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[54] **REFRIGERATION PROCESS FOR USE IN LIQUEFICATION OF GASES**

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[58] **Field of Search**............62/23, 24, 26, 27, 28, 30, 62/38, 39, 40; 55/512, 55

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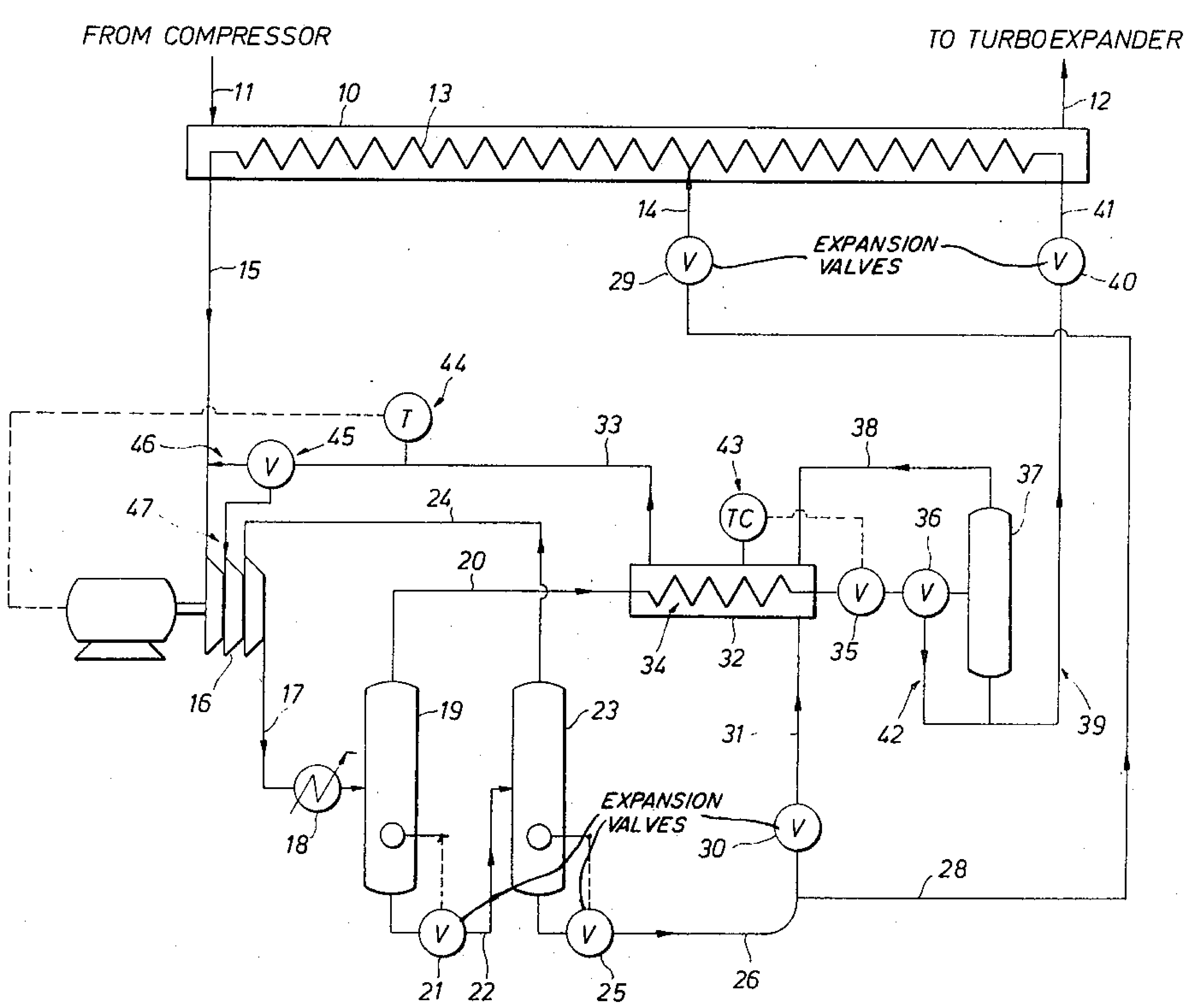
[57] **ABSTRACT**

