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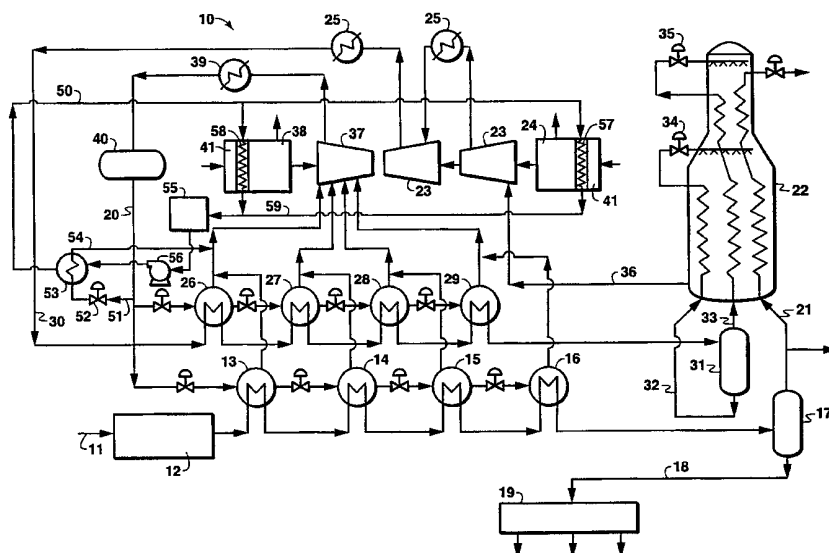
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- (71) Applicant: MOBIL OIL CORPORATION [US/US];
3225 Gallows Road, Fairfax, VA 22037 (US).
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(72) Inventors: FANNING, Robert, A.; 910 Shadow Ridge, Highland Village, TX 75077 (US). RYBERG, Brett; Apartments 33, No. 302, 24-58 Takanawa 4-chome, Minato-ku, Tokyo 108-0074 (JP). PHAN, Luan, D.; 2505 Gayle Drive, Garland, TX 75044 (US). SMITH, Bruce; 706 Dover Place, South Lake, TX 76092 (US).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: PROCESS AND SYSTEM FOR LIQUEFYING NATURAL GAS



(57) Abstract: A natural gas liquefaction system (10) and process wherein excess refrigeration available in a typical, natural gas liquefaction system is used to cool the inlet air to gas turbines (24, 38) in the system (10) to thereby improve the overall efficiency of the system (10). A cooler (57, 58) is positioned in front of the air inlet of each gas turbine (24, 38); and coolant (e.g. water) is flowed through each of the coolers (57, 58) to cool the ambient air as it flows into the gas turbines (24, 38). The water, in turn, is cooled with propane taken from a refrigerant circuit (20) in the system (10) which, in turn, is used to initially cool the natural gas which is to be liquefied.

PROCESS AND SYSTEM FOR LIQUEFYING NATURAL GAS

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DESCRIPTION1. Technical Field

The present invention relates to a process and system for liquefying natural gas and in one aspect relates to a process and system for liquefying natural gas wherein the air to the power turbines used in the system is cooled by excess refrigeration from within the system to thereby improve the operating efficiency of the turbines and hence, the overall efficiency of the system.

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2. Background

Most Liquid Natural Gas ("LNG") plants constructed in the last 20 years or so have used industrial gas turbines to drive the refrigeration compressors required to liquefy the natural gas. Typically, these gas turbines have inlet air filters but do not include any means for cooling the inlet air to the turbines. It well known that the amount of power available from a gas turbine is, in part, a function of the inlet air temperature; see "The Refrigerated Gas and Vapor Turbine Cycle", J. Hilbert Anderson and F.M. Laucks, 87-GT-15, ASME, 1987; "The Anderson Quin Cycle", J. Hilbert Anderson and W.M. Bilbow, U.S. Department of Energy, Grant # DE-FG01-91CE15535, Final Report, March 19, 1993; U.S. Patent 4,418,527, issued December 6, 1983.

