Aug. 31, 1965 M. J. FRENCH 3,203,191

ENERGY DERIVED FROM EXPANSION OF LIQUEFIED GAS

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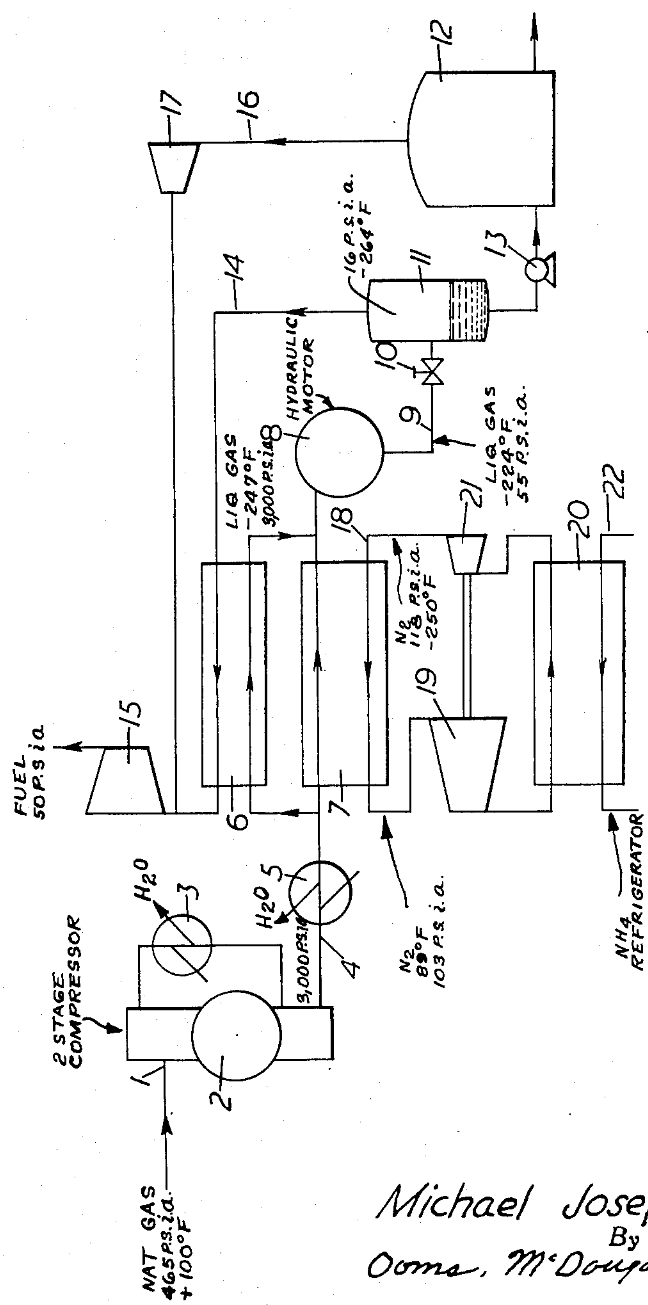