A refrigeration process for use in the liquefication of gases wherein a gaseous mixed refrigerant is compressed to form a mixture of a gas difficult to condense and a liquid, at least a portion of a liquid, after reduction to a lower pressure is used to effect cooling and condensation of substantially all of the gas, the condensed gas after reduction to lower pressure is employed as a low temperature refrigerant in the cold end of an exchanger and the remaining portion of said liquid is employed as a high temperature refrigerant in an intermediate stage of said exchanger. The process is used to supply the mechanical refrigeration needed in a turboexpansion system for the liquefication of natural gas and the like.

5 Claims, 2 Drawing Figures



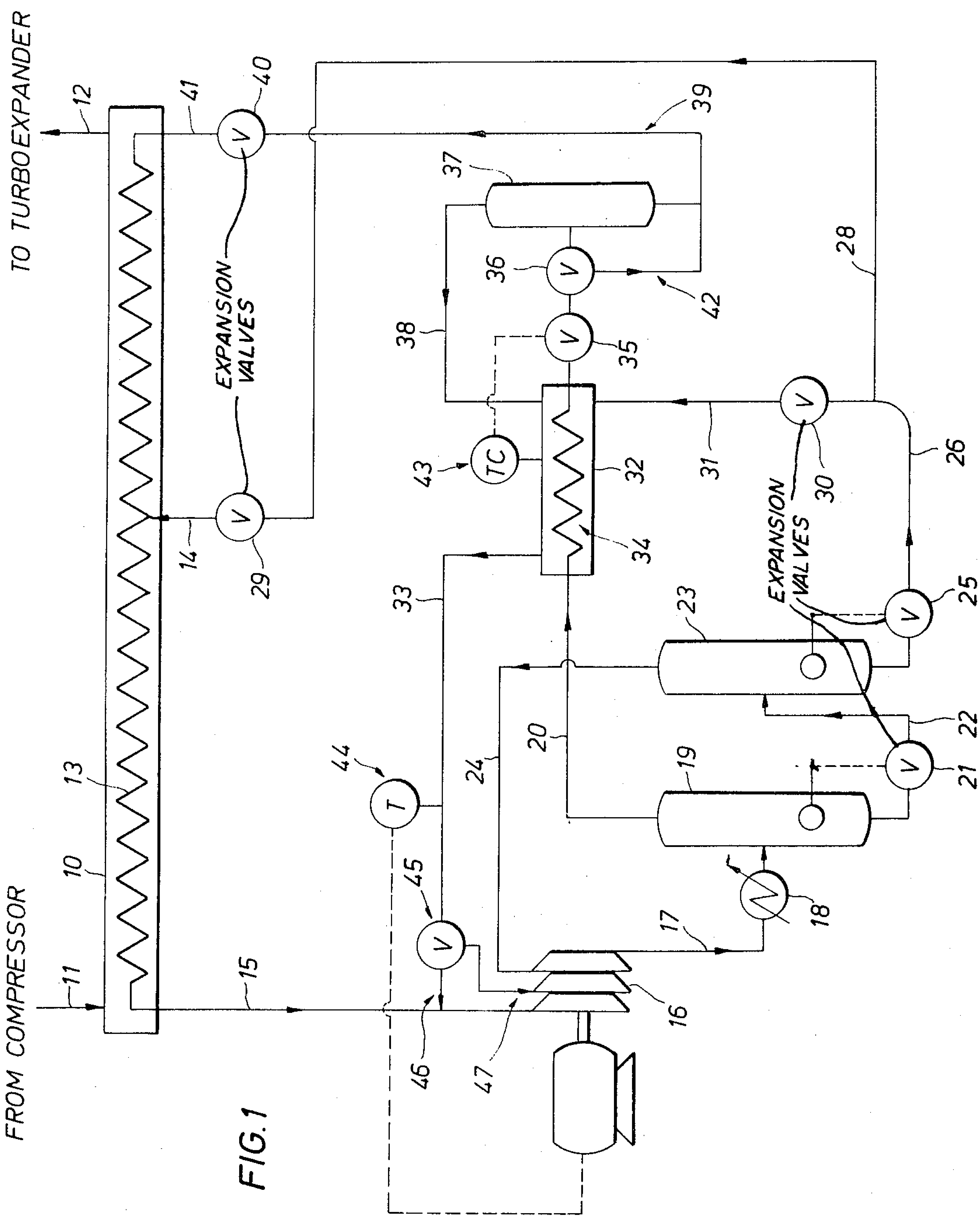


FIG. 1

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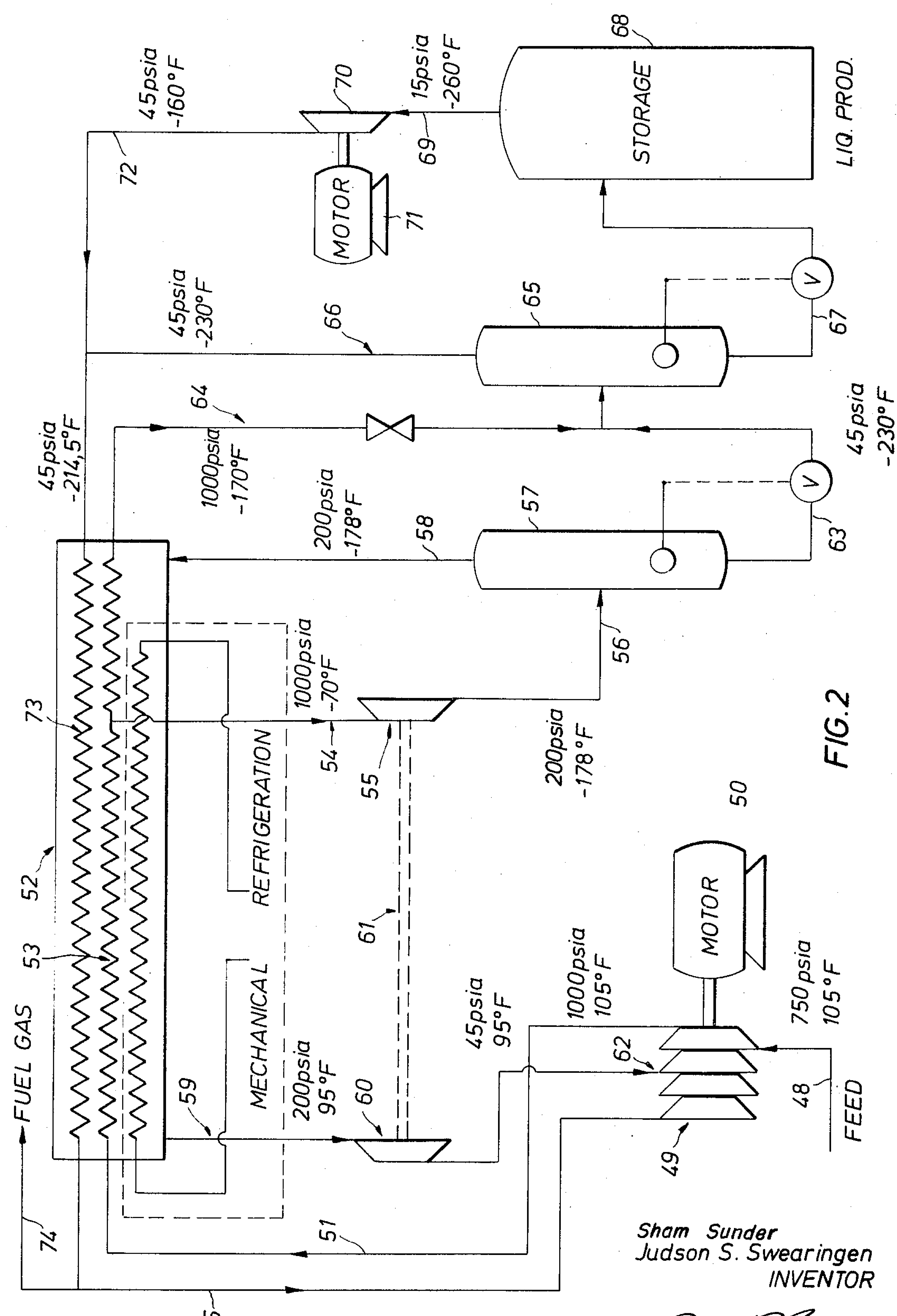

