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(54) **SYSTEM AND PROCESS FOR NATURAL GAS LIQUEFACTION**

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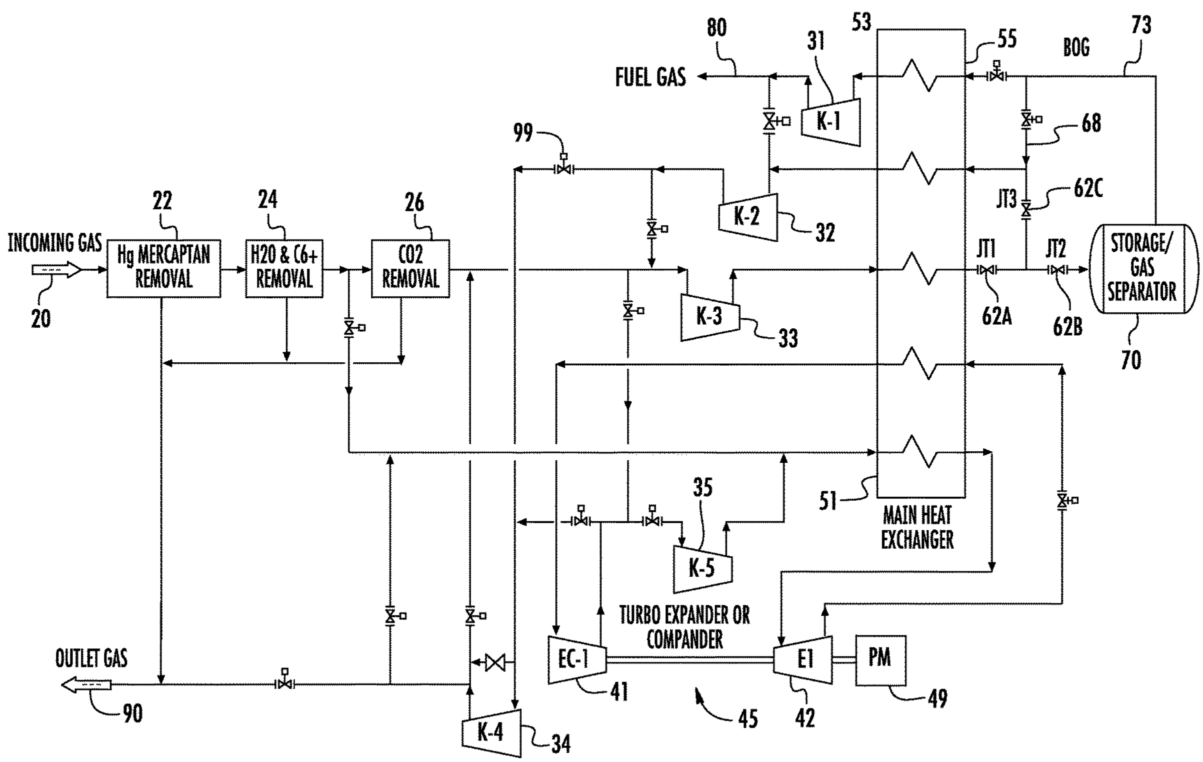
(57) **ABSTRACT**

Systems and processes for natural gas processing, liquefaction, and storage are described. The systems and processes include one or more arrangements of features which are capable of liquefying all of the gas entering an inlet of the system or a portion of the entering gas. The portion of the entering gas that is liquefied can vary based on the pressure of an outlet of the system, which can be fixed or vary based on usage downstream.



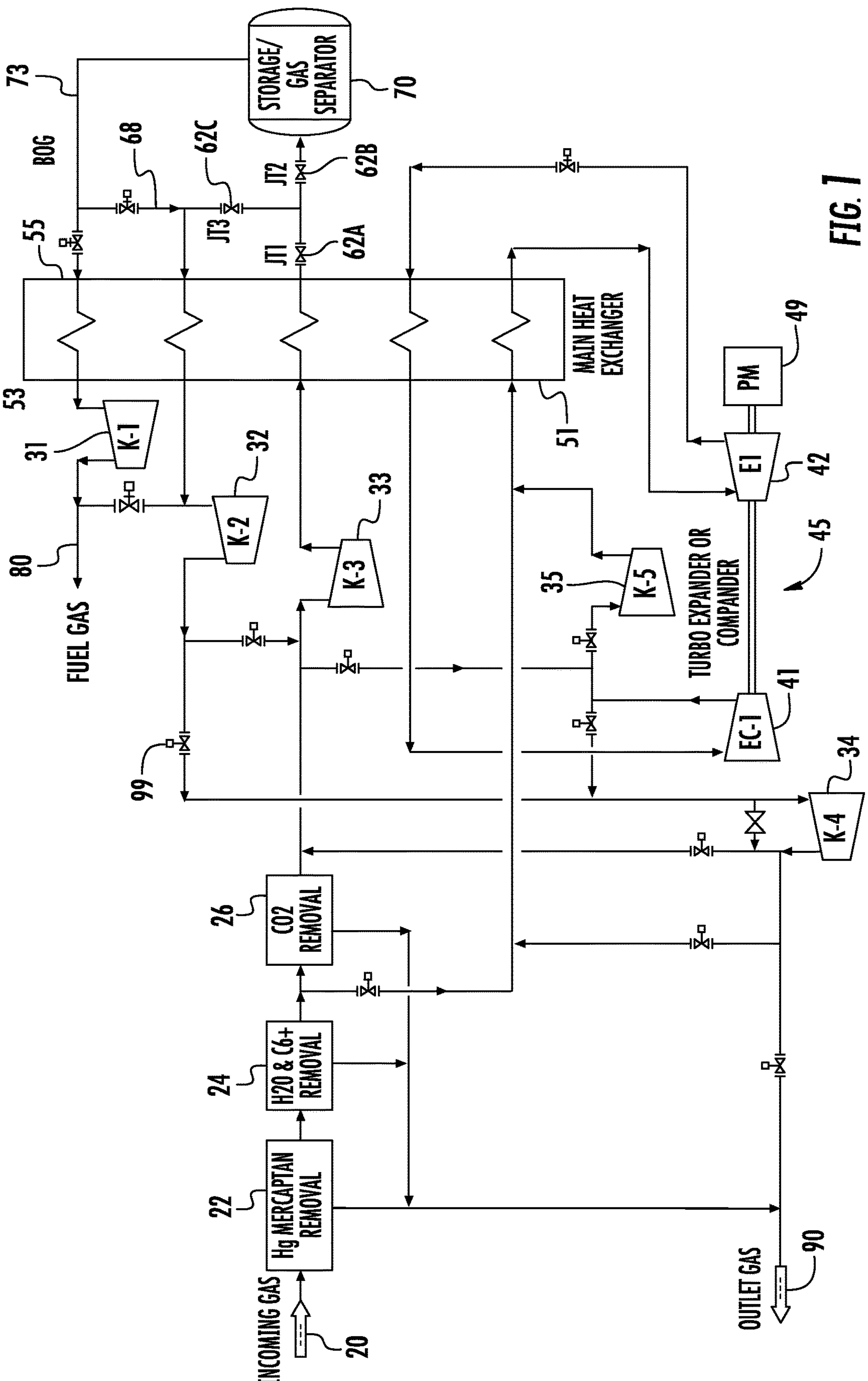

STORAGE/
GAS
SEPARATOR
70
73
BOG
68
62C
62B
JT2
JT3
JT1
62A
55
MAIN HEAT
EXCHANGER
53
51
K-1
31
K-2
32
K-3
33
K-5
35
80
FUEL GAS
PM
49
E1
42
TURBO EXPANDER OR
COMPANDER
45
EC-1
41
K-4
34
99
CO2
REMOVAL
26
H2O & C6+
REMOVAL
24
Hg MERCAPTAN
REMOVAL
22
INCOMING GAS
20
OUTLET GAS
90

