments of FIGS. **2** and **3**, etc.).

As can be appreciated from FIG. **4**, the HP condensate stream **126** can be split so a first portion is used as reflux for the first column **108** and a second portion is used as a pure reflux stream **428** for the second column **137**. The second LP nitrogen-enriched stream **450** can be output from the second column **137** and fed to the first heat exchanger **105** for cooling therein to form a pure product nitrogen stream **452** (or a substantially pure product nitrogen stream **452**). The second LP nitrogen-enriched stream **450** can be a nitrogen-enriched vapor stream that includes nitrogen in a concentration range of 95 vol % to essentially 100 vol % (e.g. having a de minimis level of impurities) or can include nitrogen in a concentration range of 95 vol % to less than or equal to 100 vol % in some embodiments. In this embodiment of FIG. **4**, the LP nitrogen-enriched stream **150** output from the LP column **137** can be considered a first LP nitrogen-enriched stream that can be emitted as waste gas to atmosphere or used in another plant unit (e.g. used as a product gas, regeneration gas, fed to another plant unit or other use, etc.).

Similar modifications as discussed above can be made to the embodiments of FIGS. **2** and **3**, as well. In such additional embodiments, the LP nitrogen-enriched stream

150 output from the LP column can be considered a first LP nitrogen-enriched stream and the LP column can also emit the second LP nitrogen-enriched stream 450 for being heated in the heat exchanger 105 for outputting the product nitrogen stream 452. The HP condensate stream 126 can be split for such embodiments as well similar to the above discussed embodiment of FIG. 4 (e.g. the HP condensate stream 126 can be split so a first portion is used as reflux for the first column 108 and a second portion is used as a pure reflux stream 428 for the second column 137).

In the embodiment of FIG. 1, the reboiler 131 can be considered a reboiler or a heat exchanger within the argon enrichment column ArC that is positioned and configured to cool the HP oxygen-enriched stream 130 output from the first column 108 within the argon enrichment column ArC and also generates vapor from the liquid descending to the bottom of the ArC.

After the HP oxygen-enriched stream 130 is cooled via the reboiler 131, the HP oxygen-enriched stream 130 can be routed as a subcooled HP oxygen-enriched stream 132. The subcooled HP oxygen-enriched stream 132 can be split into a first oxygen-enriched feed stream 133 and a second-reboiler-condenser oxygen-enriched feed stream 134. The first oxygen-enriched feed stream 133 can undergo a pressure reduction via a pressure reduction mechanism (e.g. a valve, other type of suitable mechanism, etc.) prior to being fed to the second column 137. The second reboiler-condenser oxygen-enriched feed stream 134 can be fed to the second reboiler-condenser 143 for being warmed therein to a vapor or at least a partially vaporized fluid and provide the cooling medium for condensation of the argon-rich vapor stream 142 fed therein. The second-reboiler-condenser oxygen-enriched feed stream 134 can be output from the second-reboiler-condenser 143 as a second oxygen-enriched feed stream 136 for feeding to the second column 137. The second oxygen-enriched feed stream 136 can undergo a pressure reduction to a suitable pressure for feeding to the second column 137 prior to the stream being fed to the second column 137 as well (e.g. via a pressure reduction mechanism such as a valve or other type of suitable mechanism).

The second oxygen-enriched feed stream 136 can be fed to the second column 137 at a location that is below the location at which the first oxygen-enriched feed stream 133 is fed to the second column 137. In other embodiments, the two feed streams can be mixed together (not shown) prior to being fed to the second column 137.

It should be appreciated that these various streams 133 and 134 can each be considered different portions of the HP oxygen-enriched stream 130 that is split to form those streams. Each stream can be considered a first portion or a second portion of the HP oxygen-enriched stream 130, for example.

It should also be appreciated that the HP oxygen-enriched stream 132 can be further cooled by heating other gas and or liquid streams before being utilized in the reboiler-condenser 143, such as heating liquid at the bottom of another argon column to further purify argon product stream 148.

It should also be understood that the first HP nitrogen-enriched LP feed stream 128 as well as the first oxygen-enriched feed stream 133 and the second oxygen-enriched feed stream 136 can all be fed to the second column 137 in some operational cycles or some embodiments. When all such flows are fed to the second column 137, the first HP nitrogen-enriched LP feed stream 128 can be considered a second column reflux stream. Alternatively, in such situations, the first oxygen-enriched feed stream 133 can be considered a third oxygen-enriched LP feed stream and the second oxygen-enriched feed stream 136 can be considered a second oxygen-enriched LP feed stream.

