

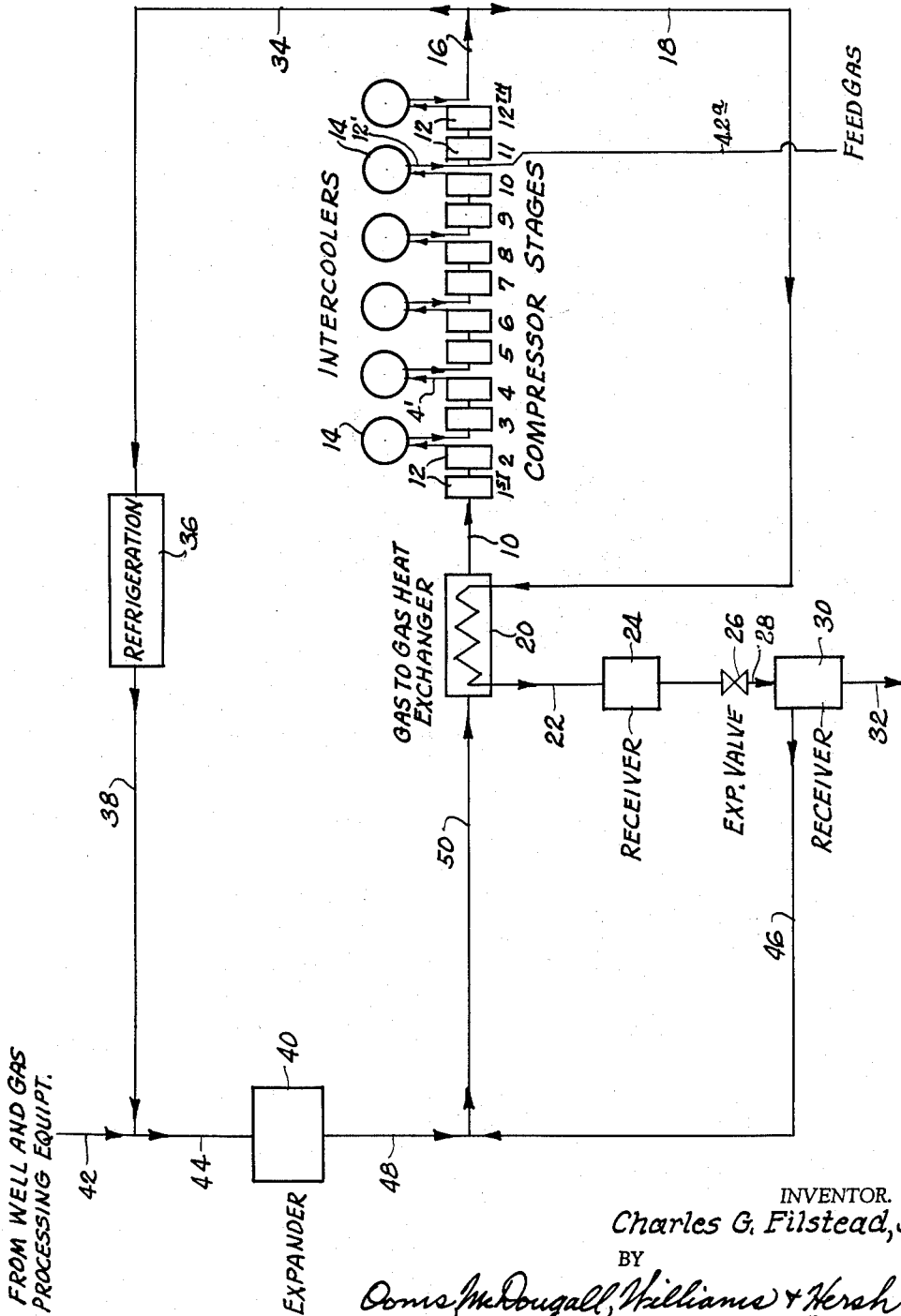
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3,116,135

GAS LIQUEFACTION PROCESS

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3,116,135

GAS LIQUEFACTION PROCESS

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This invention relates to a gas liquefaction process and, more particularly, to a liquefaction process which is economical for operation from the standpoint of balance between the power requirements and cost of equipment.

It is an object of this invention to provide a new and improved gas liquefaction process which is economical in operation from the standpoint of power requirements and cost of equipment.