FIG. 1

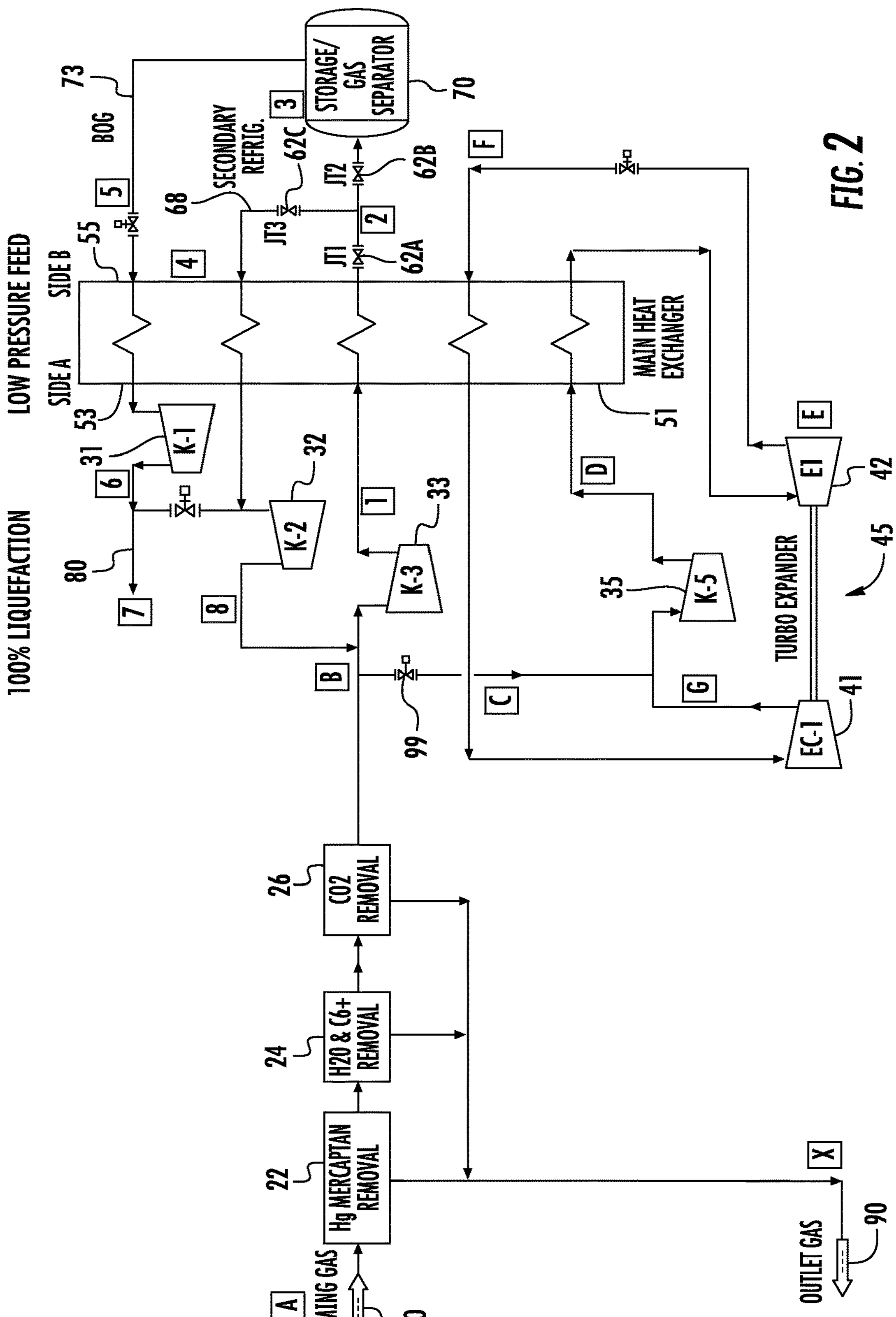

100% LIQUEFACTION
LOW PRESSURE FEED
SIDE A
SIDE B
MAIN HEAT EXCHANGER
STORAGE/ GAS SEPARATOR
BOG
SECONDARY REFRIG.
JT1
JT2
JT3
62A
62B
62C
68
73
70
55
53
51
31
32
33
35
41
42
45
80
99
K-1
K-2
K-3
K-5
E1
EC-1
TURBO EXPANDER
A
B
C
D
E
F
G
X
1
2
3
4
5
6
7
8
INCOMING GAS
20
Hg MERCAPTAN REMOVAL
22
H20 & C6+ REMOVAL
24
CO2 REMOVAL
26
OUTLET GAS
90

FIG. 2

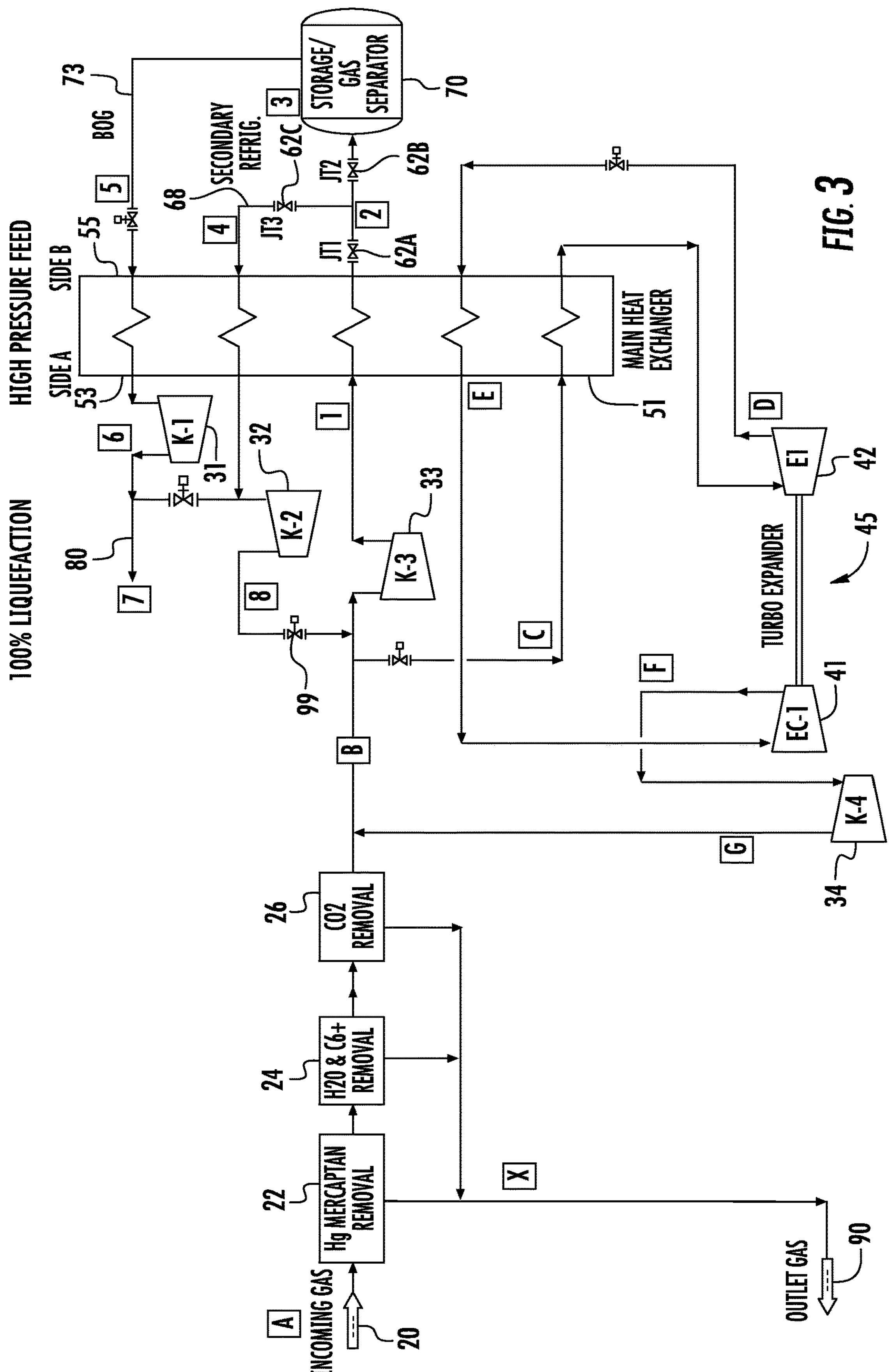

HIGH PRESSURE FEED
SIDE A
SIDE B
55
53
100% LIQUEFACTION
BOG
73
5
SECONDARY REFRIG.
68
4
JT3
62C
JT1
62A
2
JT2
62B
3
STORAGE/ GAS SEPARATOR
70
MAIN HEAT EXCHANGER
51
1
E
D
6
K-1
31
32
K-2
80
7
8
K-3
33
99
C
B
E1
42
TURBO EXPANDER
45
41
EC-1
F
K-4
G
34
26
CO2 REMOVAL
24
H20 & C6+ REMOVAL
22
Hg MERCAPTAN REMOVAL
X
A
INCOMING GAS
20
OUTLET GAS
90