The above discussed embodiments of FIGS. 1-4 can utilize a multiple column process that includes the first column 108 configured as an HP column, a second column 137 configured as an LP column, and a third column 139 configured as an argon enrichment column ArC. The argon recovery benefits of utilization of the reboiler 131 within the argon enrichment column ArC or adjacent the argon enrichment column ArC to cool the HP oxygen-enriched stream 130 prior to that stream being at least partially fed to the second reboiler-condenser 143 of the argon enrichment column ArC can also be obtained without the splitting of the HP oxygen-enriched stream 130. For example, in some implementations or in some operational cycles, the HP oxygen-enriched stream 130 may not be split and instead, the entirety of this stream may be fed to the second reboiler-condenser 143. In such embodiments or operational cycles, the second-reboiler-condenser oxygen-enriched feed stream 134 can include an entirety of the HP oxygen-enriched stream 132 output from the reboiler 131 and the second oxygen-enriched feed stream 136 output from the second reboiler-condenser can be considered a first oxygen-enriched feed stream that is fed to the second column 137 since stream 133 will not be formed for such implementations or operational cycles.

In some implementations, valves V can be provided for the conduits through which the second-reboiler-condenser oxygen-enriched feed stream 134 passes to the second reboiler-condenser 143 and through which the first oxygen-enriched feed stream 133 can pass for being fed to the second column 137. The valves can be adjusted between open and closed positions to adjust how the subcooled HP oxygen-enriched stream 132 output from the reboiler 131 can be split (e.g. proportion of subcooled HP oxygen-enriched stream 132 passed to each stream and/or adjustment of valves V to avoid formation of the first oxygen-enriched feed stream 133 and have the entirety of the subcooled HP oxygen-enriched stream 132 fed to the second reboiler-condenser 143 as the second-reboiler-condenser oxygen-enriched feed stream 134). The valves V can also (or alternatively) be included in these conduits to provide pressure reduction for these streams.

It should be appreciated that the plant 1 can be configured to utilize an air separation process that can be configured to facilitate recovery of at least one argon fluid. The air separation process can also provide for recovering at least one nitrogen fluid flow as well as at least one argon fluid flow. The air separation process can also provide for recovering at least one oxygen fluid flow as well as at least one argon fluid flow. Embodiments can also recover at least three fluids (e.g. at least one oxygen fluid flow, at least one nitrogen fluid flow, and at least one argon fluid flow) as well.

Embodiments of the plant can utilize a controller, such as the exemplary controller shown in FIG. 5, to help monitor and/or control operations of the plant. The plant can be configured as an air separation system or a cryogenic air separation system that is configured as a standalone facility or is incorporated in a larger facility having other plant facilities (e.g. a manufacturing plant for making semiconductor chips, an industrial plant for making goods, a mineral refining facility, etc.).

It should be appreciated that embodiments of the plant including the embodiments of FIGS. 1-4 can be configured as an air separation plant or other type of plant in which it is desired to recover (a) only argon from a feed gas, (b) nitrogen and argon from a feed gas, (c) oxygen and argon from a feed gas, (d) nitrogen, argon, and oxygen from a feed gas, or (e), nitrogen, argon, oxygen, as well as krypton xenon, and/or neon from a feed gas (e.g. air, waste emissions from a plant, etc.).

It should be understood that some embodiments (e.g. embodiment of FIG. **1**) can utilize a reboiler **131** positioned near or at the bottom of argon enrichment column ArC to increase boil-up therein and simultaneously provide added cooling duty to drive a condenser of the second reboiler-condenser **143** of the argon enrichment column ArC to provide improved argon recovery.

In other embodiments (e.g. embodiment of FIG. **2**), the reboiler **131** can be provided and positioned to vaporize a portion of the argon depleted fluid stream **140** before it is returned to the second column **137**. This recycled vapor may then ultimately be added into the flow of LP argon-enriched stream **138**. This arrangement can permit the reboiler **131** to provide the same additional boilup for the argon enrichment column ArC as may be provided in other embodiments (e.g. FIG. **1**). Similarly, the reboiler's output of the subcooled HP oxygen-enriched stream **132** simultaneously provides added cooling duty to drive the condenser of the second reboiler-condenser **143** (as in FIG. **1**).

In yet other embodiments (e.g. the embodiment of FIG. **3**), the reboiler **131** can be positioned and arranged to increase the temperature of the LP argon-enriched stream **138** before that flow is fed to the argon enrichment column ArC. That additional heat added to this stream can cause the liquid it contacts with in the packing of the argon enrichment column ArC to partially vaporize. This can provide the same type of improved added boilup for the argon enrichment column ArC that can be obtained in other arrangements (e.g. the embodiment of FIG. **2**). Also, the reboiler's output of the subcooled HP oxygen-enriched stream **132** can simultaneously provide added cooling duty to drive the condenser of the second reboiler-condenser **143** (as in FIGS. **1** and **2**).

