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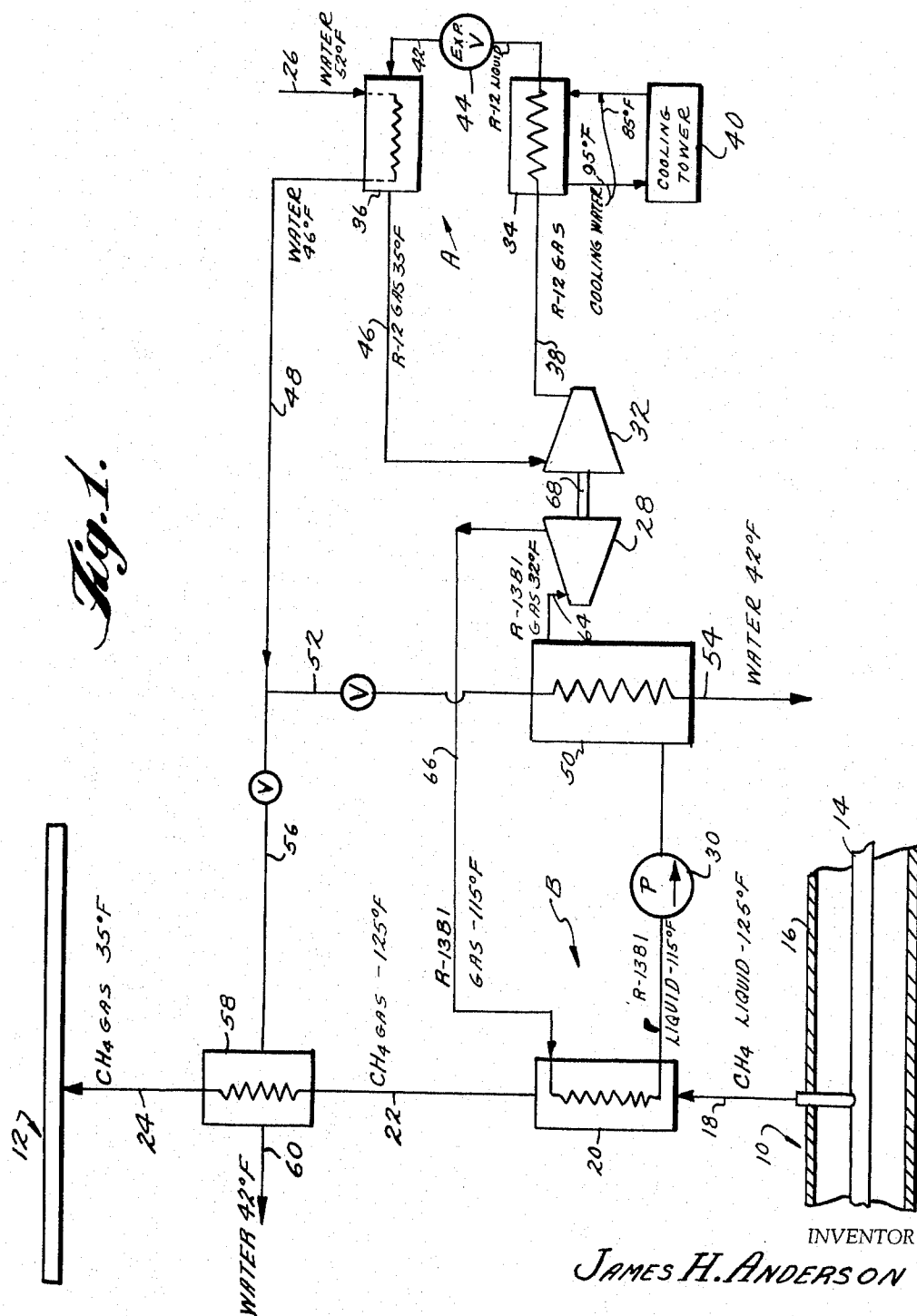
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METHOD AND APPARATUS FOR EVAPORATING LIQUEFIED GASES

Filed Nov. 27, 1964

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 2.