FIG. 3

VARIABLE PRESSURE LET DOWN LIQUEFACTION

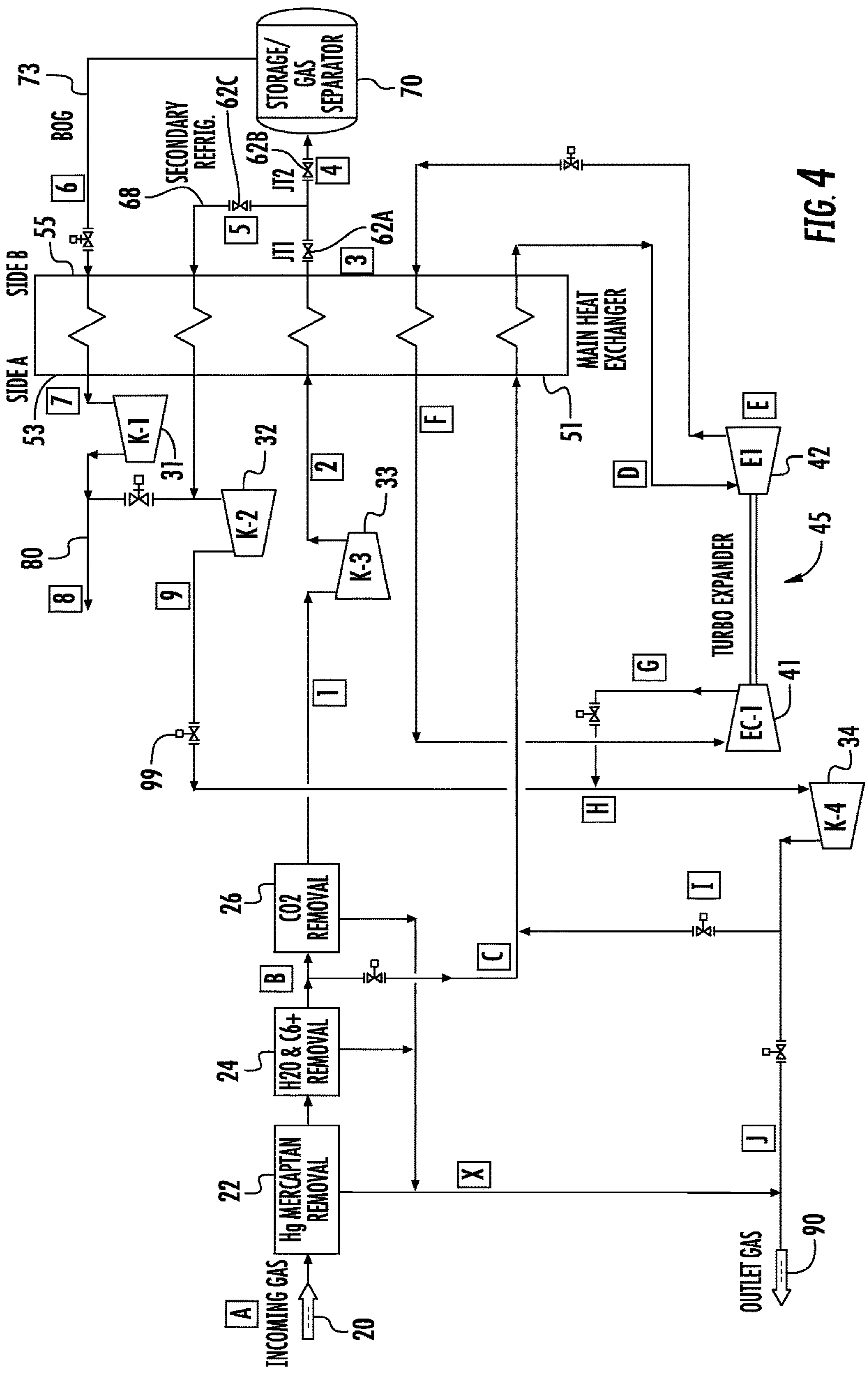


FIG. 4

PRESSURE LET DOWN WITH CONSTANT LIQUEFACTION AND OUTLET CAPACITY

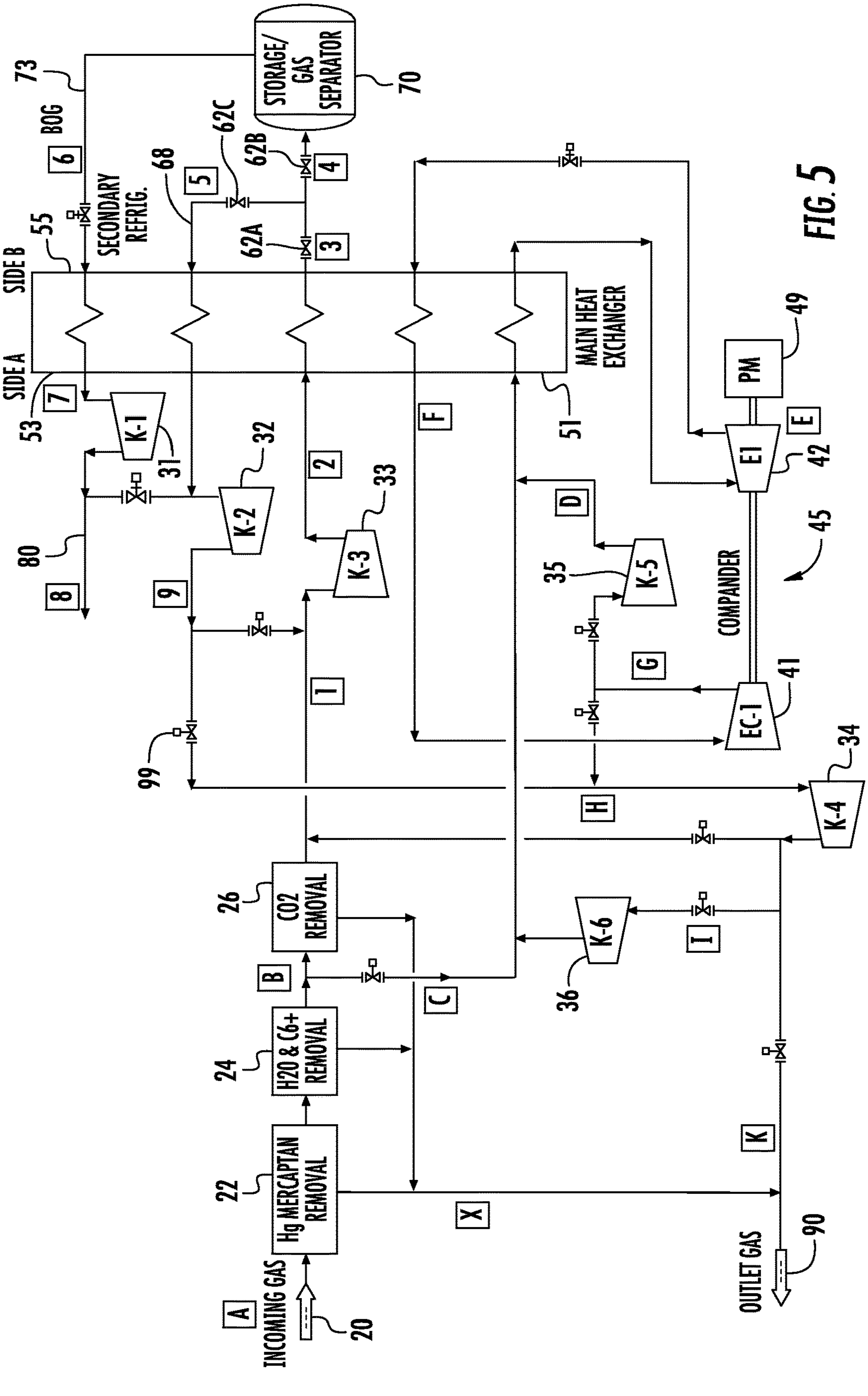


FIG. 5

SYSTEM AND PROCESS FOR NATURAL GAS LIQUEFACTION

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention is directed to the field of natural gas processing, liquefaction, and storage. More particularly, embodiments of the present invention are directed to processes and systems which are capable of liquefying all or a portion of the gas entering the system based on downstream usage.