As can be appreciated from the discussion of exemplary embodiments discussed herein, different embodiments can be arranged and configured so that there is an increased boilup and reflux provided for the argon enrichment column ArC. This increase in boilup and reflux can be proportional such that the increase in boilup is equal to the increase in reflux that can be provided. The increasing of the boilup and reflux by equal amounts can have the effect of increasing product purity and/or permit an increase in a flow rate of obtained product having the same purity (which in either case provides an improvement in recovery).

The plant can be configured to include process control elements positioned and configured to monitor and control operations (e.g. temperature and pressure sensors, flow sensors, an automated process control system having at least one work station that includes a processor, non-transitory memory and at least one transceiver for communications with the sensor elements, valves, and controllers for providing a user interface for an automated process control system that may be run at the work station and/or another computer device of the plant, etc.).

An example of such a process control system that may be included is shown in FIG. **4**, for example. The process control system can include a controller having a processor that is connected to a computer readable medium and at least one interface. The computer readable medium can have a program stored thereon that defines a process control method implemented by the controller when the processor runs the program. The controller can receive data from sensors (e.g. temperature sensors, flow sensors, pressure sensors, etc.) and utilize that data when implementing the method defined by the program. The controller can be communicatively connected to at least one input device and at least one output device as well. The at least one input device can be, for example, a workstation, a keyboard, a pointer device, or other type of input device. The output device can include a touch screen, a screen, a monitor, a printer, or other type of output device.

EXAMPLE

Fundamental simulations were carried out to evaluate the utility of different embodiments of the invention and try and ascertain the type of improvements that could be provided by implementation of the embodiments. Table 1 provides a summary of argon recovery, as well as selected material balance flows, and compositions for a simulated implementation of the embodiment of FIG. **1**, which produced zero low pressure high purity gaseous nitrogen delivery product. Table 1 also provides simulation results from a comparable conventional process used to provide an evaluation of how the simulated implementation of an embodiment of FIG. **1** would perform as compared to a comparable conventional process.

TABLE 1

Simulation Parameters and Results From Conducted Evaluation

Parameters	Conventional Process	Simulated Implementation of Embodiment Of Figure 1
Inlet dry air flow (Nm^3/hr)	518931	518916
Oxygen recovery (mole/100)	19.27	19.27
Nitrogen recovery (mole/100)	19.3	19.3
Argon recovery (%)	67.9	70.6
Liquid Argon (mTPD)	139.1	144.8
Condenser duty (kW)	−8385.88	−8836.84
Reboiler duty (kW)	0	627.302

The conventional process does not utilize a reboiler **131**. This is why the conventional process does not have any reboiler duty (e.g. a reboiler duty of 0 kW).

The information in Table 1 demonstrates that compared to the conventional process, the implementation of the embodiment of FIG. **1** can deliver significantly higher argon recovery (about a 4% increase in performance in argon recovery by increasing recovery by 2.7% points).

Further, the simulation results showing that both the condenser and reboiler duties changed significantly (reboiler duty was 627.302 kW as compared to 0 kW and the condenser duty changes from −8385.88 kW to −8836.84 kW) demonstrated that the boilup and reflux have increased, with the result being higher argon recovery.

In this conducted simulation, the increased condenser duty that was found to be provided by use of the reboiler **131** for this simulated experiment is almost fully reflected by the improvement in condenser duty that can be obtained. The simulation work that was performed confirmed our belief that embodiments can provide a significant improvement in argon recovery that can permit more flexible operation that can also provide more efficient processing.

We also ran a simulation that tried matching the base case argon recovery of a prior art process. This resulted in the simulation for an exemplary embodiment including an implementation of reboiler **131** and reducing a number of stages in at least one column to permit a matching of argon recovery to try and determine how an exemplary use of the reboiler **131** may permit other types of improvements in operational efficiency. In that simulation, we found that six stages from a column could be removed to get the same recovery of argon. The reduction in stages that can be provided can improve operational efficiency as well as reduce capital and operational costs.

It should be appreciated that embodiments can be provided without any increase in power to obtain the increased argon recovery. For instance, the reboiler and condenser duties can be provided by heat pumping and the heat pumping can be provided with or without a power impact. If there is a power impact it can appear as higher feed pressure or more feed flow, or lower product delivery pressure. In those situations, however, the supposed power impact can be negligible or insignificant in view of the improved argon recovery that is obtained. For example, the increase in a condenser duty can be essentially (if not exactly) offset by an increase in reboiler duty of the reboiler **131**.