Another object is to produce a process for the liquefaction of natural gas wherein use is made of an expansion cycle for making a large volume of dry gas available for purposes of refrigeration in gas-to-gas heat exchange with a compressed portion of the natural gas, and wherein use is made in combination therewith of a cascade cycle for liquefaction of the gas by heat transfer from the large amount of cold dry gas made available by the aforementioned expansion cycle.

Another object is to provide a liquefaction process of the type described wherein a portion of the gas is expanded for making a large amount of the cold gas available for refrigeration and wherein the expansion is achieved under conditions to avoid the production of a wet gas so that most efficient utilization can be made of the expansion equipment and maximum production can be made of cold gas for refrigeration, thereby to provide a more efficient and economical cycle.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment is shown in the accompanying drawing, in which—

FIGURE 1 is a process flow sheet illustrating the practice of this invention.

This invention has application chiefly to the liquefaction of natural gas but it can be employed also for use in the liquefaction of other gases such as air, nitrogen, helium, oxygen and the like. Natural gas, as the term is used herein, is composed mostly of methane while the remainder, making up to 20% by weight of the gas, may be composed of acid gases, nitrogen, aromatics and heavier hydrocarbons such as ethane, propane, butane and the like. These other gases may be removed from the stream of natural gas by conventional cleanup equipment prior to introduction into the liquefaction cycle, or during the liquefaction cycle.

Gas liquefaction systems can be divided generally into two main categories. One is based on an expansion cycle wherein gas at high pressure is allowed to expand, preferably with work, with a corresponding reduction in temperature until a wet gas is produced wherein the condensed portion can be removed from the dry gas residue. The latter can be recompressed and recycled with makeup gas through the expansion system. The compressed gas is usually passed in heat exchange relation with a refrigerant to remove heat of compression and to cool the gas under pressure, whereby a higher percentage of wet gas is produced during the subsequent expansion step or steps. The use of expansion cycles of the type described in the liquefaction of natural gas has been illustrated in the previously issued Patents Nos. 2,679,145 and 2,705,406.

The cascade system is based upon the use of heat exchangers arranged progressively to reduce the temper-

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ature of the gas to liquefaction temperature, at which point all of the gas is converted to a liquefied state. Heat exchange for refrigeration is usually carried out while the gas is at some higher pressure above atmospheric pressure, whereby the temperature conversion is at a higher and more accessible level. The compressed and liquefied gas is then let down to a lowered pressure for storage and transportation. During the reduction in pressure, some of the liquid will be flashed off as a gas with accompanying reduction in temperature.

The selection of a cascade cycle or an expansion cycle for liquefaction depends upon a number of factors, including the composition of the gas, the power requirements, the space available for the equipment, the cost of raw materials, the type of equipment, and the like.

This invention is addressed to a liquefaction process which is based upon the use of a combination of a cascade cycle and an expansion cycle. More specifically, it is a concept of this invention to process the natural gas to be liquefied in a manner wherein a portion thereof, including the feed gas, is subjected to an expansion step for the purpose of making a large amount of cold gas available at least expense for refrigeration purposes, while other portions of the natural gas are subjected to heat exchange while at high pressure for conversion of the gas to a liquefied state, and wherein the streams are interconnected in such a way that the feed gas is ultimately converted to liquid product in the liquefaction cycle.

The basic concepts of this invention may be outlined as follows:

(a) Compression of the main gas stream to a super-atmospheric pressure;

(b) Subdividing the compressed main stream of gas into a refrigerant portion and a liquefaction portion;

(c) Passing the refrigerant portion in heat exchange relationship with an outside refrigerant to remove heat and to cool the gas;

(d) Expanding the cooled and compressed refrigerant portion of the gas stream to a lower pressure with corresponding reduction in temperature but to a temperature level above liquefaction temperature of the gas;

(e) Passing the expanded refrigerant portion of the main gas stream in heat exchange relation with the compressed liquefaction portion to cool the latter to liquefaction temperature, whereby the latter is converted to a liquefied state;

(f) Dropping the pressure of the liquefied gas to a lower pressure for storage with the resulting release of some of the liquefied gas as a vapor flash with corresponding reduction in temperature of the liquid;

(g) Recycling the flashed gas for joinder with the expanded gas of the refrigeration stream to make up a part of the main gas stream; and

(h) Introduction of feed gas in an amount corresponding to the condensed portions removed from the system and joining the feed gas with the refrigerant gas to make up another part of the main gas stream.