Description of Related Art

[0002] Natural gas requires conversion to a liquid for efficient storage and transportation prior to use. Natural gas can be liquefied by two basic processes, a "cascade cycle" and an "expansion cycle". The cascade cycle processes the gas through a series of heat exchanges until it reaches a temperature sufficiently cold for liquefaction. The expansion cycle combines heat exchange with pressure manipulations to produce liquefaction. However, as in any art, improvements such as increased efficiency are desirable. It would be desirable for natural gas liquefaction processes to be capable of varying output based on downstream demand. For example, if large amounts of liquefied natural gas are simply stored in anticipation of future demand, a portion will tend to warm and vaporize resulting in loss of product.

SUMMARY OF THE INVENTION

[0003] Embodiments of the invention provide systems and processes for natural gas processing, liquefaction, and storage. The systems and processes include one or more arrangements of features which are capable of liquefying all of the gas entering an inlet of the system or a portion of the entering gas. The portion of the entering gas that is liquefied can vary based on the pressure of an outlet of the system, which can be fixed or can vary based on usage downstream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The accompanying drawings illustrate certain aspects of embodiments of the present invention, and should not be used to limit the invention. Together with the written description the drawings serve to explain certain principles of the invention.

[0005] FIG. **1** is a diagram showing an overview of a system and process for natural gas processing, liquefaction, and storage according to an embodiment.

[0006] FIGS. **2**-**5** are diagrams showing different exemplary implementations of a system and process for natural gas processing, liquefaction, and storage, where FIGS. **2** and **3** each show an implementation with 100% liquefaction, FIG. **4** shows an implementation with variable pressure let down liquefaction, and FIG. **5** shows an implementation with pressure letdown and constant liquefaction and outlet capacity.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS OF THE INVENTION

[0007] Reference will now be made in detail to various exemplary embodiments of the invention. It is to be understood that the following discussion of exemplary embodiments is not intended as a limitation on the invention. Rather, the following discussion is provided to give the reader a more detailed understanding of certain aspects and features of the invention.

[0008] The following table provides the reference numerals used throughout the drawings and the features they refer to:

TABLE 1

Reference Numeral	Feature
20	Incoming Gas/Gas Inlet
22	Mercury and Mercaptan Removal
24	Water and Heavy Hydrocarbon (C5+) Removal
26	Carbon Dioxide Removal
31	Natural Gas Compressor 1
32	Natural Gas Compressor 2
33	Natural Gas Compressor 3
34	Natural Gas Compressor 4
35	Natural Gas Compressor 5
36	Natural Gas Compressor 6
41	Turbo Compressor
42	Turbo Expander
45	Compander
49	Prime Mover
51	Heat Exchanger
53	First Side of Heat Exchanger
55	Second Side of Heat Exchanger
62A	Joule Thomson (JT) Valve 1
62B	Joule Thomson (JT) Valve 2
62C	Joule Thomson (JT) Valve 3
68	Secondary Refrigeration
70	Gas Storage/Separator
73	Boil Off Gas
80	Fuel Gas
90	Outgoing Gas/Gas Outlet
99	On/Off Control Valve

[0009] While the system embodiments shown in the drawings have multiple Control Valves, for simplicity and clarity not all Control Valves have reference numbers. Further, the drawings provided are merely intended to show exemplary embodiments; other configurations not shown may also fall within the scope of the invention including different arrangements of features and different flow processes. For example, one or more JT valves **62**A, **62**B, **62**C can be substituted or replaced with a turbo expander **42**. Additionally, one or more compressors **31**, **32**, **33**, **34**, **35**, **36** may be optional, especially in any of the examples provided herein, such as depending on incoming pressures at gas inlet **20** or outgoing pressures at gas outlet **90**.

[0010] Components and features used in system embodiments shown in the drawings and their physical implementation and arrangement can be chosen according to the judgement of an oil and gas engineer or similar artisan. Natural gas compressors can be implemented through selection of those known in the art such as those that operate by positive displacement; these include lobe, screw, liquid ring, scroll and vane type gas compressors all of which are rotary-type gas compressors, and diaphragm, double acting and single acting gas compressors all of which are reciprocating type gas compressors. Dynamic type gas compressors such as centrifugal gas compressors and axial flow gas compressors are also known. Further, compressors can be constant speed compressors or variable speed compressors. Similarly, heat exchangers such as countercurrent flow heat exchangers composed of aluminum plates and fins as well as turboexpanders/compressors useful for gas liquefaction are known and need not be detailed here. Flow processes can be implemented through metal piping used for transferring natural gas such as black steel, galvanized steel, copper, brass or corrugated stainless steel tubing. Polyvinyl chloride (PVC) and polyethylene (PE) can be used for pipes buried outside a plant, which may be useful for implementing transfer to plant inlets and outlets.

[0011] Embodiments of the operations and processes described or depicted herein can be implemented or assisted through one or more computer processor. Embodiments can include a non-transitory computer readable storage medium comprising one or more computer files comprising a set of computer-executable instructions for performing one or more of the processes and operations described herein and/or depicted in the drawings. In exemplary embodiments, the files may be stored contiguously or non-contiguously on the computer-readable medium. Further, embodiments include a computer program product comprising the computer files, either in the form of the computer-readable medium comprising the computer files and, optionally, made available to a consumer through packaging, or alternatively made available to a consumer through electronic distribution. As used herein, a "computer-readable medium" includes any kind of computer memory such as floppy disks, conventional hard disks, CD-ROMS, Flash ROMS, non-volatile ROM, electrically erasable programmable read-only memory (EEPROM), and RAM.

[0012] As used herein, the terms "computer-executable instructions", "code", "software", "program", "application", "software code", "computer readable code", "software module", "module" and "software program" are used interchangeably to mean software instructions that are executable by a processor. The computer-executable instructions may be organized into routines, subroutines, procedures, objects, methods, functions, or any other organization of computer-executable instructions that is known or becomes known to a skilled artisan in light of this disclosure, where the computer-executable instructions are configured to direct a computer or other data processing device to perform one or more of the specified processes and operations described herein. The computer-executable instructions may be written in any suitable programming language, non-limiting examples of which include C, C++, C#, Objective C, Swift, Ruby/Ruby on Rails, Visual Basic, Java, Python, Perl, PHP, and JavaScript.

[0013] In other embodiments of the invention, files comprising the set of computer-executable instructions may be stored in computer-readable memory on a single computer or distributed across multiple computers. A skilled artisan will further appreciate, in light of this disclosure, how the invention can be implemented, in addition to software, using hardware or firmware. As such, as used herein, the operations of the invention can be implemented in a system comprising any combination of software, hardware, or firmware.

[0014] Embodiments of the invention include one or more computers or devices loaded with a set of the computer-executable instructions described herein. The computers or devices may be a general-purpose computer, a special-purpose computer, or other programmable data processing apparatus to produce a particular machine, such that the one or more computers or devices are instructed and configured to carry out the processes and operations described herein. The computer or device performing the specified processes and operations may comprise at least one processing element such as a central processing unit (i.e. processor) and a form of computer-readable memory which may include random-access memory (RAM) or read-only memory (ROM). The computer-executable instructions can be embedded in computer hardware or stored in the computer-readable memory such that the computer or device may be directed to perform one or more of the processes and operations depicted in the drawings and/or described herein.

[0015] An exemplary embodiment includes a single computer or device that may be configured at a gas liquefaction plant to serve as a controller. The controller may comprise at least one processor, a form of computer-readable memory, and a set of computer-executable instructions for performing one or more of the processes and operations described and/or depicted herein. The single computer or device may be configured at a gas liquefaction plant to serve as a controller which sends commands to motors controlling one or more Control Valves to direct the flow of gas in accordance with one or more processes and operations described herein. For example, motors controlling the Control Valves may be connected to the controller by any suitable network protocol, including TCP, IP, UDP, or ICMP, as well any suitable wired or wireless network including any local area network, Internet network, telecommunications network, Wi-Fi enabled network, or Bluetooth enabled network. The controller may be configured at the gas liquefaction plant to control opening and closing of the Control Valves based on inputs received from one or more sensors installed within the plant. The controller may also allow an operator to directly control processes at the gas liquefaction plant through opening and closing of the Control Valves through an operator interface which may be a graphical user interface (GUI) which may be presented as an HTTP webpage that may be accessed by the operator at a remote general purpose computer with a processor, computer-readable memory, and standard I/O interfaces such as a universal serial bus (USB) port and a serial port, a disk drive, a CD-ROM drive, and/or one or more user interface devices including a display, keyboard, keypad, mouse, control panel, touch screen display, microphone, etc. for interacting with the controller through the GUI.