Moreover, embodiments can be provided for retrofitting a pre-existing air separation unit. For instance, a retrofitting method can include providing a reboiler **131** for positioned in an argon enrichment column ArC or adjacent an argon enrichment column ArC. Conduits can be rearranged or adjusted as may be needed to accommodate the use of the new reboiler **131**. The reboiler **131** can be positioned in the argon enrichment column ArC as shown in FIG. **1** during the retrofit operation. Alternatively, the reboiler **131** can be retrofit into a pre-existing facility so the reboiler **131** is positioned for subcooling an HP oxygen-enriched stream **130** output from an HP column while heating an LP argon-enriched stream **138** output from an LP column via heat transfer between these streams before the LP argon-enriched stream **138** is fed to the argon enrichment column ArC as shown in FIG. **3**. As yet another option, the retrofit operation can be performed so that the reboiler **131** is positioned for subcooling an HP oxygen-enriched stream **130** output from an HP column while warming the argon depleted fluid stream **140** after the argon depleted fluid stream **140** is output from an argon enrichment column ArC via heat transfer between these streams and before the argon depleted fluid stream **140** is fed to an LP column **137** as shown in FIG. **2** and/or can be recycled directly back to the steam **138** for feeding back to the argon enrichment column ArC as shown via broken line **140***a* in FIG. **2**.

Embodiments of the retrofitting can also include providing updated process control elements, an updated automated process control program, or other products or services for installation of the reboiler **131** and subsequent use of an embodiment of our air separation process that can include use of the reboiler **131** as discussed herein.

It should be appreciated that modifications to the embodiments explicitly shown and discussed herein can be made to meet a particular set of design objectives or a particular set of design criteria. For instance, the arrangement of valves, piping, and other conduit elements (e.g. conduit connection mechanisms, tubing, seals, etc.) for interconnecting different units of the plant for fluid communication of the flows of fluid between different units can be arranged to meet a particular plant layout design that accounts for available area of the plant, sized equipment of the plant, and other design considerations. For instance, the size of each column, number of stages each column has, the size and arrangement of each reboiler-condenser, and the size and configuration of any heat exchanger, conduits, expanders, pumps, or compressors can be modified to meet a particular set of design criteria. As another example, the flow rate, pressure, and temperature of the fluid passed through one or more heat exchangers as well as passed through other plant elements can vary to account for different plant design configurations and other design criteria. As yet another example, the number of plant units and how they are arranged can be adjusted to meet a particular set of design criteria. As yet another example, the material composition for the different structural components of the units of the plant and the plant can be any type of suitable materials as may be needed to meet a particular set of design criteria.

As another example, it is contemplated that a particular feature described, either individually or as part of an embodiment, can be combined with other individually described features, or parts of other embodiments. The elements and acts of the various embodiments described herein can therefore be combined to provide further embodiments. Thus, while certain exemplary embodiments of the processes utilized to recover fluids (e.g. argon, argon and nitrogen, argon and oxygen, etc.) from air, gas separation plants configured to recover at least argon from at least one feed gas, air separation plants, air separation systems, systems utilizing multiple columns to recover nitrogen and argon, plants utilizing such systems or processes, and methods of making and using the same have been shown and described above, it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims.

What is claimed is:

1. A process for separation of a feed gas comprising oxygen, nitrogen, and argon, the process comprising:

compressing a feed gas via a compression system of a separation system having a first column and a second column, the first column being a high pressure (HP) column operating at a pressure that is higher than the second column, the second column being a low pressure (LP) column operating at a pressure that is lower than the first column;

feeding the compressed feed gas to a first heat exchanger to cool the compressed feed gas;

feeding at least a first portion of the compressed and cooled feed gas to the HP column to produce an HP oxygen-enriched stream;

passing the HP oxygen-enriched stream output from the HP column through a reboiler positioned between the HP column and an argon enrichment column;

passing an argon depleted fluid stream output from the argon enrichment column to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the argon depleted fluid stream or passing an LP argon-enriched stream output from the LP column to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the LP argon-enriched stream;

the reboiler outputting the HP oxygen-enriched stream after the HP oxygen-enriched stream is cooled; and

passing at least a portion of the HP oxygen-enriched stream output from the reboiler to a reboiler-condenser of the argon enrichment column for condensing at least a portion of an argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser.