The foregoing describes the main concepts of this invention. It will be understood that various modifications may be made with respect to the details for introduction of the feed gas from the well into the refrigeration stream, either prior to the expansion cycle or subsequent thereto, depending upon the pressures of the two streams. It will be apparent, also, that the flash from the let-down liquefied portion may be removed from the system for use in refrigeration or in the generation of power, in which event the feed gas will make up for such differences as would be effected by the removal.

For a more detailed description of the process, reference will now be made to the process flow sheet wherein

the main gas stream in line 10 is processed through multi-stage compressors 12 to raise the main stream of gas to a high pressure. In a multiple-stage compression system of the type described, it is desirable to pass the gas through intercoolers 14 between stages to remove heat of compression to increase the efficiency of the operation and to minimize the entrainment of lubricant as a mist or otherwise in the gas stream. The intercoolers preferably comprise water coolers wherein available water is passed in heat exchange relationship with the main gas stream between stages of the compression cycle.

The compressed main gas stream in line 16 is subdivided into one increment, which will hereinafter be referred to as the liquefaction stream, and another increment, which will hereinafter be referred to as the refrigeration stream. The liquefaction stream is caused to flow through line 18 to a heat exchanger 20 wherein the liquefaction stream of gas is passed in heat exchange relation with the cold gas of the refrigeration stream to reduce the temperature of the liquefaction stream to liquefaction temperature at the pressure level of the gas whereby substantially all of the gas in the liquefaction stream is condensed to the liquefied state.

The liquefied gas, at high pressure, leaves the heat exchanger 20 through line 22 and it may be either collected as a liquid in the receiver 24 or bypassed to the expansion valve 26 where the pressure is let down to a lower pressure at which the liquid product is to be stored for use or transportation.

In the preferred practice of this invention, the high pressure liquid is let down to atmospheric pressure or slightly above. This let down in pressure is accompanied by conversion of some of the liquid to a gas with corresponding reduction in temperature to the boiling point temperature of the liquid at the lower pressure conditions existing. For methane, this would be about -258°F. at atmospheric pressure. The let-down stream is advanced through line 28 to a receiver 30 wherein the flashed vapors are separated from the liquid product which can be drained through line 32 for transfer to a storage vessel or for transportation to a conveyance means.

The refrigeration stream is caused to flow through line 34 to one or more heat exchangers, identified by the numeral 36, for passage in heat exchange relation with refrigerants to extract heat from the gas at a level where heat transfer is most efficient and where horsepower of refrigeration per ton of gas is lower, thereby to make use of refrigeration where greatest efficiencies can be practiced for heat extraction. The cold compressed gas from the heat exchangers 36 is advanced through line 38 to an expander 40.

If the feed gas from the well is at a pressure corresponding to that of the refrigeration stream, it can be introduced into the system through line 42 for joinder with the refrigeration stream in line 44 in advance of the expander to blend the feed gas with the cold and compressed refrigeration stream. It is preferred, however, to introduce the feed gas through line 42a for joinder with the main stream intermediate a stage of compression, such as before the last compression.

If the feed gas is derived from a well having sufficient casinghead pressure, it will be unnecessary to compress the gas to the desired level for blending with the main stream. If the pressure from the casinghead has been insufficient or if the pressure has been used during the intervening cleanup to remove acid gases, heavier hydrocarbons and the like, the feed stream may be introduced into the system by connecting line 42a to lines feeding into earlier stages of compression, depending on the casinghead pressure. It is preferred to clean up the feed gas prior to introduction into the liquefaction cycle, but removal of all of the acid gases, water or heavier hydrocarbons in advance of processing through the liquefaction system is unnecessary. For purposes of this description, it will be assumed that the feed stream has been cleaned

up and that it is at a pressure and temperature corresponding to the cooled and compressed main gas stream in the line feeding into the last compression stage.

The combined feed and refrigeration stream in line 44 is expanded with work through an expander turbine 40 to a lower pressure, with an accompanying reduction in temperature. The amount of expansion and/or the temperature of the stream prior to expansion is calculated to provide an expanded stream of gas which remains above the condensation temperature for methane, whereby a large volume of cold gas is made available for purposes of refrigeration. Controlled expansion to a level where condensation is avoided further increases the amount of cold refrigeration gas, and the avoidance of condensate during the expansion cycle eliminates the erosions of the expander parts which might otherwise take place.