[0016] FIG. **1** shows an embodiment of a system, incorporated or implemented in a gas liquefaction plant, useful for natural gas processing, liquefaction, and storage; the combination of features of the system and their arrangement provide unique flexibility for varying the amount of gas liquefied according to downstream usage and demands on the system. Unliquified natural gas (which may otherwise be referred to as pipeline natural gas or natural gas, including pipeline quality gases that may have been processed to improve the methane content and/or to remove heavy hydrocarbons) enters the system through an inlet **20** where it is directed to various systems for removing contaminants which can include systems for mercury and/or mercaptan removal **22**, water and heavy hydrocarbon (such as pentanes, hexanes and higher carbon alkanes, including benzene, toluene, ethylbenzene and/or xylene (BTEX)) removal **24**, as well as carbon dioxide removal **26**. Also shown in FIG. **1** and subsequent drawings are lines with arrows depicting various flow processes, such as a flow from system **22** to system **24** and then to system **26**, and so on. It should be noted that the linear arrangement of contaminant removal systems **22**, **24**, and **26** and flow therebetween shown in FIG. **1** and subsequent drawings is merely exemplary; embodiments of the invention can encompass other arrangements and systems not depicted or may eliminate some contaminant removal systems as well. As shown in FIG. **1**, a waste stream can be directed out of the system to gas outlet **90** after processing by each system or after sequential processing by each system as shown by **22**, **24**, and **26**.

[0017] As will be detailed further in the foregoing Examples, the system provides unique arrangements and flow processes among natural gas compressors **31**, **32**, **33**, **34**, **35**, **36**, a heat exchanger **51**, a turbo compressor **41**, a turbo expander **42**, and JT valves **62**A, **62**B, **62**C to provide flexibility for natural gas processing, liquefaction, and storage. The following will highlight various features of the system.

[0018] As shown in FIG. **1**, a product gas stream can be directed to flow to heat exchanger **51**, optionally after one or more contaminant removal processes, such as mercury, mercaptan, BTX (benzene, toluene, or xylene), C5+, such as C6 hydrocarbons, H_2S or SO_2, water, and/or carbon dioxide removal **22**, **24**, **26**. The product gas stream can pass through one or more optional compressor such as compressor **33** before or after any other added functionality. It is important to note that compressor **33** is optional and may not be needed if the incoming gas pressure is already high enough. Additionally, one or more additional cooling functionality can be included instead of compressor **33**, and/or between compressor **33** and the first side of the heat exchanger **51**. One or more refrigeration streams can be present in the system, such as two refrigeration streams for example which run countercurrent to the product gas stream through the heat exchanger. As shown in FIG. **1** below the product gas stream, a primary refrigeration stream passes through a first side of heat exchanger **51**, optionally through one or more additional functionalities and into turbo expander **42**, optionally through one or more additional functionalities and through a second side of heat exchanger **51** and through turbo compressor **41**. Additionally, other functionalities can be included anywhere as appropriate in the system, such as (i) one or more sensors to monitor temperature and/or pressure, and/or (ii) one or more pressure drop valves, and/or (iii) one or more filters (to capture for example CO_2 or other unwanted components, especially those that might freeze out) included at a point in the flow path between turbo expander **42** and the second side of heat exchanger **51**. The primary refrigeration stream can be directed through compressor **35** before being passed through heat exchanger **51** and back to an inlet of turbo expander **42**. The primary refrigeration stream can circulate as a closed loop, but can be charged by a portion of the product gas stream that is diverted before it reaches compressor **33**. Also notable are a secondary refrigeration stream **68** (shown in FIG. **1** above the product stream) running through heat exchanger **51**, for example, in a flow path that passes through compressor **31** and compressor **32**, or just compressor **32**. The secondary refrigeration stream **68** results from diversion of a portion of the product gas stream through one or more JT valves (**62**A, **62**B) before it reaches storage tank/separator **70**. A boil off gas (BOG) stream **73** from the storage tank/separator **70** is mixed with the secondary refrigeration stream **68**, which mixed stream passes through heat exchanger **51** (to compressor **31** then **32**, or to compressor **32**). In embodiments, the gas stream passes through a series of one or more compressors such as **31**, **32**, and/or **34** to increase the pressure back to inlet pressure. After compressor **34**, the compressed gas can be introduced back to the product stream or the primary refrigeration stream, or exit the system through gas outlet **90**. In some cases, compressor **34** is optional, for example, when the pressure in gas outlet **90** is low enough, the gas can bypass compressor **34** and go directly to the outlet **90**.

[0019] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas from the inlet **20** can be directed to the mercury and mercaptan removal system **22**, alone or in addition to being treated by other contaminant removal functionalities and/or processes and in any desired order.

[0020] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas exiting the mercury and mercaptan removal system **22** can be directed to the outlet **90** and/or the water and heavy hydrocarbon removal system **24**.

[0021] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas exiting the water and heavy hydrocarbon removal system **24** can be directed to the outlet **90**, a first side **53** of the main heat exchanger **51**, and/or to the carbon dioxide removal system **26**.

[0022] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas entering or exiting one or more contaminant removal systems, such as the carbon dioxide removal system **26**, can be directed to the outlet **90** and/or to one or more heat exchangers, or optionally to one or more natural gas compressors such as compressor **33** before the heat exchanger and/or before or after any treatment for contaminant removal.

[0023] In embodiments, the gas stream can be treated in any order by one or more contaminant removal systems, including one or more of mercury, mercaptan, BTX (benzene, toluene, or xylene), C5+, such as C6 hydrocarbons, H_2S or SO_2, water, and/or carbon dioxide removal. Additionally, the gas stream can be compressed before and/or after being treated by one or more contaminant removal systems.

[0024] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas exiting one or more natural gas compressor such as compressor **33** and/or **35** can be directed to a first side **53** of the main heat exchanger **51**.

[0025] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas exiting the heat exchanger **51** on a first side **53** can be directed to one or more natural gas compressor such as compressor **31** and/or compressor **32**.

[0026] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to flow through one or more compressors optionally consecutively, with or without any intervening additional functionality, such as through compressor **33**, through compressors **32**, **34** and/or compressor **32** and compressor **33** and/or compressor **34** and compressor **33**, and/or compressor **31** and compressor **32**, and/or compressors **33**, **31**, **32**, **34**.

[0027] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to exit from first side **53** of main heat exchanger **51**, such as to turbo compressor **41**, and/or exit from second side **55** of main heat exchanger **51**, such as to turbo expander **42**.

[0028] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to flow from turbo expander **42** to enter second side **55** of main heat exchanger **51**.

[0029] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to flow from turbo compressor **41** to one or more natural gas compressor such as compressor **34** and/or compressor **35**.

[0030] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to exit from second side **55** of heat exchanger **51** to flow to one or more JT valves such as **62**A and/or **62**B to storage **70**.

[0031] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to exit from second side **55** of heat exchanger **51** to flow to one or more JT valves such as **62**A and/or **62**C to provide a secondary refrigeration stream **68**.

[0032] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to flow from secondary refrigeration stream **68** to enter second side **55** of heat exchanger **51**.

[0033] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, boil off gas **73** can be directed to flow from gas storage/separator **70** to enter second side **55** of main heat exchanger **51**.

[0034] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, fuel gas **80** can be directed to flow from one or more compressor such as compressor **31**.

[0035] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas can be directed to flow from one or more compressor such as compressor **34** to gas outlet **90**.

[0036] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, the turbo compressor **41** and turbo expander **42** are mechanically coupled together such as by a common shaft and driven by motor **49**.

[0037] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas exiting the turbo expander **42** can be directed to the main heat exchanger **51** to enter on second side **55** to provide a primary refrigeration stream to cool product gas entering the heat exchanger **51** on a first side **53**.

[0038] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, a portion of product gas exiting the heat exchanger **51** on second side **55** can be directed to pass through one or more JT valve such as **62**A to provide a secondary refrigeration stream which enters back into heat exchanger **51** on second side **55**.

[0039] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, primary refrigeration stream exiting the heat exchanger **51** on first side **53** can be directed to turbo compressor **41**.