Since the temperature and density of the inlet air changes with the ambient temperature, the amount of power available from a particular turbine varies from day to night and from summer to winter. This change in available power can be quite large; e.g. at times the power available during the hottest summer day will be less than 60% of the power available during the coolest winter night. Also, the horsepower from the turbine needed to provide the required refrigeration in an LNG process increases as the heat sink temperature increases (i.e. seawater or air). Due to these varying factors, the gas turbines used in a typical

LNG plant usually include gas turbines large enough to supply the required horsepower when operating at the warmest ambient temperatures even though they may only operate at these temperature for short periods of time. This means that most LNG
5 plants have to be significantly oversized in order to insure that the required horsepower is always available regardless of the then current ambient temperature.

The effect that the temperature of the inlet air has on the power output of a gas turbine in an LNG process has been
10 recognized. For example, the gas liquefaction system disclosed in U.S. Patent 4,566,885, issued January 28, 1986, is designed with gas turbines large enough to provide the necessary horsepower to liquefy LNG even when operating at the maximum (i.e. warmest) expected ambient temperature. If and when the
15 ambient temperature cools off from this maximum temperature, the turbines can generate additional power which, in turn, can then be used to drive a generator to produce additional electrical power. While this system recovers some of the excess power from the turbines, it still requires unnecessarily large turbines
20 which significantly add to the capital and maintenance costs involved.

Another LNG process in which the temperature of the inlet air to the turbines is used to improve the operation thereof is disclosed in U.S. Patent 5,139,548, issued August 18, 1992
25 wherein the ambient temperature of the inlet air is periodically predicted. Each predicted temperature is then used to optimize the operating conditions for the system, e.g. minimize the fuel consumption by the turbines at a given LNG production rate. Again, the turbines used in this system must be large enough to
30 produce the horsepower needed at the warmest ambient temperature even though some of the costs can be recouped by reducing the fuel consumption during cooler periods.

While cooling the inlet air for turbines is used in a variety of known commercial operations, e.g. electrical power
35 generation, air conditioning, ice making, etc.; see U.S. Patents

5,203,161; 5,321,944; 5,444,971; 5,457,951; 5,622,044;
5,626,019; 5,666,800; 5,758,502; and 5,806,298, it has not found
use in gas liquefaction processes such as LNG processes wherein
the costs of the turbines required to furnish the power in such
operations is a significant factor in the capital and operating
costs of the system. With LNG becoming a more important energy
source each year, there exists a real need for improving the
efficiency of the LNG processes and reducing their costs in
order to deliver LNG to market at a competitive price.

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SUMMARY OF THE INVENTION

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The present invention provides a natural gas liquefaction
(LNG) system and process wherein excess refrigeration available
in a typical, LNG system is used to cool the inlet air to the
gas turbines in the system thereby improving the overall
efficiency of the system. By maintaining the inlet air for the
gas turbines at a constant low temperature, the amount of power
generated by the turbines remains at a high level regardless of
the ambient air temperature. This allows a LNG plant to be
designed for more capacity and allows the plant to operate at a
constant production rate throughout the year. Further, since
the present invention utilizes the propane circuit which is
already present in LNG systems of this type, no additional
cooling source is required to carry out the invention.

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More specifically, the present invention is especially
useful in LNG systems which use first and second closed circuits
of first and second refrigerants to cool a feed gas to the low
temperatures needed for liquefaction. The first closed circuit
carries a first refrigerant (e.g. propane) which is used to
initially cool the feed gas (e.g. natural gas). This first
circuit, in addition to the necessary heat exchanger needed for
cooling the feed gas, also includes a first gas turbine which
drives a first compressor which, in turn, compresses and
circulates the propane through the first closed circuit. The
second closed refrigerant circuit carries a mixed refrigerant
"MR" (e.g. nitrogen, methane, ethane, and propane) for further

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cooling the feed gas to the final low temperature required to produce LNG. The mixed refrigerant is compressed and circulated through the second closed refrigerant circuit by a second compressor which is driven by a second gas turbine.

5 In accordance with the present invention, the above described LNG system further includes a means for cooling the inlet air to the respective gas turbines. This means is comprised of (1) a cooler positioned in front of the air inlet of each of the respective gas turbines and (2) a closed coolant
10 circuit which is in fluid communication with each of the coolers. Coolant (e.g. water) flows through each of the coolers to cool the ambient air as air flows therethrough and into the turbines.