FIG. 2

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REFRIGERATION PROCESS FOR USE IN LIQUEFICATION OF GASES

BACKGROUND OF THE INVENTION

The present invention relates to the liquefication of gases. More particularly, the present invention relates to a refrigeration process for use in the liquefication of gases, especially natural gas.

The so-called cascade method of refrigeration is widely known and used as a refrigeration method in plants liquefying natural gas. Briefly, the method involves liquefying a first refrigerating fluid under pressure, expanding it to a lower pressure and vaporizing it in heat exchange with a second more volatile refrigerating fluid under pressure, expanding the second refrigerating fluid at a lower pressure and then vaporizing it in heat exchange with a third more volatile refrigerating fluid, and so on, each of the successive refrigerating fluids enabling a lower temperature to be reached. Unfortunately, this process requires the use of equipment which is relatively complicated and which presents great regulation and control difficulties, each of the refrigerating fluids traveling through its own closed loop and requiring a compressor, a condenser, an expansion valve and a heat exchanger.

Plants employing expansion processes and in particular those employing turboexpanders as the expansion engine are meeting with increasing favor in natural gas liquefication installations because of their simplicity, ease of operation, rangeability and relatively low investment cost. In order for these expansion processes to operate, they require, among other things, some mechanical refrigeration at moderate temperatures where the Carnot efficiency of the expander system would be penalized. Such mechanical refrigeration must be efficient, relatively inexpensive and trouble-free in order to make the use of turboexpanders economical.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a refrigeration process.

It is another object of the present invention to provide a refrigeration process for use in the liquefication of gases, particularly natural gas.

Yet another object of the present invention is to provide a single refrigeration system having an adjustable rate of refrigeration at relatively high temperature levels and another adjustable rate of refrigeration at relatively low temperature levels.

Still another object of the present invention is to provide a single mechanical refrigeration system for use in a natural gas liquefying plant employing turboexpanders.

These and other objects of the present invention which will become apparent from the drawings, the description given herein and the appended claims are accomplished in one respect by a refrigeration process comprising introducing a gaseous refrigerant mixture into a compression zone to form a first liquid fraction and a first gas fraction, separating the first gas fraction from the first liquid fraction and subsequently condensing substantially all of said first gas fraction in a cooling zone, expanding said first liquid fraction to a lower pressure and forming a second gas fraction and a second liquid fraction, separating said second gas fraction from said second liquid fraction and returning said second gas fraction to said compression zone, expanding said second liquid fraction to a lower pressure, passing at least a portion of the expanded second liquid fraction through said cooling zone counterflow to said first gas fraction passing through said cooling zone and returning said portion of said expanded second liquid fraction, now vaporized, to said compression zone, returning any remaining portion of said expanded second liquid fraction to said compression zone, expanding the condensed first gas fraction to a lower pressure and returning the expanded condensed first gas fraction after vaporization to said compression zone.

In another embodiment, the present invention provides in a process for the liquefication of a gas wherein a gaseous feed is compressed and cooled to a temperature of at least −60°F, at least a portion of the compressed and cooled gaseous feed is passed through a turboexpansion engine, the liquid from the discharge of said turboexpansion engine is flash cooled at least once to obtain a colder gas, the gaseous fraction from the flash cooling being used to augment cooling of the compressed gaseous feed, an improvement wherein said compressed gaseous feed is cooled by the refrigeration process described above.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic flow sheet of the refrigeration process of the present invention.