[0040] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, boil off gas **73** exiting gas storage/separator **70** can be directed to enter heat exchanger **51** through second side **55**.

[0041] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas entering the process at gas inlet **20** can have a pressure in the range of 100-1,000 psig and a temperature in the range of 40–100° F.

[0042] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas entering the liquid storage tanks can have a pressure in the range of 1 to 10 pounds per square inch, gauge (psig), such as 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 psig, or any range encompassing any of these values, and a temperature in the range of −260 to −300° F., such as −200, −210, −220, −230, −240, −250, −260, −270, −280, −290, or −300° F., or any range encompassing any of these values, and generally a minimum temperature of about −260° F.

[0043] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, gas entering the turbo expander **42** can have a temperature in the range of 20 to −20° F., such as 20° F., 15° F., 10° F., 5° F., 0° F., −5° F., −10° F., −15° F., or −20° F., or any range encompassing any of these values, and gas exiting the turbo expander **42** for primary refrigeration can have a temperature in the range of −100° F. to −180° F., such as −100° F., −105° F., −110° F., −115° F., −120° F., −125° F., −130° F., −135° F., −140° F., −145° F., −150° F., −155° F., −160° F., −165° F., −170° F., −175° F., or −180° F., or any range encompassing any of these values.

[0044] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, one or more compressor such as compressor **33** can boost the pressure of the product stream prior to entering the heat exchanger **51**, such as a pressure in the range of 650 to 950 psig, such as 650, 675, 700, 725, 750, 775, 800, 825, 850, 900, 905, 910, 915, 920, 925, 930, 935, 940, 945, or 950 psig, or any range encompassing any of these values.

[0045] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, a secondary refrigeration stream **68** can have a pressure in the range typically of 50 to 100 psig, or at least 50 psig or up to 100 psig or more, such as 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 psig, or any range encompassing any of these values, and a temperature in the range of −200 to −250° F., such as −200, −205, −210, −215, −220, −225, −230, −235, −240, −245, or −250° F., or any range encompassing any of these values.

[0046] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, fuel gas for ancillary systems can have a pressure in the range of 20 to 60 psig, such as 25, 30, 35, 40, 45, 50, 55, or 60 psig, or any range encompassing any of these values, and a temperature in the range of 50 to 150° F., such as 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 130, 135, 140, 145, or 150° F., or any range encompassing any of these values.

[0047] According to some embodiments of a system and process for natural gas processing, liquefaction, and/or storage, one or more compressor such as compressor **31** or **32** compresses boil off gas **73** such that the gas reaches inlet pressure for example of compressor **33** in the range of about 150 to 600 psig and a temperature in the range of 50 to 150° F., such as 80 to 120° F., such as 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 130, 135, 140, 145, or 150° F., or any range encompassing any of these values.

[0048] According to some embodiments of a system and process for natural gas processing, liquefaction, and storage, one or more compressor such as compressor **32** compresses boil off gas **73** and/or secondary refrigeration gas **68** such that the gas reaches a pressure in the range of 50 to 650 psig and a temperature in the range of 50 to 150° F., such as 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 130, 135, 140, 145, or 150° F., or any range encompassing any of these values. Under certain circumstances, the pressure could be in the 150 to 650 psig range, if for example the gas is being recirculated, or the pressure could be as low as 50 psig if it is going to a low pressure outgas line. Generally, for the Small BOG compressor **31** which feeds into compressor **32** the system could be designed to a 30 psig pressure build, which will put the output of 31 in the range of 25-30 psig, depending on pressure drops across the heat exchanger and post coolers of the compressor package.

[0049] The following Examples describe various flow processes for processing, liquefaction, and storage of natural gas according to the system described herein and are depicted in FIGS. **2** through **5**. Block letters and numbers are added to the drawings as references to individual stages in the flow processes. The Examples are provided to further illustrate the capabilities and versatility of the system and should not be construed as limiting; a skilled artisan will recognize that the individual stages in the processes can be modified or deleted, or other stages can be added, and these variations will fall within the scope of the invention.

Example 1

[0050] In this Example, shown in FIG. **2**, the functionalities presented are arranged in such a manner such that the goal is that all of the natural gas that enters the plant is liquified (except for waste streams and the optional fuel gas source).

[0051] As shown in Block A, incoming natural gas from the pipeline, which may present without or with contaminants such as heavy hydrocarbons (C5+, such as C6 hydrocarbons), water, carbon dioxide, and/or mercury enters gas inlet **20** and is optionally processed through one or more contaminant removal systems **22**, **24**, and **26**, and/or additional contaminant removal systems as desired, and in any order. Block X shows the waste stream from the cleaning process exits the system at gas outlet **90**. At Block B, the product stream, optionally previously cleaned, splits into a liquefied natural gas product steam (shown by Block **1**), and a primary refrigeration stream (shown by Block C). The primary refrigeration stream is used to 'charge' the closed loop methane primary refrigeration. Gas is mixed with the gas in the closed loop before it enters compressor **35**. As shown by Block D, compressor **35** boosts the pressure before gas enters the heat exchanger and is directed to the turbo expander **42**. At Block E, the turbo expander **42** rapidly reduces the pressure of the stream providing primary cooling for the process. In this example, the expander inlet temperature is −10° F. and the expander outlet temperature is −140° F., although it can go as low as possible without freezing carbon dioxide, since in this example CO_2 has been removed. At Block F, cold gas exiting the turbo expander **42** enters the heat exchanger **51** on second side **55** to cool the product stream above it flowing in the opposite direction (i.e. entering heat exchanger on first side **53**). At Block G, the turbo compressor **41** uses the energy from the turbo expander **42** (via a common shaft) to recompress the gas to an intermediate pressure prior to compressor **35**.

[0052] Referring now to the product stream at Block **1**, compressor **33** boosts the product stream pressure to optimal levels before entering the main heat exchanger. In this Example, the pressure is increased to 925 psig. At Block **2**, product gas is cooled in the heat exchanger **51** then takes an additional pressure drop at JT valve **62**A. At this point the gas is split into a stream for storage **70** and secondary refrigeration stream **68** (Pressure: 70 psig, Temp: −220° F.). At Block **3**, a final pressure drop is taken at JT valve **62**B before the liquid enters the liquefied natural gas storage tanks **70** (Pressure: 5 psig, Temp: −252° F.). As shown at Block **4**, when additional cooling is needed part of the product stream can be re-directed through JT valve **62**C, taking a pressure drop, then enter back through the heat exchanger **51** on second side **55** as secondary refrigeration stream **68**, and through compressor **32**. Boil off gas (BOG) **73** from the tank is warmed by the heat exchanger **51** entering on second side **55** so it can be recompressed to a usable pressure, as shown at Block **5** (Pressure: 5 psig, Temp: −252° F.). Compressor **31** increases the boil off gas **73** pressure so that it can mix with the gas from the secondary refrigeration **68**. At Block **7**, fuel gas **80** for ancillary systems gas be pulled off after compressor **31** (Pressure: 40 psig, Temp: 100° F.). At Block **8**, compressor **32** compresses the boil off gas and/or secondary refrigeration gas back up to the inlet pressure of compressor **33** (Pressure: same as inlet, Temp: 100° F.).

Example 2

[0053] In this Example, shown in FIG. **3**, the configuration provided is organized such that the goal is for all the gas that enters the plant to be liquified (except for waste streams and the optional fuel gas source).

[0054] As shown in Block A, incoming natural gas from the pipeline with contaminants such as heavy hydrocarbons, water, carbon dioxide, and/or mercury enters gas inlet **20** and is processed through one or more contaminant removal systems **22**, **24**, and **26**, and/or additional contaminant removal systems, and in any order. Block X shows the waste stream from the cleaning process exits the system at gas outlet **90**. At Block B, the optionally previously cleaned gas stream splits into a liquefied natural gas product steam (shown by Block **1**), and a primary refrigeration stream (shown by Block C). High pressure clean gas for primary refrigeration at Block C is cooled by the heat exchanger **51** prior to feeding the turbo expander **42**. The refrigeration gas pressure and temperature are reduced on the outlet of the turbo expander **42**. At Block D, the cold refrigeration gas is directed to enter the heat exchanger **51** on second side **55** where it provides the majority of the cooling (Expander Inlet: Temp: −10° F.; Expander Outlet: Temp: −140° F. (can go as low as possible without freezing carbon dioxide, since in this example CO_2 has been removed before charging the refrigeration loop). At Block E, the warm, post heat exchanger, gas is sent to turbo compressor **41**. Block F shows that the turbo compressor **41** uses the energy from the turbo expander **42** via a common shaft to recompress the gas to an intermediate pressure prior to feeding compressor **34**. Shown at Block G, compressor **34** recompresses the primary refrigeration gas so it can re-mix with the initial gas stream, for example, on the outlet of the clean-up system(s) at Block B.