The closed coolant circuit includes a heat exchanger which
15 is fluidly connected to the first refrigerant circuit whereby at least a portion of the propane in the first refrigerant circuit will flow through the heat exchanger to cool the water in said closed coolant circuit. Preferably, the ambient air is cooled to a temperature no lower than about 5°C (41°F) in order to
20 prevent icing in the system. An anti-freeze agent (e.g. ethylene glycol) with corrosion inhibitors can be added to the water as needed.

BRIEF DESCRIPTION OF THE DRAWINGS

The actual construction, operation, and advantages of the
25 present invention will be better understood by referring to the drawings, not necessarily to scale, in which like numerals identify like parts and in which:

FIG. 1 (PRIOR ART) is a flow diagram of a typical, prior art, system for liquefying natural gas (LNG);

30 FIG. 2 is a flow diagram of the system for liquefying natural gas (LNG) in accordance with the present invention; and

FIG. 3 is an enlarged view of the turbine inlet air cooling circuit of the system of FIG. 2.

While the invention will be described in connection
35 with its preferred embodiments, it will be understood that this

invention is not limited thereto. On the contrary, the invention is intended to cover all alternatives, modifications, and equivalents which may be included within the spirit and scope of the invention, as defined by the appended claims.

5 BEST KNOWN MODE FOR CARRYING OUT THE INVENTION

Referring more particularly to the drawings, FIG. 1 (PRIOR ART) illustrates a typical, known system 10 and process for liquefying natural gas (LNG). In system 10, feed gas (natural gas) enters through inlet line 11 into a preparation unit 12
10 where it is treated to remove contaminants. The treated gas then passes from unit 12 through a series of heat exchangers 13, 14, 15, 16, where it is cooled by evaporating propane which, in turn, is flowing through the respective heat exchangers through propane circuit 20. The cooled natural gas then flows to
15 fractionation column 17 wherein pentanes and heavier hydrocarbons are removed through line 18 for further processing in fractionating unit 19.

The remaining mixture of methane, ethane, propane, and butane is removed from fractionation column 17 through line 21
20 and is liquefied in the main cryogenic heat exchanger 22 by further cooling the gas mixture with a mixed refrigerant (MR) which flows through MR circuit 30. The MR is a mixture of nitrogen, methane, ethane, and propane which is compressed in compressors 23 which, in turn, are driven by gas turbine 24.
25 After compression, the MR is cooled by passing it through air or water coolers 25 and is then partly condensed within heat exchangers 26, 27, 28, and 29 by the evaporating propane from propane circuit 20. The MR is then flowed to high pressure MR separator 31 wherein the condensed liquid (line 32) is separated
30 from the vapor (line 33). As seen in FIG. 1, both the liquid and vapor from separator 31 flow through main cryogenic heat exchanger 22 where they are cooled by evaporating MR.

The cold liquid stream in line 32 is removed from the middle of heat exchanger 22 and the pressure thereof is reduced
35 across expansion valve 34. The now low pressure MR is then put

back into exchanger 22 where it is evaporated by the warmer MR streams and the feed gas stream in line 21. When the MR vapor steam reaches the top of heat exchanger 22, it has condensed and is removed and expanded across expansion valve 35 before it is
5 returned to the heat exchanger 22. As the condensed MR vapor falls within the exchanger 22, it is evaporated by exchanging heat with the feed gas in line 21 and the high pressure MR stream in line 32. At the middle of exchanger 22, the falling condensed MR vapor mixes with the low pressure MR liquid stream
10 within the exchanger 22 and the combined stream exits the bottom exchanger 22 as a vapor through outlet 36 to flow back to compressors 23 to complete MR circuit 30.

Closed propane circuit 20 is used to cool both the feed gas and the MR before they pass through main cryogenic heat
15 exchanger 22. Propane is compressed by compressor or compressors 37 which, in turn, is powered by gas turbine 38. The compressed propane is condensed in coolers 39 (e.g. seawater or air cooled) and is collected in propane surge tank 40 from which it is cascaded through the heat exchangers (propane
20 chillers) 13-16 and 26-29 where it evaporates to cool both the feed gas and the MR, respectively. Both gas turbines 24 and 38 have air filters 41 but neither have any means for cooling the inlet air.