FIG. **2** is a schematic flow sheet of a turboexpansion cycle for liquefying a gas incorporating the refrigeration process of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is now made to FIG. **2** for a detailed description of a system for the liquefication of gases employing a turboexpansion engine. For purposes of illustration, the system is described with particular reference to the liquefication of natural gas and more particularly methane. But it is to be understood that the system can be applied to the liquefication of other gases. The mechanical refrigeration shown in the dotted box of FIG. **2**, is the refrigeration process set forth in FIG. **1** hereinafter described in detail. The pressures and temperatures of the streams at various points in the process are shown on FIG. 2.

Referring, then, to FIG. **2**, methane via line **48** enters compressor **49** which is driven by motor **50**. The compressed methane exits compressor **49** via line **51** and passes into exchanger **52** where it is cooled. A portion of the cooled methane exits via line **54** and enters turboexpander **55** by which it is further cooled and a portion condensed, exiting expander **55** via line **56** and passing into separator **57** where the vapor and liquid are disengaged, the vapor portion passing overhead via line **58** and back through exchanger **52**. It leaves the exchanger via line **59** and is compressed in compressor **60** driven by the shaft **61** from turboexpander **55**, returning to main compressor **49** via line **62**. A second portion of the compressed methane after further cooling and condensation exits exchanger **52** via line **64** and is combined with the liquid from the separator **57** both passing into a second flash evaporator **65** where the liquid is further cooled by flash evaporation of a portion thereof. The vapor from flash evaporator **65** passes overhead via line **66** back through coil **73** of exchanger **52** a portion being employed as fuel gas and exiting via line **74**. The remaining portion passes via line **75** back into main compressor **49**. The liquid from flash evaporator **65** is sent to storage tank **68** for use as desired. Any vapor from storage tank **68** due to some flash vaporization of stream **67** as a result of the latter's reduction in pressure and from evaporation in the storage tank is taken overhead via line **69**, compressed in compressor **70**, driven by motor **71** and is combined via line **72** with the vapor coming from separator **65** via line **66**, the combined streams passing through exchanger **52** as described above. While in the gas liquefication cycle described above, two stages of flash cooling are shown, it is to be understood that more than two stages may be employed or alternately that a single stage of flash cooling, while insufficient, may also be employed.

Reference is now made to FIG. **1** for a detailed description of the refrigeration process of the present invention, referred to as the mechanical refrigeration in FIG. **2**. The stream of gas to be cooled enters heat exchanger **10** via line **11**, is cooled by evaporator coil **13** and exits at a reduced temperature through line **12**. The mixed gaseous refrigerant exiting from coil **13** through line **15** is fed into the first stage inlet of compressor **16** where it, along with other streams hereinafter described, is compressed through several stages of compression and is discharged via line **17** into condenser **18** where the less volatile portion of the mixture is condensed.

The partially condensed mixture of refrigerant is discharged into separator **19** where the uncondensed vapor is separated from the liquid fraction, the former exiting separator **19** via line **20**, the latter exiting through expansion valve **21** into line **22**. On passing through expansion valve **21**, the liquid fraction from separator **19** has its pressure reduced whereupon a portion of the liquid flash vaporizes. This vapor-liquid mixture is disengaged in separator **23**, the uncondensed vapor portion passing via line **24** into the last stage of compressor **16**, the condensed liquid portion being discharged through expansion valve **25** into line **26**. Upon passing through expansion valve **25**, the liquid fraction from separator **23** has its pressure reduced, whereupon a portion is flash vaporized. This gas-liquid mixture exiting valve **25** is partially separated into a liquid-rich and gas-rich fraction by a centrifugal separation process, which as shown, is accomplished by passing the gas-liquid mixture from valve **25** through curved section **27** of line **26**, the heavier liquid being thrown to the outside and exiting through line **28**, the gas-rich portion passing through expansion valve **30** through line **31** into exchanger **32** and out of exchanger **32** via line **33** back to compressor **16**. The gas-rich fraction upon passing through the shell of exchanger **32** counterflow to the uncondensed gas fraction from separator **19** fully vaporizes; whereupon it cools and causes complete condensation of the latter. The liquid-rich fraction obtained from the partial centrifugal separation of the gas-liquid mixture from expansion valve **25** is passed via line **28**, expansion valve **29** and line **14** into an intermediate zone of coil **13** of exchanger **10** where it serves as the higher temperature refrigerant in exchanger **10**.