[0055] Referring now to the product stream at Block **1**, compressor **33** boosts the product stream pressure to optimal levels before entering the main heat exchanger. In this Example, the pressure is increased to 925 psig. At Block **2**, product gas is cooled in the heat exchanger **51** then takes an additional pressure drop at JT valve **62**A. At this point the gas is split into a stream for storage **70** and secondary refrigeration stream **68** (Pressure: 70 psig, Temp: −220° F.). At Block **3**, a final pressure drop is taken at JT valve **62**B before the liquid enters the liquefied natural gas storage tanks **70** (Pressure: 5 psig, Temp: −252° F.). As shown at Block **4**, when additional cooling is needed part of the product stream can be re-directed through JT valve **62**C, taking a pressure drop, then back through the heat exchanger **51** on second side **55**, and through compressor **32**. Boil off gas **73** from the tank is warmed by the heat exchanger **51** entering on second side **55** so it can be recompressed to a usable pressure, as shown at Block **5** (Pressure: 5 psig, Temp: −252° F.). Compressor **31** increases the boil off gas pressure so that it can mix with the gas from the secondary refrigeration. At Block **7**, fuel gas **80** for ancillary systems gas be pulled off after compressor **31** (Pressure: 40 psig, Temp: 100° F.). At Block **8**, compressor **32** compresses the boil off gas and/or secondary refrigeration gas back up to the inlet pressure of compressor **33** (Pressure: same as inlet, Temp: 100° F.).

Example 3

[0056] In this Example, shown in FIG. **4**, a fraction of the gas that enters the plant is liquefied. The percent of gas that is liquified can be varied as a function of outlet gas pressure. Outlet gas pressure/capacity will be a function of usage downstream.

[0057] As shown in Block A, incoming natural gas from the pipeline with contaminants such as heavy hydrocarbons, water, carbon dioxide, and/or mercury enters inlet **20**. Block X shows that the waste stream from the cleaning process is directed to outlet **90**. At Block B, gas is cleaned (treated for one or more contaminant removal) and is free or substantially free of heavy hydrocarbons, water, and/or mercury but has not been treated for carbon dioxide removal. This stream is cleaned to the same level of contaminants as all previous models, except for the CO_2. Since this is generally pipeline gas there should be no more CO_2 than 2 mole %. In most cases, pipeline gas will be lower than 2 mole %, which is better. The higher the percentage of CO_2 the more restrictive this model becomes. If the CO_2 concentrations are high, some level of CO_2 removal may be required before this model can be used.

[0058] This gas stream splits into the liquefied natural gas product stream (shown by Block **1**) and the primary refrigeration stream (Block C) where high pressure gas free of water, heavy hydrocarbons and mercury but not carbon dioxide is used for primary refrigeration and is cooled by the heat exchanger **51** prior to feeding the turbo expander **42**. At Block D, the primary refrigeration gas enters the turbo expander **42**. The turbo expander rapidly reduces the pressure and temperature of the gas stream and provides primary cooling for the process (gas exiting at Block E). Cold gas enters the heat exchanger **51** on second side **55** to cool the product stream entering above it from first side **53** flowing in the opposite direction (Expander Inlet: Temp: −10° F.; Expander Outlet: Temp: −140° F. (can go as low as practical, for example without leading to problems resulting from the presence of any carbon dioxide). In embodiments, a limiting factor in how cold the gas stream can be at this point in the process/system is the amount of CO_2 in the stream. Designs of the primary refrigeration stream should consider the quantity of CO_2 to ensure the stream does not get too cold, or CO_2 may form and plug the downstream filters and possibly foul and plug the heat exchanger. At Block F, the warm, post heat exchanger, refrigeration gas is sent to turbo compressor **41**. Then, at Block G, the turbo compressor **41** uses the energy from the turbo expander (via a common shaft) to recompress the gas to an intermediate pressure. Block H shows that compressed primary refrigeration gas from turbo compressor **41** is mixed with compressed product gas from compressor **32**. This combined product stream is fed into compressor **34**. At Block I, if outlet gas capacity is limited compressor **34** compresses the gas to a pressure which is sufficiently high to re-mix back with the primary refrigeration gas stream. If outlet gas capacity is not limited compressor **34** compresses the gas and sends the compressed gas to the outlet **90** which is at a much lower pressure than the primary refrigeration stream which requires less energy. The volumes directed to paths indicated by Blocks I and J can be varied in real time to control the efficiency of the process. The energy required by compressor **34** is dependent on how the gas is distributed between paths I and J. If there is sufficient flow in the outlet **90** that receives the gas, and the pressure is low enough there may be no need for compressor **34**, and it can be replaced with a pass-through pipe. Gas will then not need to recirculate in line I and that line can also be eliminated, with all the flow going to outlet **90** with no additional compression above compressors **32** and **41**.

[0059] Referring now to the product stream at Block **1**, gas is cleaned and is free or substantially free of heavy hydrocarbons, water, mercury, and carbon dioxide. Preferably, this stream is contaminant free, as in all previous examples. Being contaminant free in some cases may mean trace or undetectable amounts of certain contaminants are present. For example, typical amounts of contaminants are CO_2 less than 50 ppmv, H_2S less than 2 ppmv, water less than 0.1 ppmv, mercury less than 1 pptv, benzene less than 0.1% by weight or volume, and C6 hydrocarbons less than 0.06 mol %, such as 0.01 mol %. At Block **2**, compressor **33** boosts the pressure of the product stream to optimal levels before entering the main heat exchanger **51** on first side **53**. Product gas is cooled in the heat exchanger **51** then takes an additional pressure drop at the JT valve **62**A as shown at Block **3**. At this point the gas is split into a storage stream, indicated at Block **4**, and secondary refrigeration stream, indicated at Block **5** (Pressure: 70 psig, Temp: −220° F.). At Block **4**, a final pressure drop is taken at JT valve **62**B before the liquid enters the liquefied natural gas storage tanks **70** (Pressure: 5 psig, Temp: −252° F.). When additional cooling is needed part of the product stream can be re-directed through JT valve **62**C, taking a pressure drop, then enter back through the heat exchanger **51** on second side **55**, as shown by Block **5**, and then passes to compressor **32**. Boil off gas **73** from the tank **70** is warmed by the heat exchanger **51** entering on second side **55** (Block **6**) so it can be recompressed to a usable pressure (Pressure: 5 psig, Temp: −252° F.). At Block **7**, compressor **31** increases the boil off gas pressure so that it can mix with the gas from the secondary refrigeration **68**. Fuel gas **80** for ancillary systems gas can be pulled off after compressor **31** at Block **8** (Pressure: 40 psig, Temp: 100° F.), while Block **9** shows that compressor **32** compresses the boil off gas and/or secondary refrigeration gas to mix with gas from the turbo compressor **41** at Block H (Pressure: same as turbo compressor **41** discharge pressure, Temp: 100° F.).

Example 4

[0060] In this Example, shown in FIG. **5**, a fraction of the gas that enters the plant is liquefied. The percent of gas that is liquified is relatively fixed as determined by the relatively fixed outlet gas pressure.