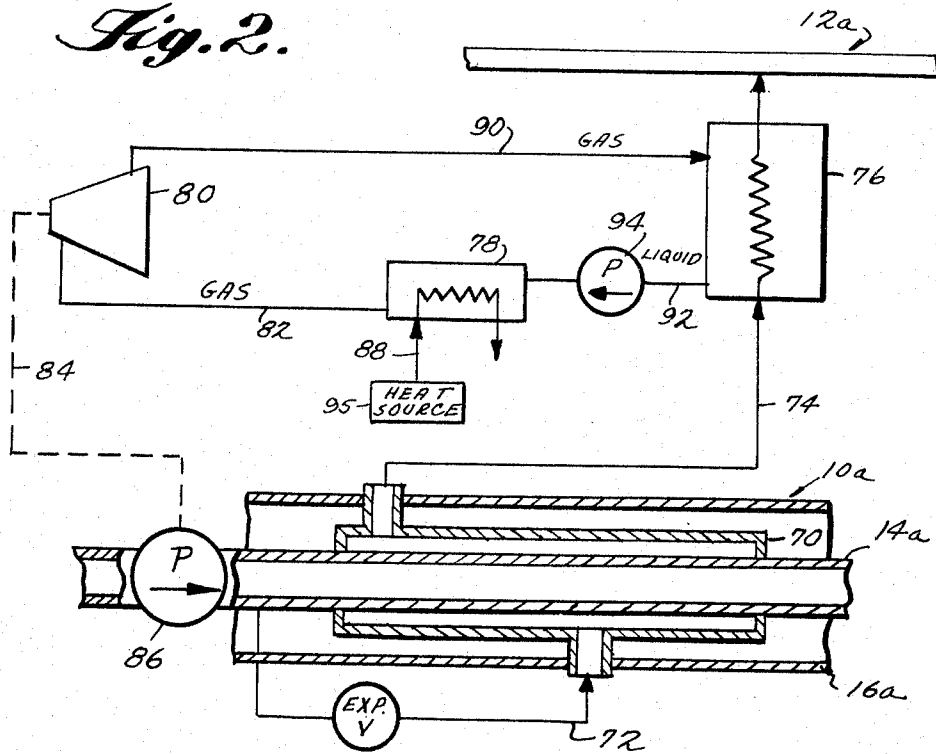
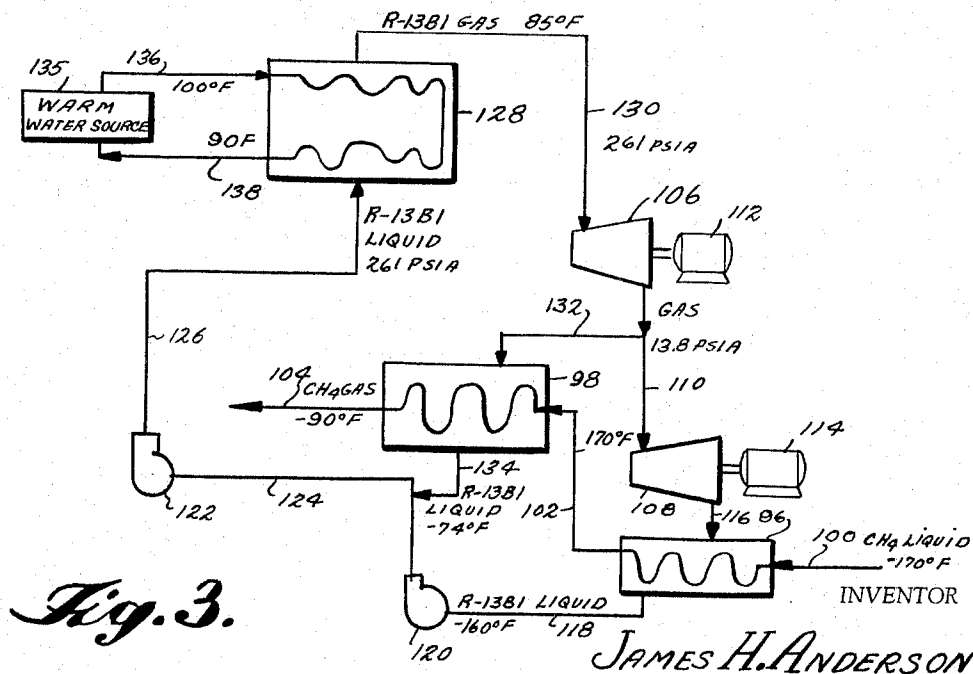


Fig. 3.