Now referring to FIG. 2, in accordance with the present
25 invention, means is provided in the typical system 10 of FIG. 1 for cooling the inlet air to both gas turbines 24 and 38 for improving the operating efficiency of the turbines. FIG. 3 is an enlarged view of the turbine inlet air cooling circuit of the system illustrated in FIG. 2. Basically, the cooling means in
30 the present invention utilizes excess refrigeration available in a typical gasification system 10 to cool water which, in turn, is circulated through a closed, inlet coolant loop 50 to cool the inlet air to the turbines.

To provide the necessary cooling for the inlet air,
35 refrigerant (e.g., propane) is withdrawn from first closed

circuit 20 (i.e. propane surge tank 40) through line 51 and is flashed across expansion valve 52. Since first closed circuit 20 (e.g., propane circuit 20) is already available in gas liquefaction processes of this type, there is no need to provide
5 a new or separate source of cooling in the process thereby substantially reducing the costs of the system of this invention. The expanded propane is passed from valve 52 and through heat exchanger 53 before it is returned to propane circuit 20 through line 54. The propane evaporates within heat
10 exchanger 53 to thereby lower the temperature of a coolant (e.g. water) which, in turn, is pumped through the heat exchanger 53 from a storage tank 55 by pump 56.

The cooled water is then pumped through coolers 57, 58 positioned at the inlets for turbines 24, 38, respectively. As
15 air flows into the respective turbines, it passes over coils or the like in the coolers 57, 58 which, in turn, cool the inlet air before the air is delivered to its respective turbine. The warmed water is then returned to storage tank 55 through line 59. Preferably, the inlet air will be cooled to no lower than
20 about 5°C (41°F) since ice may form at lower temperatures. In some instances, it may be desirable to add an anti-freeze agent (e.g. ethylene glycol) with inhibitors to the water to prevent ice from forming in the water coolant and to control corrosion.

By maintaining the inlet air for the turbines at a
25 substantially constant low temperature, the amount of power generated by the turbines remains at a high level regardless of the ambient air temperature. This allows the LNG plant to be designed for more capacity and allows the plant to operate at a substantially constant production rate throughout the year.
30 Further, since the present invention utilizes the propane circuit which is already present in LNG systems of this type, no addition cooling source is required to carry out the invention.

CLAIMS

What is claimed is:

1. In a natural gas liquefaction process using a gas turbine to drive a compressor to circulate a refrigerant through a closed refrigerant circuit, said refrigerant being used in cooling said natural gas, said process comprising the step of:
cooling the inlet air for said turbine before said air is fed into said turbine to increase the efficiency of said turbine.
2. The natural gas liquefaction process of claim 1 wherein said air is cooled to a temperature of no lower than about 5°C (41°F).
3. The natural gas liquefaction process of claim 1 wherein said inlet air is cooled by heat exchanging said air with a coolant.
4. The natural gas liquefaction process of claim 3 wherein said coolant is water.
5. The natural gas liquefaction process of claim 4 wherein said water is cooled by heat exchanging said water with said refrigerant from said closed refrigerant circuit.
6. The natural gas liquefaction process of claim 5 wherein said refrigerant is propane.
7. A system for liquefying natural gas comprising:
a first closed circuit of a first refrigerant for initially cooling said natural gas;
a first compressor for compressing said first refrigerant as said first refrigerant flows through said first closed circuit;

a first gas turbine for driving said first compressor, said first compressor having an air inlet; and
means for cooling the ambient air before said air enters said air inlet.

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8. The system of claim 7 wherein said means for cooling said ambient air comprises:

a cooler in front of said air inlet of said first turbine; and

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a closed coolant circuit for carrying a coolant therethrough, said closed coolant circuit being in fluid communication with said cooler whereby said coolant flows through said cooler to cool said air as said air flows through said cooler and into said turbine through said air inlet.

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9. The system of claim 7 wherein said first refrigerant is comprised of propane.

10. The system of claim 9 wherein said coolant is water.

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11. The system of claim 10 including:

a heat exchanger in said closed coolant circuit;

means for fluidly connecting said heat exchanger to said first refrigerant circuit whereby at least a portion of
said first refrigerant flows through said heat exchanger to cool
said water in said closed coolant circuit.

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12. The system of claim 11 including:

a second closed circuit of a second refrigerant for
additionally cooling said natural gas after said natural gas has
been initially cooled;

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a second compressor for compressing said second refrigerant as said second refrigerant flows through said second closed circuit;

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a second gas turbine for driving said second compressor; said second compressor having an air inlet; and

means for cooling the ambient air before said air enters said air inlet of said second gas turbine.