2. The process of claim **1**, wherein the reboiler is positioned in a bottom of the argon enrichment column or within the argon enrichment column.

3. The process of claim 1, wherein the passing of at least a portion of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column for condensing at least a portion of the argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser comprises:

splitting the HP oxygen-enriched stream output from the reboiler to form a first oxygen-enriched stream to feed to the LP column and a second oxygen-enriched stream to feed to the reboiler-condenser of the argon enrichment column.

4. The process of claim 1, wherein the passing of at least a portion of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column for condensing at least a portion of the argon-enriched vapor output from the argon enrichment column that is fed to the reboiler-condenser comprises:

passing an entirety of the HP oxygen-enriched stream output from the reboiler to the reboiler-condenser of the argon enrichment column.

5. The process of claim 1, comprising:

the HP column outputting a second column reflux stream to feed the second column reflux stream to the LP column.

6. The method of claim 1, wherein the passing of the argon depleted fluid stream output from the argon enrichment column to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the argon depleted fluid stream is performed.

7. The method of claim 1, wherein the passing of the LP argon-enriched stream output from the LP column to the reboiler so that the HP oxygen-enriched stream is cooled via heat transfer with the LP argon-enriched stream is performed.

8. A separation system comprising:

a first column and a second column, the first column being a high pressure (HP) column operating at a pressure that is higher than the second column, the second column being a low pressure (LP) column operating at a pressure that is lower than the first column, the HP column being connected to the LP column;

an argon enrichment column;

a reboiler;

the HP column connected to the reboiler so that an HP oxygen-enriched stream output from the HP column is feedable to the reboiler for cooling of the HP oxygen-enriched stream;

the reboiler positioned to receive an argon depleted fluid stream output from the argon enrichment column so that the HP oxygen-enriched stream is coolable via heat transfer with the argon depleted fluid stream; and

the reboiler connected to a reboiler-condenser of the argon enrichment column so that at least a portion of the HP oxygen-enriched stream is feedable to the reboiler-condenser for condensing at least a portion of an argon-enriched vapor output from the argon enrichment column that is feedable to the reboiler-condenser.

9. The separation system of claim 8, wherein the reboiler is positioned in a bottom of the argon enrichment column.

10. The separation system of claim 8, wherein the HP column is connected to the LP column such that a second column reflux stream outputtable from the HP column is feedable to the second column reflux stream to the LP column.

11. The separation system of claim 8, wherein the reboiler is connected to the reboiler-condenser of the argon enrichment column and the LP column such that the HP oxygen-enriched stream outputtable from the reboiler is splittable into a first oxygen-enriched stream to feed to the LP column and a second oxygen-enriched stream to feed to the reboiler-condenser of the argon enrichment column.

12. The separation system of claim 8, wherein the reboiler is connected to the reboiler-condenser of the argon enrichment column such than an entirety of the HP oxygen-enriched stream outputtable from the reboiler is feedable to the reboiler-condenser of the argon enrichment column.

13. A method of retrofitting an air separation unit, comprising:

positioning a reboiler between a high pressure (HP) column and an argon enrichment column so that an HP oxygen-enriched stream output from an HP column is feedable to the reboiler to cool the HP oxygen-enriched stream and (i) so that an argon depleted fluid stream output from the argon enrichment column is feedable to the reboiler so that the HP oxygen-enriched stream feedable to the reboiler is coolable via heat transfer with the argon depleted fluid stream or (ii) so that a low pressure (LP) argon-enriched stream output from a second column is feedable to the reboiler so that the HP oxygen-enriched stream is coolable via heat transfer with the LP argon-enriched stream;

connecting the reboiler to a reboiler-condenser of the argon enrichment column so that at least a portion of the HP oxygen enriched stream output from the reboiler is feedable to the reboiler-condenser for condensing at least a portion of an argon-enriched vapor outputtable from the argon enrichment column that is feedable to the reboiler-condenser.

14. The method of claim 13, wherein the reboiler is positioned in a bottom of the argon enrichment column or within a lower portion of the argon enrichment column.

15. The method of claim 13, wherein the positioning of the reboiler includes adjusting conduits to accommodate use of the reboiler.

16. The method of claim 13, wherein the reboiler is positioned so that the argon depleted fluid stream output from the argon enrichment column is feedable to the reboiler so that the HP oxygen-enriched stream feedable to the reboiler is coolable via heat transfer with the argon depleted fluid stream.

17. The method of claim 13, wherein the reboiler is positioned so that the LP argon-enriched stream output from the second column is feedable to the reboiler so that the HP oxygen-enriched stream is coolable via heat transfer with the LP argon-enriched stream.

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