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METHOD AND APPARATUS FOR EVAPORATING LIQUEFIED GASES

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9 Claims. (Cl. 62-52)

This invention relates to the withdrawal of liquefied gas from a source thereof and the subsequent evaporation of the withdrawn portion and in particular to the achievement of economies in carrying out these operations.

The invention is particularly useful in the handling of liquefied natural gas. Although natural gas is conventionally transmitted over long distances through pipe lines in a gaseous state at high pressure, economies can be gained by transmitting the gas in cold, liquefied form. For a given flow rate pipes of smaller diameter can be employed if the gas is first liquefied, because the resulting liquid has a higher density than the gas. The wall thickness of the pipe can also be reduced because, for a given flow rate, the liquid can be pumped at lower pressure than the gas. The wall thickness can be further reduced if the liquid is maintained at a low temperature and corresponding by low vapor pressure. While these savings in the cost of the line are offset to an extent by the cost of liquefaction of the gas and the necessity of insulating the pipe line, the transmission of gas in liquid form retains significant economic advantages.

Since natural gas is ordinarily delivered to customers as a gas, an additional consideration is the vaporization of the liquefied gas which must be effected at various consumer service points along the line. When large amounts of gas are being drawn from the main pipe line, for example 2 billion cubic feet per day, the amount of heat energy required in the vaporization step is of considerable economic significance.

Another consideration in the cost of operating a liquefied gas line is the effect of pressure drop due to friction between the pipe wall and the liquid. Pressure must be maintained by placing pumps in the line at intervals, and the work done on the liquid by the pumps increases the temperature of the liquid. This higher temperature and any temperature increase resulting from heat absorption from the surroundings must be reduced by refrigeration in order to maintain the pressure in the line at a safe operating level.

These considerations are not restricted to liquefied natural gas lines, however, and the principles of the invention are applicable to the vaporization of any liquefied gas.

It is one object of the present invention to provide a method and apparatus for reclaiming some of the energy used to liquefy gas for transmission in a liquid state through a pipe line by economically and efficiently utilizing the cooling effect obtained when liquid is withdrawn from the pipe line and vaporized prior to being transmitted to a consumer.

It is a more specific object to provide a method and apparatus for efficiently utilizing the above-mentioned cooling effect as a source of refrigeration for an installation, such as a large air conditioning unit located at the site of the consumer.

It is still a more specific object to provide a method and apparatus for utilizing the above-mentioned cooling effect to chill a greater amount of water than would be achieved by chilling the water directly with the vaporizing of the liquefied gas.

It is a further specific object to utilize the above-mentioned cooling effect as a heat sink for a power-producing heat engine which may be employed, for example, to aid in pumping the liquefied gas through the main pipe line.

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The invention will be further understood from the following detailed description taken with the drawings in which:

FIGURE 1 is a flow sheet illustrating a system for withdrawing liquefied gas from a main pipe line for transmission as a gas to a consumer pipe line and for chilling water by means of the cooling effect produced by vaporizing the withdrawn liquefied gas;

FIGURE 2 is a flow sheet illustrating a system for withdrawing liquefied gas from a main pipe line for transmission as a gas to a consumer pipe line and for employing the cooling effect of vaporizing the withdrawn liquid as a heat sink for a heat engine which provides pumping power for the main pipe line; and

FIGURE 3 is a flow sheet illustrating another system for employing the cooling effect of a vaporizing gas as a heat sink for a power producing heat engine.

Referring to FIGURE 1 there is shown a main pipe line 10 for transporting liquefied natural gas, a vaporizing system for withdrawing a portion of the main liquefied gas stream and delivering it as a gas to a consumer pipe line 12, and a system for chilling water with the heat absorbed during the vaporization of the withdrawn liquefied gas. The consumer pipe line 12 is illustrative of a piping system of an entire town or factory and is not intended to be restricted to a single household gas pipe. For simplicity natural gas is shown in all the drawings as CH₄. The main liquefied gas pipe line 10 is preferably a thermally insulated line and, as shown, includes an inner liquid-carrying pipe 14 supported concentrically within an outer pipe 16. The annular space between the two pipes is evacuated in order to insulate the cold inner pipe 14 from its surroundings. Details of the construction of vacuum-jacketed pipe lines are given in my application Serial No. 374,448 filed June 11, 1964.