The completely condensed liquid fraction passing through exchanger **32** from separator **19** is expanded through valve **35** and can then take one of two routes. If the temperature in the cold end of exchanger **10** is colder than is required, the liquid from condenser coil **34** of exchanger **32** upon passing through valve **35** is sent to separator **37** through three-way valve **36** whereupon the vapor portion is passed via line **38** back through the shell of exchanger **32** counterflow to the gas passing via line **20** through coil **34** of exchanger **32**. The liquid fraction in separator **37** is passed via line **39** expansion valve **40** and line **41** to the cold end of exchanger **10** where it acts as the low temperature refrigerant. However, if there is difficulty in attaining the low temperature desired in the cold end of exchanger **10**, then three-way valve **36** is adjusted such that the entire flow of fluid exiting through valve **35** bypasses separator **37** and passes via line **42** into line **39** and thence through expansion valve **40** and line **41** into the cold end of exchanger **10**. Thus it is seen that separator **37** serves the purpose of an economizer and saves power when the temperature in the cold end of exchanger **10** is lower than required.

As will be readily recognized, the quantity of the low temperature refrigerant in the low temperature end of exchanger **10** is determined by valve **40**. However, if valve **40** is open too widely such that too much low-temperature refrigerant is flowing into the cold end of exchanger **10**, then expansion valve **35** will serve to act as an over-ride or check. This is accomplished by the fact that valve **35** is controlled by temperature controller and sensor **43** which reads the temperature at an intermediate zone of heat exchanger **32**. If too much refrigerant is withdrawn from condenser coil **34** of exchanger **32**, there will not be enough refrigerant entering the shell of exchanger **32** from line **35** to completely condense the former with the result that the temperature in the intermediate zone of exchanger **32** will rise perceptively. This temperature rise will be sensed by controller **43** which will then automatically adjust valve **35** to reduce the flow therethrough. On the other hand, if the temperature in the cold end of exchanger **10** is such that more refrigerant is available at valve **40** than is required, there will be a reduced flow in line **20** with the result that the discharge pressure from compressor **16** will increase reducing the flow through compressor **16** and also the power required to drive it.

The moderate to high temperature requirement in exchanger **10** are determined by the setting of valve **29**. For example if the refrigeration requirement throughout exchanger **10** is low, a reduced flow will then be passing through valves **40** and **29** resulting in an excessive flow through line **31** into the shell side of exchanger **32** with the result that the stream in line **33** leaving exchanger **32** will have its temperature reduced and in the extreme case will be reduced to the extent that there will be unvaporized liquid in line **33**.

In order to optimize the process, temperature sensor **44** is provided in line **33** to detect the temperature of the stream returning therethrough to compressor **16**. Depending on the temperature sensed by sensor **44**, the speed of compressor **16** is adjusted such that if a temperature low enough to indicate liquid in line **33** is detected, the speed of compressor **16** is accordingly reduced insuring that only the output from compressor **16** absolutely needed is produced. As can be seen, the stream passing in line **33** can take two routes back to compressor **16**. If, for example, it is desired to reduce the temperature in coil **13** of exchanger **10**, the stream in line **33** passes through three-way valve **45** and is then fed to the first stage of compressor **16** through line **46** thereby reducing the pressure in the shell of exchanger **32** thereby condensing more of vapor stream **20**. In this case, the flow through expansion valve **40** is increased. Alternately, the stream in line **33** may pass through three-way valve **45** and line **47** into an intermediate stage of compressor **16** if the low temperature requirements of exchanger **10** are being met.