13. The system of claim 12 wherein said means for cooling
5 said ambient air for said second gas turbine comprises:

a second cooler in front of said air inlet of said second turbine; and

means for fluidly connecting said second cooler to said closed coolant circuit whereby said coolant flows through
10 said second cooler to cool said ambient air before it enters said second gas turbine.

14. The system of claim 7 wherein said second refrigerant is a mixed refrigerant comprised of nitrogen, methane, ethane,
15 and propane.

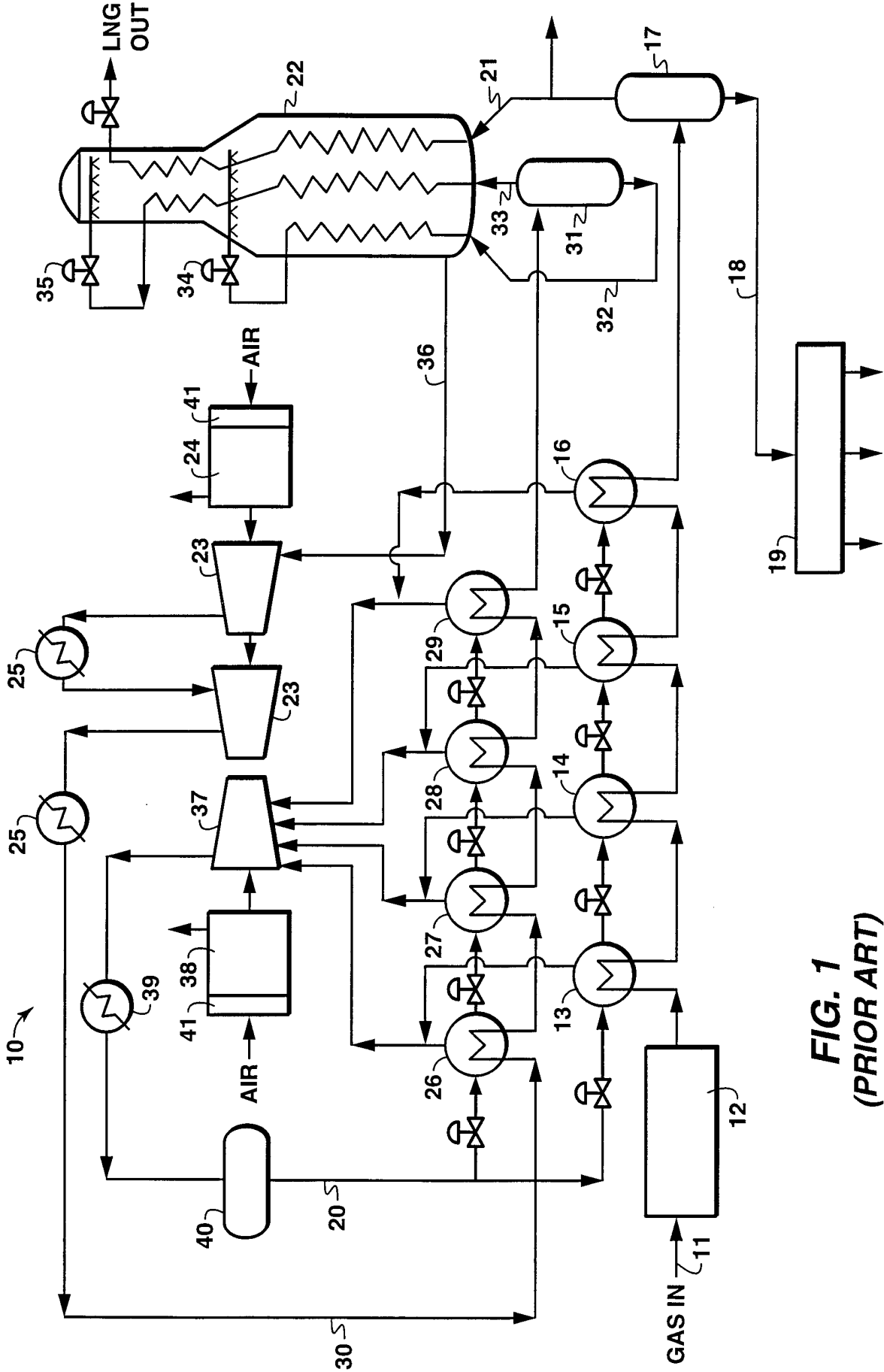


FIG. 1
(PRIOR ART)