In the illustrated process flow sheet, the cold flash from the receiver 30 is returned through line 46 for joinder with the cold expanded gas in line 48 for passage together through line 50 to the heat exchanger 20. Thus, the cold gas passed in heat exchange relationship for condensation of the liquefaction stream of gas constitutes the main gas stream made up of the feed gas from the well, the flash from the expanded condensate, and the refrigeration stream which has been divided out from the main gas stream subsequent to recompression. The gas-to-gas heat exchange made available by the expansion of the refrigeration stream to a cold dry gas provides for most efficient heat transfer to effect condensation of the liquefaction stream.

It will be apparent that the amount of feed gas from the well will correspond to the amount of gas that is removed from the system as liquefied product, and that the feed gas from the well first forms a part of the refrigeration stream before becoming a part of the liquefaction stream whereby a continuous cycle is established.

An important concept of this invention resides in the optimum efficiencies secured wherein less horsepower, in the form of horsepower of refrigeration, is required to convert a unit volume of gas into a liquid by comparison with conventional expander cycles and less equipment is required by comparison with conventional cascade cycles. This improved efficiency is derived in part from a number of sources, including the use of a high level of refrigeration at the point where the refrigeration stream is reduced to a lower temperature subsequent to recompression but before expansion to enable removal of the greatest amount of heat with the least amount of power. The improved efficiency is also traceable, in part, to making a maximum amount of cold gas available for refrigeration when passed in gas-to-gas heat exchange with the liquefaction stream by utilizing a portion of the compressed stream of gas for refrigeration purposes and by expansion of this stream under conditions wherein a maximum amount of cold gas is produced, as distinguished from a lesser amount which would otherwise be secured if liquefaction took place. Expansion under controlled conditions to avoid the production of a wet gas also provides for more efficient expansion and less erosion on the blades of the expander.

Thus, there is provided a liquefaction process embodying new and novel concepts which makes use of a combination of cascade and expansion systems and which leads to greater efficiencies in operation and utilization of less power and equipment for purposes of liquefaction.

A separator may be introduced in line 50 prior to the heat exchanger 20 for the removal of any heavier hydrocarbons and other condensate which might form in the expanded main stream of gas. Similarly, some of the compressed gas from either of the streams in lines 18 or 34 may be bled off for use in the generation of power to supplement the power made available from the expander 40 and which can be used to operate the compressors and the like.

By way of example, starting with a main stream of gas

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at 70° F. and 14.7 p.s.i.a., flowing at a rate of 1641 pounds per minute through line 10, the gas is processed through the 6 stages of compression with water cooling between alternate stages to remove heat of compression. The feed gas at 697 p.s.i.a. and flowing at a rate of 878 pounds per minute is joined with line 12¹ and undergoes the last stage compression. The stream of gas issuing from the last compression stage and intercooler will have a pressure of about 1515 p.s.i.a. at 90° F. This stream is divided to flow about 1491 pounds of gas per minute through line 34 to constitute the refrigeration stream, while the remainder corresponding to 884 pounds per minute is circulated through line 18 as the liquefaction stream. The fuel gas at a rate of 144 pounds per minute and a pressure of 32.4 p.s.i.a. is taken from the discharge of the fourth stage compressor, and through line 4¹.

The liquefaction stream in line 18 issues as a condensed natural gas from the heat exchanger at a pressure of 1515 p.s.i.a. and at a temperature of -215° F. When let down to atmospheric pressure (14.7 p.s.i.a.), the liquid collected in the receiver will have a temperature of about -259° F. and will be introduced at a rate of about 734 pounds per minute.

The dry gas at the same pressure and temperature will flow at a rate of about 150 pounds per minute through line 46 for joinder with the cold gas issuing at about atmospheric pressure from the expander 40.

The refrigeration stream in line 34 is reduced to a temperature of about +20° F. upon refrigeration through the heat exchanger 36 wherein the gas can be passed in heat exchange relationship with refrigerants operated, for example, on an ethane or propane cycle, or both. The refrigeration stream at 1500 p.s.i.a. and at +20° F. is expanded in the turbine 40 to atmospheric pressure (14.7 p.s.i.a.), with a corresponding reduction in temperature to about -258° F. The joinder of the flash with the expanded stream of gas results in a main gas stream having a temperature of about -258° F. and flowing at atmospheric pressure at a rate of about 1641 pounds per minute.

Thus the cycle is completed with the main gas stream being processed through the multi-stage compressors after having been passed in gas-to-gas heat exchange with the liquefaction stream in the heat exchanger 20.