[0061] As shown in Block A, incoming natural gas from the pipeline with or without contaminants such as heavy hydrocarbons, water, carbon dioxide, and/or mercury enters inlet **20**. Block X shows that the waste stream from the cleaning process is directed to outlet **90**. At Block B, gas is optionally treated for removal of one or more contaminants and as such is cleaned and is free or substantially free of heavy hydrocarbons, water, and/or mercury but at this point not yet treated for removal of carbon dioxide. This gas stream splits into the liquefied natural gas product stream (shown by Block **1**) and the primary refrigeration stream (Block C) where high pressure gas free or substantially free of water, heavy hydrocarbons and mercury but not necessarily treated for carbon dioxide removal is fed for primary refrigeration and is cooled by the heat exchanger **51** prior to feeding the turbo expander **42**. This stream can be clean to the production of LNG standards, except for the presence of any CO_2. After Block D, the primary refrigeration gas enters the turbo expander **42**. The turbo expander **42** rapidly reduces the pressure and temperature of the gas stream and provides primary cooling for the process (gas exiting at Block E). Cold gas enters the heat exchanger **51** on second side **55** to cool the product stream entering above it on first side **53** and flowing in the opposite direction (Expander Inlet: Temp: −10° F.; Expander Outlet: Temp: −140° F. (can go as low as practical, for example without freezing carbon dioxide). Preferably, the turbo expander is designed such that it does not exceed a temperature that will freeze out any CO_2 that is still in the gas stream, which CO_2 particles could block the downstream filter and foul and/or block the heat exchanger **51**. At Block F, the warm, post heat exchanger, refrigeration gas is sent to turbo compressor **41**. Then, at Block G, the turbo compressor **41** uses the energy from the turbo expander (via a common shaft) to recompress the gas to an intermediate pressure. Block H shows that compressed primary refrigeration gas from turbo compressor **41** is mixed with compressed product gas from compressor **32**. This combined product stream is fed into compressor **34**. At Block I, compressor **34** compresses the gas and sends the compressed gas to the inlet of compressor **36** to be recompressed back up to inlet pressures.

[0062] Referring now to the product stream at Block **1**, gas is cleaned and is free or substantially free of heavy hydrocarbons, water, mercury and/or carbon dioxide. At Block **2**, compressor **33** boosts the pressure of the product stream to optimal levels before entering the main heat exchanger **51** at first side **53**. Product gas is cooled in the heat exchanger then takes an additional pressure drop at the JT valve **62**A as shown at Block **3**. At this point the gas is split into a storage stream, indicated at Block **4**, and secondary refrigeration stream, indicated at Block **5** (Pressure: 70 psig, Temp: −220° F.). At Block **4**, a final pressure drop is taken at JT valve **62**B before the liquid enters the liquefied natural gas storage tanks **70** (Pressure: 5 psig, Temp: −252° F.). When additional cooling is needed part of the product stream can be re-directed through JT valve **62**C, taking a pressure drop, then enter back through the heat exchanger **51** on second side **55**, as shown by Block **5**, and then passes to compressor **32**. Boil off gas **73** from the tank **70** enters the heat exchanger **51** on second side **55** and is warmed (Block **6**) so it can be recompressed to a usable pressure (Pressure: 5 psig, Temp: −252° F.). At Block **7**, compressor **31** increases the boil off gas pressure so that it can mix with the gas from the secondary refrigeration **68**. Fuel gas **80** for ancillary systems gas can be pulled off after compressor **31** at Block **8** (Pressure: 40 psig, Temp: 100° F.), while Block **9** shows that compressor **32** compresses the boil off gas and/or secondary refrigeration gas to mix with gas from the turbo compressor **41** at Block H (Pressure: same as turbo compressor **41** discharge pressure, Temp: 100° F.).

[0063] The present invention has been described with reference to particular embodiments having various features. In light of the disclosure provided above, it will be apparent to those skilled in the art that various modifications and variations can be made in the practice of the present invention without departing from the scope or spirit of the invention. One skilled in the art will recognize that the disclosed features may be used singularly, in any combination, or omitted based on the requirements and specifications of a given application or design. When an embodiment refers to "comprising" certain features, it is to be understood that the embodiments can alternatively "consist of" or "consist essentially of" any one or more of the features. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention.

[0064] It is noted in particular that where a range of values is provided in this specification, each value between the upper and lower limits of that range is also specifically disclosed. The upper and lower limits of these smaller ranges may independently be included or excluded in the range as well. The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. It is intended that the specification and examples be considered as exemplary in nature and that variations that do not depart from the essence of the invention fall within the scope of the invention. Further, all of the references cited in this disclosure are each individually incorporated by reference herein in their entireties and as such are intended to provide an efficient way of supplementing the enabling disclosure of this invention as well as provide background detailing the level of ordinary skill in the art.

1. A system for natural gas processing, liquefaction, and/or storage, comprising:
- one or more natural gas inlet;
- structure configured for containing, processing, and/or storing all or a portion of natural gas received by one or more of the inlets, the structure comprising:
  - one or more contaminant removal systems;
  - one or more heat exchanger;
  - one or more compressors;
  - one or more expanders or JT valves;
  - one or more gas storage unit and/or separator; and/or
  - one or more control valves;

one or more gas outlet; and

a controller in direct or indirect operable communication with one or more of the inlets, all or a portion of the structure, and/or one or more of the outlets;

wherein the controller is operably configured for controlling operation of one or more of the inlets, all or a portion of the structure, and/or one or more of the outlets in a manner to provide for either: (i) liquefaction of all of the natural gas received, except for waste gas or a fuel gas source, or (ii) liquefaction of a portion of the natural gas received, the controlling being based on pressure of gas in one or more of the gas outlets.

2. The system of claim **1**, wherein the controller is configured to separate all or a portion of gas received from one or more of the inlets, and optionally exiting one or more of the contaminant removal systems, into a product stream and a primary refrigeration stream.

3. The system of claim **2**, wherein the controller is configured to direct all or a portion of gas of the primary refrigeration stream to circulate within the primary refrigeration stream in a closed loop.

4. The system of claim **2**, wherein the controller is configured to direct all or a portion of gas of the primary refrigeration stream to mix with all or a portion of gas received from one or more of the inlets, and optionally exiting one or more of the contaminant removal systems.

5. The system of claim **1**, wherein one or more of the contaminant removal systems comprises a carbon dioxide removal system, and the controller is configured to direct all or a portion of gas to the carbon dioxide removal system and/or to a primary refrigeration stream.

6. The system of claim **5**, wherein the controller is configured to direct all or a portion of gas entering the primary refrigeration stream to stay and circulate in the primary refrigeration stream in a closed loop or exit through one or more of the gas outlets.

7. The system of claim **5**, wherein the controller is configured to direct all or a portion of gas entering the primary refrigeration stream to stay and circulate in the primary refrigeration stream in a closed loop, to return and mix with all or a portion of gas received from one or more of the inlets, or to exit through one or more of the gas outlets.

8. A process for natural gas processing, liquefaction, and/or storage, comprising:

inputting a natural gas stream through one or more contaminant removal systems to provide a cleaned gas stream;

compressing, expanding, and/or inputting through a heat exchanger the cleaned gas stream to provide a plurality of streams of gas comprising:

a product stream; and

primary and secondary refrigeration streams;

circulating the primary refrigeration stream such that it is capable of flowing in a closed loop, and/or recirculating to mix with the cleaned gas stream, and/or exiting the process through an outlet; and

liquefying and storing gas from the product stream in a gas storage tank and separator.

9. The process of claim **8**, further comprising directing the primary and secondary refrigeration streams to flow through the heat exchanger in a direction opposite that of the product stream.

10. The process of claim **8**, further comprising inputting a boil off gas stream from the gas storage tank and separator through the heat exchanger.

11. The process of claim **10**, further comprising directing the boil off gas stream to flow through the heat exchanger in a direction which is opposite that of the product stream.

12. The process of claim **11**, further comprising mixing the boil off gas stream with the secondary refrigeration stream to provide a mixed stream of gas.

13. The process of claim **8**, further comprising compressing the product stream prior to the inputting of the product stream through the heat exchanger.

14. The process of claim **8**, further comprising inputting a pre-refrigeration stream through the heat exchanger and expanding the pre-refrigeration stream through a turbo expander to provide the primary refrigeration stream.

15. The process of claim **8**, further comprising compressing the primary refrigeration stream through a turbo compressor upon exiting the heat exchanger.

16. The process of claim **8**, further comprising directing the product stream through one or more JT valves upon exiting the heat exchanger thereby reducing the pressure of the product stream to provide liquefied natural gas for storage and/or to provide the secondary refrigeration stream.

17. The process of claim **12**, further comprising directing the mixed stream of gas through the heat exchanger.

18. The process of claim **17**, further comprising compressing the mixed stream of gas by way of one or more compressors upon exiting the heat exchanger.

19. The process of claim **18**, wherein the one or more compressors increase the pressure of the mixed stream of gas such that it reaches the pressure of the inputted natural gas stream.

20. The process of claim **19**, further comprising directed the mixed stream of gas exiting the one or more compressors to provide fuel gas to one or more ancillary systems.

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