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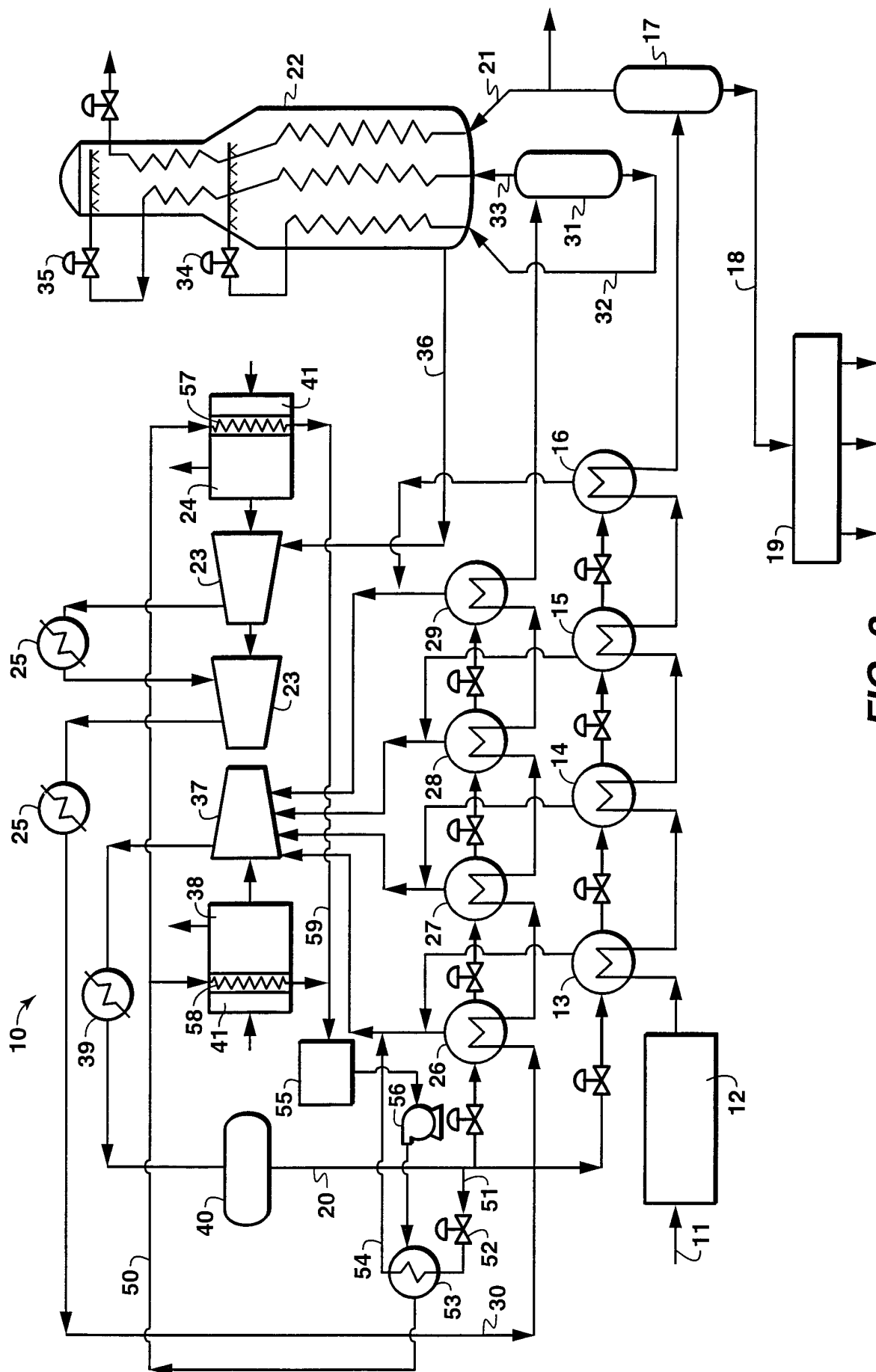
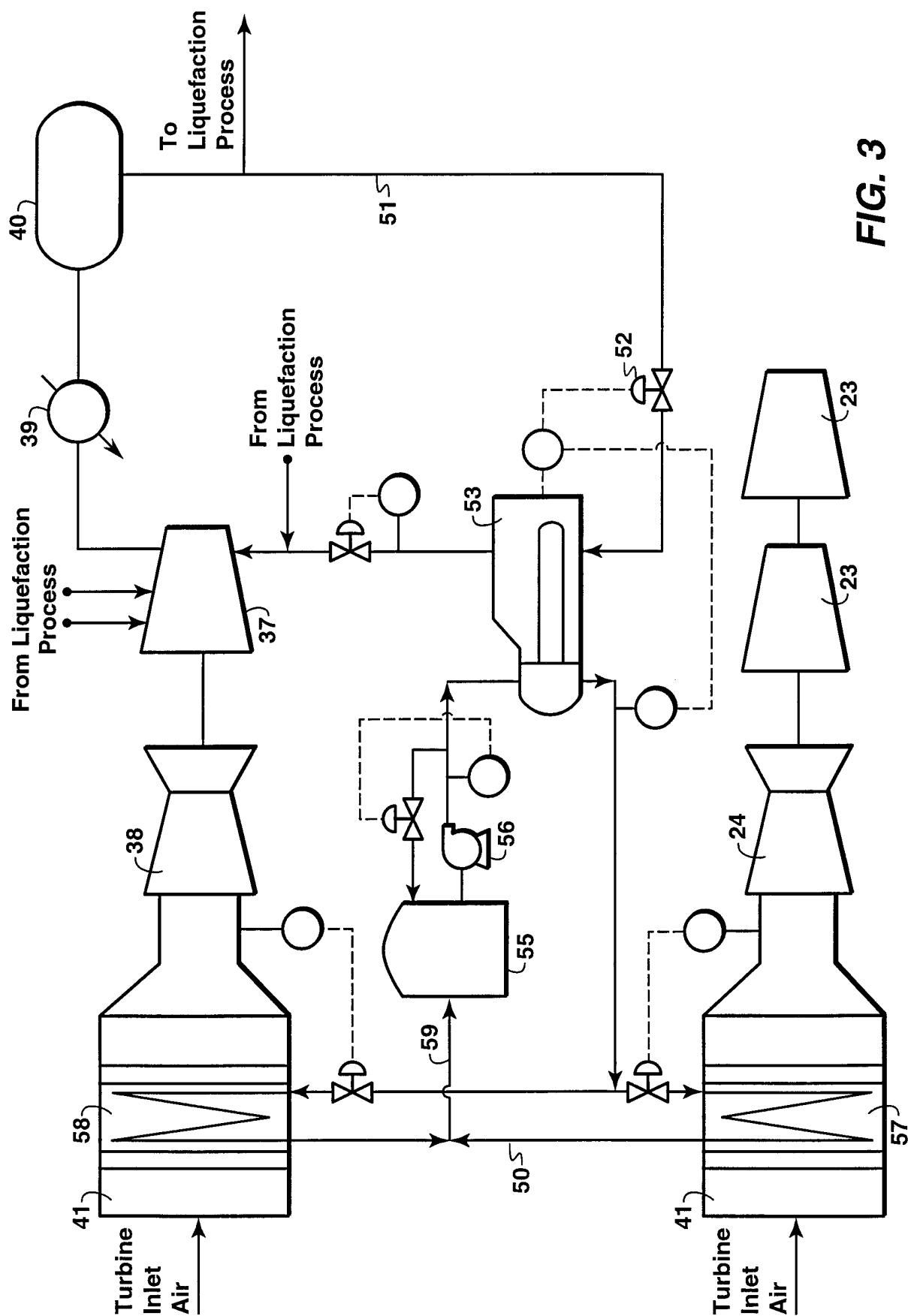


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/16341

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :F25 J 3/00

US CL :62/613, 619

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 62/613, 619

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, 3,257,813 A (HASHEMI-TAFRESHI) 28 June 1966, see the entire document.	1-14
A	US 3,323,315 A (CARR) 06 June 1967, see the entire document.	1-14
A	US 5,450,728 A (VORA ET AL) 19 September 1995, see the entire document.	1-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

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Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer


Ronald C. Caposeta

Telephone No. (703) 308-0688