It will be understood that the above temperature and pressure conditions may be varied over a fairly wide range depending upon the pressure of gas available or the type of gas or the amounts of gas to be liquefied. It will be further understood that more than one refrigeration step may be employed for reducing the temperature of the refrigeration gas in unit 45 but it would be undesirable to reduce the gas to a temperature at which condensation would take place upon expansion of the gas to the desired lower pressure for the production of a large volume of gas to be passed in heat exchange relationship with the liquefaction portion of the main gas stream. Such additional refrigeration units may be arranged in series or in parallel for the treatment of the same or separate increments of the gas respectively.

It will be understood that various changes may be made in the details of construction and operation without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. In the process for the liquefaction of natural gas composed mostly of methane, the steps of supplying the gas continuously as a main process stream at high pressure and at relatively high temperature, continuously removing a portion of the high pressure gas from the main process stream for use as a refrigeration gas, refrigerating the portion of the gas removed from the main process stream to reduce the temperature thereof without noticeable reduction in pressure bypassing it in heat exchange relation with an external refrigerant, expanding the removed and refrigerated portion of the gas to a lower pressure with corresponding reduction in temperature to

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a temperature below that at which the remaining gas in the main process stream is liquefied at the pressure of the main process stream but to a level above condensation temperature for the methane component of the expanded refrigeration portion of the gas thereby to produce a large volume of cold gas for refrigeration, passing the cold expanded portion of the gas in heat exchange relation with the remainder of the process stream at high pressure to reduce the temperature thereof to a level to condense the remainder of the main process stream at the pressure conditions existing, dropping the pressure of the condensed portion of the main process stream whereby some of the condensed gas is flashed off with a further reduction in temperature, separating the condensate from the flashed gases, recompressing the expanded refrigeration portion of the stream and introducing it into said main process stream to the pressure of the main process stream continuously to form a part thereof.

2. The process as claimed in claim 1 which includes the step of combining the flashed gases separated from the condensate with the expanded refrigeration portion removed from the main process stream prior to passage thereof in heat exchange relation with the remainder of the main process stream thereby to include the flashed gases as a part of the main process stream upon recompression.

3. In the process for the liquefaction of natural gas composed mostly of methane, the steps of supplying the gas continuously as a main process stream at high pressure and at relatively high temperature, continuously removing a portion of the high pressure gas from the main process stream for use in refrigeration, passing the portion of the gas removed from the main process stream in heat exchange relationship with an external refrigerant to reduce the temperature of the gas without noticeable reduction in pressure, expanding the removed and refrigerated portion of the gas to a lower pressure with corresponding reduction in temperature to a temperature below that at which the remaining gas in the main process stream is liquefied at the pressure of the main process stream but to a level above condensation temperature for the methane component of the expanded refrigeration portion of the gas thereby to produce a large volume of cold gas for refrigeration, passing the cold expanded portion of the gas in heat exchange relationship with the remainder of the process stream at high pressure to reduce the temperature thereof to a level wherein the gas in the remaining portion of the main process stream is condensed under the pressure conditions existing, reducing the pressure of the condensed portion of the main process stream whereby some of the condensed gas is flashed off with a further reduction in temperature, separating the condensate at lower pressure from the flashed gases as product, introducing an amount of feed gas into the refrigeration portion separated from the main process stream in an amount corresponding to the amount of gas removed from the main process stream as condensate and recompressing the expanding refrigeration portion together with said feed gas to the pressure of the main process stream and introducing these compressed gases into the main process stream to form a part thereof.

4. The process as claimed in claim 3 which includes the additional step of combining the flashed gases separated from the condensate with the refrigeration portion of the gas separated from the main process stream prior to passage of the refrigerated portion in heat exchange relationship with the remainder of the main process stream.