Inventor
Michael Joseph French
By
Ooms, McDougall & Hersh
Attorney

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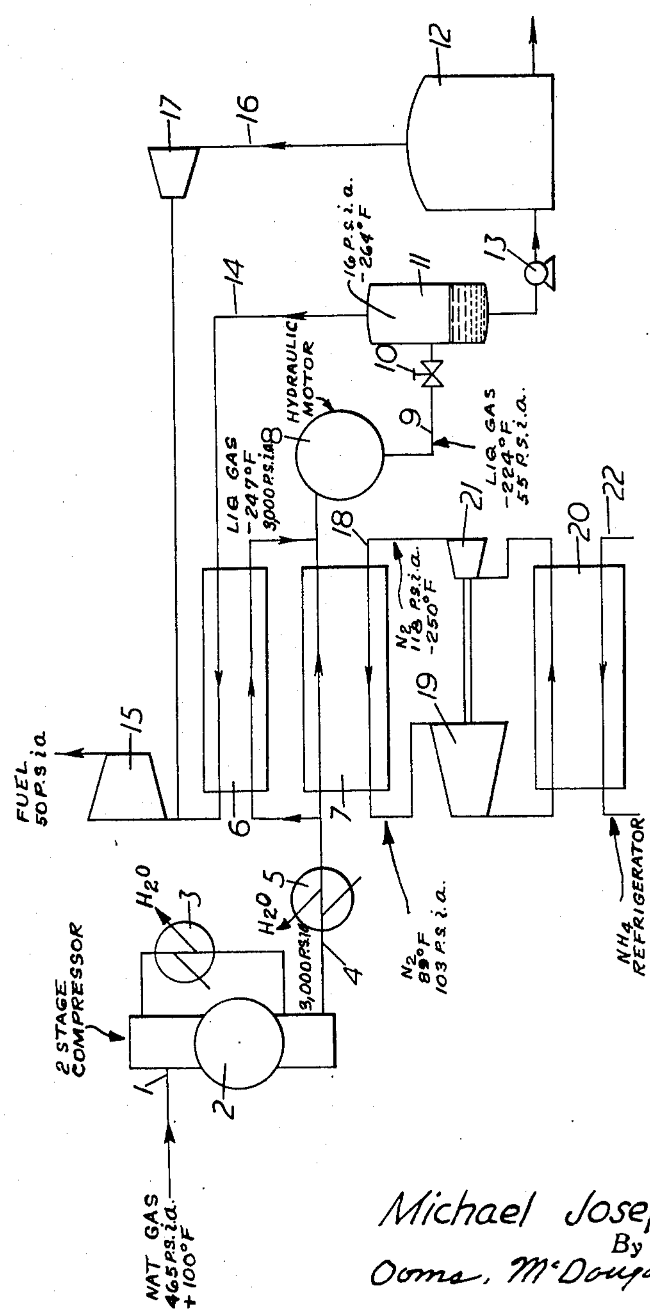

Inventor
Michael Joseph French
By
Ooms, McDougall & Hersh
Attorney

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ENERGY DERIVED FROM EXPANSION OF LIQUEFIED GAS

Michael Joseph French, New Malden, England, assignor to Conch International Methane Limited, Nassau, Bahamas, a company of the Bahamas

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11 Claims. (Cl. 62—9)

This invention relates to improvements in processes for the liquefaction of gases.

Processes for the liquefaction of gases include those in which the gas is liquefied under high pressure, usually by mechanical refrigeration, and the pressure on the liquefied gas is then reduced to produce a cold liquid at a lower pressure. Typical examples of such processes are described in U.S. Patent No. 2,896,414, and the copending application Ser. No. 698,667, filed November 25, 1957, now U.S. Patent No. 3,020,723, and the copending application Ser. No. 114,199, filed June 1, 1961.

Heretofore, the reduction in pressure on the liquefied gas has been achieved by passing the liquefied gas through an expansion valve. This method involves the conversion of a considerable proportion of the liquefied gas into a gas phase, and the gas phase so produced has to be recycled and reliquefied. It is clear that any method of reducing the amount of gas formed during this pressure reduction step will result in a saving in the horse power required to operate the liquefaction plant.

I have now found that, if the liquefied gas be passed through a hydraulic motor under such conditions that substantially no gas is produced in the motor before being passed through a conventional expansion valve, then the amount of vapour produced for a given pressure reduction is far less than if the expansion valve were used on its own.

Accordingly, the present invention provides a process for the liquefaction of a gas in which the gas is liquefied under a high pressure and the pressure of the liquefied gas is then reduced, the method of effecting such reduction in pressure comprising passing the liquefied gas at the high pressure through a hydraulic motor under such conditions that substantially no gas phase is formed in the motor and energy is produced.

The conditions necessary to ensure that no gas phase is formed in the hydraulic motor are achieved by maintaining the back pressure on the motor in excess of the saturation pressure of the liquid.

Generally, the liquefied gas will require further cooling after passing through the hydraulic motor and and this may be achieved by then passing the liquefied gas through an expansion means in which part of the liquid is converted to gas and the pressure and temperature of the liquid are reduced to the required level. However, other means of further cooling may be employed in suitable circumstances, e.g. further refrigeration by heat exchange.