In the arrangement illustrated in FIGURE 1, liquefied gas in the amount required by the consumer is withdrawn through a line 18 from the inner pipe 14 of the main pipe line 10, vaporized in a heat exchanger 20 and passed to the consumer gas line 12 through lines 22 and 24. The remainder of FIGURE 1, which is described below, relates to the economic utilization of the heat absorbed in the vaporizer 20 to chill water for use in, for example, a large air-conditioning system or refrigeration plant located at or near the site of the vaporizer 20. Such a system might be employed, for example, to provide refrigeration for a meat packing plant or ice plant or to cool buildings.

Broadly described, the cooling of a stream of water entering the system through a pipe 26 is effected in two stages, A and B, each of which involves heat exchange between the water stream and a stream of refrigerant contained within a separate closed compression-expansion circuit. A refrigerant other than the evaporating natural gas is employed for each cycle, A and B. Cycle B includes a turbine 28 which extracts work from high pressure refrigerant gas after the same is compressed by a pump 30 and the work is employed to operate a refrigerant compressor 32 in cycle A. It has been found that the arrangement of cycles A and B produces a total chilling effect in excess of that which would be produced by cooling the water stream with heat exchange between the water and the vaporizing natural gas. There is the additional advantage over the use of direct heat exchange between the gas and water in that in the latter system there is a danger that the water might freeze due to the low temperature of the gas.

Referring now to the right-hand part of FIGURE 1 it will be seen that the refrigerant cycle A includes the refrigerant compressor 32, a refrigerant condenser 34, and a refrigerant evaporator 36, the latter being a heat exchanger in which water from the pipe 26 is passed in

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heat exchange relationship with vaporizing refrigerant. In the embodiment being described the refrigerant is CCl_2F , commonly referred to as R-12, but other refrigerants, such as propane, may be employed depending on the pressure at which the cycle is operated.

The refrigerant condenser 34 in cycle A, the R-12 cycle, receives compressed refrigerant gas from the compressor 32 through a line 38 and is provided with a separate stream of cooling water. The latter is recycled between the condenser 34 and a conventional cooling tower 40 in a manner well known in the refrigeration art.

The evaporator 36 receives the condensed refrigerant from the condenser 34 through a line 42 which contains an expansion valve 44, as is conventional in refrigeration practice. From the evaporator 36 the vaporized refrigerant passes to the inlet of the compressor 32 through a line 46, and the semi-chilled water passes to cycle B through a line 48.

Cycle B is a Rankine power cycle using R-13B1 refrigerant, CB_2F_8 , as the working fluid. The cycle includes the natural gas vaporizer 20, which serves as the refrigerant condenser of cycle B and a refrigerant evaporator 50 where semi-chilled water from the cycle A heat exchanger 36 is further cooled. As seen in FIGURE 1, water leaving the heat exchanger 36 through the pipe 48 enters the cycle B heat exchanger through a valved branch pipe 52 and leaves through a pipe 54 which conducts it to a large air conditioning system (not shown) where it is employed for cooling purposes. If desired, some of the water from the pipe 48 may be sent through a valved branch pipe 56 to a heat exchanger 58 in the natural gas line 22, 24 where it is cooled and then passed to the air conditioning system (not shown) by pipe 60.

Still referring to cycle B, condensed refrigerant from the natural gas vaporizer 20 is pumped through a line 62 by the pump 30 to the refrigerant evaporator, or water cooler. Refrigerant vapor at high pressure then passes from the evaporator to the inlet of the turbine 28 through a line 64 and then from the turbine outlet back to the natural gas vaporizer 20 through a line 66. The turbine 28 has an output shaft 68 which is connected to the shaft of the refrigerant compressor 32 in cycle A. While the refrigerant in cycle B is R-13B1, other refrigerants, such as ethylene, could be employed.