5. In the process for the liquefaction of natural gas composed mostly of methane, the steps of supplying the gas continuously as a main process stream at high pressure, continuously removing a portion of the high pressure gas from the main process stream for use in refrigeration, passing the portion of the gas removed from the main process stream in heat exchange relationship

with an external refrigerant to reduce the temperature thereof without noticeable reduction in pressure, expanding the removed and refrigerated portion of the gas with work to a lower pressure with a corresponding reduction in temperature to produce a large amount of cold gas for refrigeration but without reduction of temperature to a level for condensation of the methane portion thereof, passing the cold expanded portion of the gas in heat exchange relationship with the remainder of the process stream at high pressure to condense the main process stream at the pressure conditions existing, letting down the pressure of the condensed portion of the main process stream whereby some of the condensed gas is flashed off with a corresponding reduction in temperature, separating the condensate from the flashed gases, joining the cold flashed gases with the expanded portion of the main process stream prior to passage thereof in heat exchange relationship with the remainder of the main process stream for condensation, recompressing in a plurality of stages the expanded portion of the main process stream and the flashed gases, introducing these compressed gases into the main process stream to form a part thereof and introducing an amount of feed gas corresponding to the amount of gas removed from the main process stream as condensate interstage of the compression cycle to make up the main process stream whereby the feed gas is subject to compression in the final stages of recompression of the main process stream and whereby a main process stream at high pressure is continuously provided.

6. In the process for the liquefaction of natural gas composed mostly of methane, the steps of supplying the gas continuously as a main process stream at high pressure, continuously removing a portion of the high pressure gas from the main process stream for use in refrigeration, passing the portion of the gas removed from the main process stream in heat exchange relationship with an external refrigerant to reduce the temperature thereof without noticeable reduction in pressure, expanding the removed and refrigerated portion of the gas with work to a lower pressure with a corresponding reduction in temperature to produce a large amount of cold gas for refrigeration but without reduction of temperature to a level for condensation of the methane portion thereof, passing the cold expanded portion of the gas in heat exchange relationship with the remainder of the process stream at high pressure to condense the main process stream at the pressure conditions existing, letting down the pressure of the condensed portion of the main process stream whereby some of the condensed gas is flashed off with a corresponding reduction in temperature, separating the condensate from the flashed gases, joining the cold flashed gases with the expanded portion of the main process stream prior to passage thereof in heat exchange relationship with the remainder of the main process stream for condensation, introducing an amount of feed gas into the refrigeration portion separated from the main process stream in an amount corresponding to the amount of condensate removed from the main process stream whereby the main process stream is continuously formed of the flashed gas, the refrigeration gas and the feed gas, and recompressing such gases forming the main process stream to the pressure level of the main process stream subsequent to passage of said gases in heat exchange relationship with the remainder of the main process stream at high pressure.

7. The process as claimed in claim 5 which includes the steps of intercooling the main process stream between stages of compression.

8. The process as claimed in claim 5 in which the condensed portion of the main process stream is expanded to about atmospheric pressure.

9. The process as claimed in claim 5 in which the refrigeration portion of the gas separated from the main process stream and the feed gas is expanded with work to about atmospheric pressure.

10. In the process for the liquefaction of a gas, the steps of supplying the gas continuously as a main process stream at high pressure, continuously removing a portion of the high pressure gas from the main process stream to provide a refrigeration portion and a condensable portion, passing the refrigeration portion in heat exchange relationship with an external refrigerant to reduce the temperature thereof without noticeable reduction in pressure, expanding the refrigeration portion of the gas to a lower pressure with corresponding reduction in temperature but to a level above condensation temperature for the gas, thereby to produce a large volume of cold gas for refrigeration, passing the expanded refrigeration portion of the gas in heat exchange relationship with the condensable portion of the main process stream at high pressure to condense the portion at the pressure conditions existing, reducing the pressure of the condensed portion whereby some of the condensed gas is flashed off with a corresponding reduction in temperature, separating the flash from the condensate, combining the flash with the refrigeration portion prior to passage thereof in heat exchange relationship with the condensable portion of the main process stream, compressing a feed gas to the pressure of the main process stream and introducing the feed gas into the refrigeration portion of the main process stream prior to expansion thereof and in an amount corresponding to the amount of gas removed as condensate from the condensable portion of the main process stream, and recompressing the gases passed in heat exchange relationship with the condensable portion of the main process stream to the pressure of the main process stream whereby such gases constitute the main process stream.

11. The process as claimed in claim 3, in which the recompression is carried out in a plurality of stages and the feed gas is introduced into an intermediate stage in said recompression.

12. The process as claimed in claim 3, in which the feed gas is introduced into the refrigeration portion before the said portion is expanded.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,116,135

December 31, 1963

Charles G. Filstead, Jr.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, lines 16 and 17, strike out "and introducing it into said main process stream" and insert the same after "stream" in line 18, same column 6.

Signed and sealed this 28th day of July 1964.

(SEAL)

Attest:

ESTON G. JOHNSON
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