In this specification, the term "hydraulic motor" includes any motor driven by passage of a liquid through it. It thus includes hydraulic turbines of the impulse or Pelton type, of the reaction or Francis type or of the propeller or axial flow type, and also displacement machines.

This invention is applicable to the liquefaction of any gas, such as oxygen, nitrogen, helium or hydrogen, but is particularly useful in the liquefaction of hydrocarbon gases, such as natural gas or methane or ethane.

The following shows the savings that can be achieved by the present invention.

If liquid methane at a pressure of 3000 pounds per square inch and a temperature of —245° F. is passed through a hydraulic turbine to let the pressure down to

50 pounds per square inch, and then through an expansion valve to reduce its pressure to 15 pounds per square inch and its temperature to —258° F., the amount of gaseous methane produced is about a third of the amount of gaseous methane produced when the liquefied methane at 3000 pounds per square inch and —245° F. is passed through an expansion valve only to reduce its pressure to 15 pounds per square inch and its temperature to —258° F. This means that there is a reduction of about two thirds in the energy required to reliquefy the gaseous methane. In addition, the energy produced by the hydraulic turbine is the equivalent of 20 B.t.u./pound methane which is a further saving.

The process of the present invention is applicable to all liquefaction processes in which the gas is liquefied under high pressure, and the pressure of the liquefied gas is then reduced, irrespective of the refrigeration system employed. Thus, for example, a gas expansion process of refrigeration or a vapour compression or two-phase process of refrigeration may be employed.

The invention will now be illustrated by reference to the accompanying drawing which represents a flow sheet for the liquefaction of natural gas using a gas expansion process of refrigeration.

Natural gas at a pressure of 465 p.s.i.a. and a temperature of 100° F. is fed through pipe **1** into a two-stage reciprocating compressor **2** in which it is compressed to 3000 p.s.i.a. Cooling between the two stages of the compressor is achieved by water in inter-cooler **3**, and the compressed natural gas passes from the compressor by pipe **4** through a further water cooler **5** and then through two heat exchangers **6** and **7** in parallel. In these heat exchangers, the temperature of the compressed natural gas is reduced to —247° F. and the gas is liquefied. The liquefied gas then passes through a Pelton wheel **8** from which it issues still as a liquid at a temperature of —224° F. and a pressure of 55 p.s.i.a. The power output of the Pelton wheel which, for a flow of 240,000 lbs. per hour of natural gas, will amount to about 1500 horsepower, may be used in any convenient manner, for example in driving one or more of the compressors in the system.

The liquefied natural gas leaves the Pelton wheel through line **9** and passes through expansion valve **10** into the flashing vessel **11**. The pressure in the flashing vessel **11** is 16 p.s.i.a., and the temperature —264° F. The liquefied natural gas collecting in flashing vessel **11** is finally pumped to storage tank **12** via pump **13**.

The gas phase at —264° F. formed in flashing vessel **11** is led by line **14** through heat exchanger **6** to condense some of the high pressure natural gas and is then recompressed to 50 p.s.i.a. in compressor **15** for use as fuel. Similarly, the boil-off from the storage tank **12** is led through line **16** and compressors **17** and **15** for subsequent use as fuel.

The refrigerating means in heat exchanger **7** which effects the refrigeration of the bulk of the pressurized natural gas is pipe **18** which carries gaseous nitrogen at 118 p.s.i.a. and —250° F. At the heat exchanger exit, the temperature of the nitrogen is 89° F. and its pressure 103 p.s.i.a. The nitrogen is then compressed in compressor **19** to 2312 p.s.i.a., cooled to —33° F. in heat exchanger **20** against liquid ammonia in line **22** and expanded back to 118 p.s.i.a. and a temperature of —250° F. in expander **21** to complete the refrigeration cycle. Expander **21** provides some of the power for driving the compressor **19**. The ammonia refrigeration cycle for cooling in heat exchanger **20** may be of any conventional type and is not shown in the drawing.