In operation of the system of FIGURE 1, liquid natural gas, shown in the figure as CH_4 leaves the main pipe line 10 at a temperature of -125°F . and the corresponding saturation pressure and passes to the natural gas vaporizer 20 through the line 18. The natural gas is evaporated in the vaporizer at constant temperature by heat furnished by the warm R-13B1 refrigerant gas of cycle B which enters through the line 66. The refrigerant gas condenses in the natural gas vaporizer at -115°F . and is then pumped to a high pressure by the pump 30. The high pressure liquid is delivered to the refrigerant evaporator, or water cooler 50, where it evaporates to a saturated gas at 32°F .

The heat absorbed by the evaporating R-13B1 in the cooler 50 is provided by the water stream entering the cooler 50 through the line 52 from cycle A at a semi-chilled temperature of 46°F . The water stream is thereby cooled to 42°F . and is then made available through the line 54 to the air conditioning system (not shown). The high pressure R-13B1 gas leaving the cooler 50 through the line 64 is expanded through the turbine 28 to a lower pressure and is returned to the natural gas vaporizer 20. This lower pressure corresponds to a condensing temperature of -115°F . so that condensation occurs in the vaporizer 20 at constant temperature.

The work output from the turbine shaft 68 drives the refrigerant compressor in cycle A to compress the R-12 gas in that cycle. The compressed R-12 passes through the line 38 to the condenser 34 where its heat of vaporization is removed with a captive water circuit from the cooling tower. From the condenser the liquid refrigerant

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passes through the line 42 to the water cooler, or refrigerant evaporator 36 where it evaporates. Water entering the cooler through the line 26 at 52°F . is thereby cooled to 46°F . and is sent on to the other cooler 50 in cycle B for further cooling. The vaporized refrigerant leaves the cooler 36 at 35°F . and returns to the inlet of the compressor 32 through the line 46.

Ordinarily, the entire chilled water flow will be passed through the line 52 and the cooler 50. The additional cooler 58 to which the cold natural gas at -125°F . passes on its way from the vaporizer 50 to the consumer gas line 12 is an optional feature which may be employed. It will be understood, of course, that the cold natural gas in the lines 22, 24 can be employed as a cooling medium for any purpose, the decision to utilize the cooling being primarily one of balancing the value of the cooling with the cost and operating expense of the necessary heat exchanger equipment.

Thus, in the operation of the system of FIGURE 1 the heat given up by the water which is being chilled is given up partly to the natural gas as it vaporizes in the natural gas vaporizer 20 and partly to deliver work at the turbine shaft 68. It is known, in common practice, that one horsepower at the compressor shaft will produce about one refrigeration ton of chilled water equivalent to 200 B.t.u./min. In terms of heat energy the one horsepower input is equivalent to 42.4 B.t.u./min. In the FIGURE 1 system the use of the water cooler 50 as a R-13B1 boiler to produce mechanical power at the turbine 28 produces greater cooling of the water stream in the cooler 50 and cooler 36 than would be produced if the R-13B1 vapor were condensed in the cooler 20 without having been expanded in the turbine. As a result, the total refrigerating effect of the evaporating natural gas is greater in the FIGURE 1 system than if the vaporizing natural gas were employed as a direct coolant for the water stream or for some other direct heat exchange process.

It will be understood that the principles of the increased chilling effect obtained with the FIGURE 1 system are applicable to the vaporization of any liquefied gas which boils at a low temperature. The increased cooling effect is not restricted to the chilling of a water stream for use in a refrigeration system; obviously the cold liquid refrigerants in both cycles A and B could be employed as coolants for a variety of purposes.

In FIGURE 2 there is illustrated, schematically, a system for extracting pumping energy from an available source of heat and a stream of cold natural gas being removed from a main pipe line 10a for use in a consumer gas line 12a. The inner liquid-carrying pipe 14a is surrounded by a concentric cooling jacket 70 which receives liquid natural gas from the inner pipe 14a through a small line 72 containing an expansion valve. A line 74 conducts vaporized natural gas from the cooling jacket 70 through a heat exchanger 76 to the consumer line 12a. Where all the gas is to be vaporized, the jacket 70 is not required, as at the end of the liquefied gas line 10a where all of the gas would naturally be delivered to a user.

A captive circuit containing a working fluid, such as R-13B1 refrigerant, is employed to produce mechanical work and includes a refrigerant boiler 78 from which refrigerant vapor passes to a power-producing turbine 80 through a line 82. The turbine shaft is mechanically connected, as indicated by the dotted line 84 to the shaft of a pump 86 in the pipe 14a. The boiler 78 is a heat exchanger in which heat is transferred to the stream of refrigerant from a stream of water or air, conducted through a line 88. The turbine outlet is connected by a line 90 to the heat exchanger 76 which serves as a condenser for the refrigerant. The bottom of the heat exchanger 76 is connected to the refrigerant boiler 78 by a line 92 containing a pump 94.

In operation of the system of FIGURE 2 a stream of

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liquefied natural gas from the main line 14a is conducted through the small line 72 to the cooling jacket 70 where it at least partially vaporizes before it passes to the consumer gas line 12a by way of the heat exchanger 76. In the arrangement illustrated it is assumed that consumer demand is relatively high so that both liquid and vapor enter the heat exchanger 76, but the principles of cooling and power production are the same even if only vapor leaves the cooling jacket 70. The principles of power production apply also if the jacket 70 is omitted and only liquid is sent to the heat exchanger 76.

The cooling effect of the cold vapor and of the vaporization of the remaining liquid in the heat exchanger 76 serves as a heat sink for a power-producing cycle. The heat exchanger 76 is a working fluid condenser in this cycle, and the heat exchanger 78 is a working fluid boiler for producing a stream of vapor for operating the turbine 80. The pump 94, as in conventional practice, is employed to raise the pressure of the working fluid to an acceptable turbine operating pressure. Since pressurized R-13B1 can be vaporized at usual ambient temperatures, the heat source for the heat exchanger 78 may be a stream of any available warm fluid. Waste warm water leaving a condenser in a power plant, illustrated at 95, would be a convenient source of heat for this purpose. The cooled fluid may be employed for cooling purposes in another system or it may be discarded. Other working fluids, such as R-13 (CClF_3), R-22 (CHClF_2) and ethylene, may also be used.

It will be appreciated that the work output of the turbine 80 may be employed for purposes other than driving the pump 86, such as driving a generator for providing current for the plant or for commercial power lines.

FIGURE 3 shows schematically, another power-producing system which employs a stream of vaporizing natural gas as a heat sink and a stream of warm water as a heat source. The natural gas circuit includes first and second heat exchangers 96, 98 in which liquefied natural gas is vaporized and warmed slightly and in which a refrigerant working fluid is condensed. Liquefied natural gas enters the system through a line 100 from a main line (not shown). The natural gas channels of the heat exchangers 96, 98 are connected in series by a line 102, and a line 104 delivers vaporized natural gas from the exchanger 98 to a point of consumption (not shown).

The refrigerant working fluid circuit includes a pair of series-connected turbines 106, 108 which are connected by a line 110 and which are drivingly connected to electric generators 112, 114, respectively. An exhaust line 116 leads from the outlet of the turbine 108 to the working fluid channels in the heat exchanger 96, or working fluid condenser. The outlet ends of these channels are connected by a line 118 to the inlet of a pump 120 which is in series with another pump 122 through a line 124. A line 126 leads from the outlet of the pump 122 to a heat exchanger 128 which serves as a working fluid boiler. The working fluid channels of the heat exchanger 128 are connected to the inlet of the turbine 106 by a line 130. The second heat exchanger 98 is connected to receive working fluid from the turbine 106 through a line 132 connecting with the line 110 and is connected to pass working fluid to the pump 122 through a line 134 connecting with the line 124.

The working fluid boiler 128 receives a stream of warm fluid from a source 135 through a line 136 and discharges it at a lower temperature through a line 138. The warm water source 135 may be any available stream of warm water, such as the cooling water of an air conditioning system for a building or a stream of waste warm water from a power plant.