In the above-described process, other refrigerants may be used if desired, for example methane can be used in place of nitrogen, and propane in place of ammonia.

Another particularly useful application of the present invention is in connection with the invention described in the aforementioned copending application Serial No. 114,199 and can be applied, for example, by passing the liquefied natural gas leaving heat exchanger **4** through a hydraulic turbine before it passes through expansion valve **6** as shown in the drawing accompanying that application.

Another useful application of the present invention is in connection with the invention described in the aforementioned copending application Serial No. 698,667, now Patent No. 3,020,723. That invention provides a method of liquefying natural gas comprising inter alia the steps of supplying the gas in a process stream at an elevated temperature and pressure, removing heat from the process stream to reduce the natural gas to a temperature at which it is condensed to a liquefied state at the pressure conditions existing, and expanding the liquefied gas to lower pressure for storage and transportation. Heat is removed from the process stream by heat exchange with a plurality of separate refrigerants, each of said refrigerants passing though a compession and expansion cycle, the expansion step being subdivided into a higher pressure section and a lower pressure section, the refrigerant flowing from the higher pressure section to the lower pressure section and the process stream passing in heat exchange relationship first with the higher pressure section and then with the lower pressure section.

The pressure reduction step in that method may be accomplished in accordance with the present invention. Thus, the liquefied natural gas stream leaving heat exchanger **144** may be passed through a Pelton wheel before it passes through throttling valve **146** as shown in FIGURE 1 of the drawings accompanying said copending application Serial No. 698,667. Similarly, the pressure reducing valve **156** in the said FIGURE 1 could be preceded by a Pelton wheel.

The expanion means through which the liquefied gas is passed after leaving the hydraulic motor may be an expansion valve or throttle valve or an expansion engine which may be of the reciprocating piston type or a turbine.

The work developed by the hydraulic motor and also by the expansion engine if used may of course be used for any suitable purpose such as driving the compressors required in the liquefaction cycle or for generating electricity.

In many liquefaction processes, the liquefied gas stream has to be subjected to pressure reduction in a number of stages, and the method of the present invention may be used in any one or more of these stages as may be found convenient.

I claim:

1. A process for the liquefaction of a gas in which the gas is liquefied under a high pressure and the pressure of the liquefied gas is then reduced, the method of effecting such reduction in pressure comprising passing the liquefied gas at the high pressure through a hydraulic motor

while maintaining the back pressure on the motor in excess of the saturation pressure of the liquid whereby substantially no gas phase is formed in the motor and energy is produced.

2. A process as claimed in claim **1** in which, after passing through the hydraulic motor, the liquefied gas is then passed through an expansion means in which part of the liquid is converted to gas and the pressure and temperature of the liquid are reduced to the required level.

3. A process as claimed in claim **2** in which the expansion means in which part of the liquid is converted to gas is an expansion valve.

4. A process as claimed in claim **1** in which the hydraulic motor is a hydraulic turbine.

5. A process as claimed in claim **4** in which the hydraulic turbine is a Pelton wheel.

6. A process as claimed in claim **1** in which the gas is liquefied under high pressure by heat exchange against a refrigerant operating in a gas expansion process of refrigeration.

7. A process as claimed in claim **1** in which the gas is liquefied under high pressure by heat exchange against a refrigerant operating in a vapour compression process of refrigeration.

8. A process as claimed in claim **1** applied to the liquefaction of natural gas.

9. A process for the liquefaction of a gas in which the gas is liquefied under high pressure and the liquefied gas is then passed at the high pressure through a hydraulic turbine while maintaining the back pressure on the motor in excess of the saturation pressure of the liquid whereby substantially no gas phase is formed in the turbine and energy is produced and then passed through an expansion valve in which part of the liquid is converted to gas and the pressure and temperature of the liquid are reduced to the required level.

10. A process as claimed in claim **9** in which the hydraulic turbine is a Pelton wheel.

11. A process as claimed in claim **9** applied to the liquefaction of natural gas.

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NORMAN YUDKOFF, *Primary Examiner.*

ROBERT A. O'LEARY, *Examiner.*