The operation of the FIGURE 3 system is analogous to the operation of FIGURE 2 and of cycle B in FIGURE 1. However, the FIGURE 3 system has the additional advantage of employing the natural gas a second

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time as a heat sink at 98, at a higher temperature, thereby adding to the power produced. More specifically, liquefied natural gas enters the system through the line 100 from a main line (not shown) at, for example -170°F ., and leaves as a gas through the line 104 at -90°F . after having given up heat in the working fluid condensers 96 and 98. In the exemplary embodiment shown, the liquefied natural gas vaporizes in the working fluid condenser 96 at constant temperature and flows as a gas through the line 102 to the working fluid condenser 98.

The working fluid, which is R-13B1 in the system illustrated, enters the working fluid boiler 128 under a pressure of 261 p.s.i.a. and is vaporized and heated to a temperature of 85°F . by the warm water stream entering the boiler 128 through the line 136. The warm water is obtained at 100°F . from the source 135, assumed to be an air conditioning system for a building, and is returned to the source 135 at 90°F .

The high pressure R-13B1 vapor from the boiler 128 passes to the turbine 106 where it is expanded to 13.8 p.s.i.a. to produce work for driving the generator 112. The exhaust from the turbine 106 passes partly through the line 132 to the condenser 98 and partly through the line 110 to the other turbine 108. In the latter the vapor is further expanded to 0.64 p.s.i.a. to drive the generator 114 and then passes to the condenser 96. The electric current from the generators 112 and 114 may be employed for any useful purpose.

In the condenser 96 the lower pressure R-13B1 vapor gives up heat at generally constant pressure to cause vaporization of the liquefied natural gas. The working fluid vapor condenses in the condenser 96 and flows to the pump 120 as a liquid at -160°F . The pump 120 slightly raises the pressure of the liquid R-13B1 and sends it through the line 124 to the pump 122 where its pressure is raised to 261 p.s.i.a. for transmittal to the boiler 128. The stream of R-13B1 vapor in the line 132 is condensed at -74°F . in the condenser 98 by the cold natural gas flowing from the condenser 96. The condensed liquid then passes through the line 134 into the line 124 and thence to the pump 122.

It will thus be appreciated that the present invention provides for the economic and effective utilization of the cooling effect produced when a source of liquefied gas is vaporized prior to use. The invention shows that, while the cooling effect may be employed directly as an evaporating refrigerant, higher ultimate cooling capacity can be achieved by incorporating a compression expansion system (FIGURE 1) between the evaporating liquid and a fluid stream which is to be cooled. The invention also shows how the withdrawn liquefied gas may be efficiently employed as a refrigerant for maintaining the main body of liquid at low temperature (FIGURE 2) and as a heat sink for a power-producing compression-expansion circuit (FIGURES 2 and 3). While specific examples have been given, modifications will occur to those skilled in the art, and it is therefore not intended that the described and illustrated details be limiting except as they appear in the appended claims.

What is claimed is:

1. In a system for vaporizing and dispensing a liquefied gas from a source thereof under pressure: means for conducting a stream of liquefied gas from the source; container means for receiving the stream of liquefied gas and vaporizing the same; means for dispensing vapor under pressure from said container means; and a closed working fluid circuit for producing power, said circuit including means for condensing a vaporized working fluid, said condensing means including a conduit for conducting a vaporized working fluid in heat exchange relationship with said container means whereby heat is transferred from the working fluid to the liquefied gas to condense the former and vaporize the latter, means for pressurizing the condensed working fluid, working fluid boiler means including a heat exchanger having separate flow passages

therethrough for vaporizing the pressurized working fluid from the pressurizing means, power-producing means for expanding vaporized working fluid from said boiler means to thereby extract work from the working fluid, and conduit means for returning expanded working fluid from said power-producing means to said condenser conduit means for recondensation; means for supplying heat to the heat exchanger of said working fluid boiler means; a second closed cycle working fluid circuit, said second circuit including a compressor operatively connected to and run by the power-producing means in said first circuit for compressing a second gaseous working fluid, condenser means including a heat exchanger for condensing the compressed second working fluid, evaporator means including a heat exchanger for evaporating the condensed second working fluid and conduit means for returning the evaporated second working fluid to said compressor; conduit means for conducting to said evaporator means a stream of warm fluid which is to be cooled and conduit means for conducting the same fluid from said evaporator means to the boiler means in said first-mentioned circuit for heat exchange with the working fluid therein whereby said stream of warm fluid is cooled in two stages and whereby the cooling of said fluid stream is greater than would have been produced by cooling said fluid stream by direct heat exchange with the liquefied gas from said source.

2. Apparatus as in claim 1 wherein said vaporizing container means includes: means for at least partially expanding the stream of liquefied gas and for passing the same in heat exchange relationship with said source of liquefied gas to cool the latter, and conduit means for subsequently passing the stream of liquefied gas in heat exchange relationship with the condenser conduit in said working fluid circuit.

3. Apparatus as in claim 2 wherein said source of liquefied gas is a pipe line for transmitting liquefied natural gas and wherein said means for expanding the stream of liquefied gas to cool the source includes a cooling jacket surrounding a longitudinal portion of said pipe.

4. Apparatus as in claim 1 in combination with a chilled water refrigeration circuit, said means for supplying heat to the heat exchanger of said working fluid boiler means including a conduit for conducting water from said circuit to said heat exchanger.

5. A method of vaporizing and dispensing a liquefied gas from a source thereof maintained at superatmospheric pressure and simultaneously producing power, the steps comprising: withdrawing a stream of liquefied gas from said source; vaporizing at least a portion of said withdrawn stream; dispensing the vaporized gas; raising the pressure of a stream of condensed working fluid; passing the pressurized stream of working fluid in heat exchange relationship with a stream of warm fluid at a higher temperature from a heat source; extracting mechanical work from said pressurized stream of working fluid by expansion thereof to a lower pressure and returning said working fluid to heat exchange relationship with said stream of cold liquefied gas; employing the mechanical work obtained by expansion of said working fluid to compress a second working fluid vapor; withdrawing heat from the compressed second working fluid vapor to condense the same to a liquid; evaporating the second liquid working fluid by passing the same in heat exchange relationship with a stream of warmer fluid which is desired to be cooled; and recompressing the second working fluid vapor with the mechanical work obtained by expansion of said first-named working fluid.

6. A method as in claim 5 wherein a single stream

of warmer fluid is passed first in heat exchange relationship with said second working fluid and then in heat exchange relationship with said first-named working fluid.

7. In a system for vaporizing and dispensing a liquefied gas from a source thereof under pressure: means for conducting a stream of liquefied gas from the source; a first heat exchanger for receiving the stream from the source; a second heat exchanger for receiving the stream from said first heat exchanger; means for dispensing vapor under pressure from said second heat exchanger; and a closed working fluid circuit for producing power, said circuit including means for pressurizing a condensed working fluid, working fluid boiler means including a heat exchanger for vaporizing the pressurized working fluid from the pressurizing means, first and second expansion engines for expanding vaporized working fluid from said boiler means to thereby extract work from the working fluid, said first expansion engine being connected to receive pressurized working fluid from said working fluid boiler means and to pass expanded working fluid partly to said second heat exchanger and partly to said second expansion engine, said second expansion engine being connected to pass expanded working fluid to said first heat exchanger whereby heat is transferred from the working fluid to the liquefied gas to condense the former and vaporize the latter, and means for conducting condensed working fluid from said first and second heat exchangers to said working fluid pressurizing means.

8. Apparatus as in claim 7 in combination with a power plant having a waste warm water circuit, said means for supplying heat to the heat exchanger of said working fluid boiler means including a conduit for conducting warm water from said warm water circuit to said heat exchanger.

9. A method of vaporizing a liquefied gas from a source thereof maintained at superatmospheric pressure and low temperature and simultaneously producing power comprising: withdrawing a stream of liquefied gas from said source; raising the pressure of a stream of condensed working fluid; passing the pressurized stream of working fluid in heat exchange relationship with a stream of warm fluid at a higher temperature from a heat source to thereby vaporize said working fluid; extracting mechanical work from said pressurized stream of working fluid by partial expansion thereof in a first stage; dividing the partly expanded working fluid into first and second streams; extracting additional work by further expanding said first stream in a second stage; condensing said first and second streams and simultaneously vaporizing said stream of liquefied gas, said first stream being condensed by passing it in heat exchange relationship with said stream of liquefied gas, said second stream being condensed by passing it in heat exchange relationship with the stream of liquefied gas after it has given up heat to said first stream.

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