The advantages of the above described refrigeration process are best demonstrated by reference to the table below which gives the temperatures and pressures at various points in the system shown in FIG. **1**. Refrigerant A consisted of a mixture of 35 percent ethylene, 35 percent propane, 20 percent n-butane and 10 percent n-pentane. Refrigerant B consisted of a mixture of 25 percent ethylene, 50 percent propane and 25 percent n-butane.

Refrigerant Pressure and Temperature Table

Point	Refrigerant A Pressure PSIA	Refrigerant A Temperature °F	Refrigerant B Pressure PSIA	Refrigerant B Temperature °F
13	15	—	15	—
41	15	–115	15	–95
14	15	–15	15	–30
15	15	80	15	80
17	202	160	202	160
19	200	95	200	95
20	200	95	200	95
22	85	50	90	50
23	85	50	90	50
26	85	50	90	50
27	85	50	90	50
31	15	–15	35	5
28	85	50	90	50
33	15	40	35	72

As can be seen from an examination of the data in the above table, the refrigeration process described herein provides an efficient and simple means for supplying mechanical refrigeration in a plant for liquefying natural gas wherein a turboexpander is used as the expansion engine. It generally preferable in such plants that the inlet temperature to the turboexpander be in the order of –60°F. However, the exact temperature depends on numerous valuables and optimum operation may dictate temperatures considerably higher.

The refrigerant employed will be a mixed type containing several components which though not necessarily hydrocarbons, preferably will condense to miscible liquids, and a portion of which condenses at ordinary cooling water temperatures and the remainder at temperatures substantially lower than this.

The liquid-rich fraction centrifugally separated out of the expanded fraction passing through valve **25** is shown as being sent through a single expansion valve and then to an intermediate temperature zone of exchanger **10**. It is to be understood however that the liquid-rich fraction can be divided into a plurality of streams, each stream passing through an expansion valve and each entering the exchanger at different points.

As will be readily recognized by those skilled in the art, numerous modifications of the above described process can be made without departing from either the spirit or scope thereof.

We claim:

1. In a process for the liquefication of a gas wherein a gaseous feed is compressed and cooled to a temperature of at least –60°F., at least a portion of the compressed and cooled gaseous feed is passed through a turboexpansion engine, the liquid from the discharge of said turboexpansion engine is flash cooled at least once to obtain a liquefied gas, the gaseous fractions from the flash cooling being used to augment cooling of the compressed gaseous feed, a portion of said gaseous feed after passing through said turboexpansion engine being recycled and compressed with the fresh gaseous feed, the improvement wherein the compressed gaseous feed is cooled by a refrigeration process comprising:

A. introducing a gaseous refrigerant mixture in a compression zone to form a first liquid fraction and a first gas fraction;

B. separating said first gas fraction from said first liquid fraction and subsequently condensing in a single step substantially all of said first gas fraction in a cooling zone;

C. expanding said first liquid fraction to lower pressure and forming a second gas fraction and a second liquid fraction;

D. separating said second gas fraction from said second liquid fraction and returning said second gas fraction to said compression zone;

E. expanding said second liquid fraction to a lower pressure;

F. passing at least a portion of the expanded second liquid fraction through said cooling zone and returning said portion to said compression zone, said portion of said expanded second liquid fraction passing through said cooling zone counterflow to said first gas fraction passing through said cooling zone;

G. returning any remaining portion of said expanded second liquid fraction to said compression zone;

H. expanding the condensed first gas fraction to a lower pressure; and

I. returning the expanded condensed first gas fraction to said compression zone, said remaining portion of said expanded second liquid fraction and said expanded condensed first gas fraction being used to effect cooling of said compressed gaseous feed.

2. The process of claim **1** wherein said discharge from said turboexpansion engine is flash cooled in multiple stages.

3. The process of claim **2** wherein a minor portion of said compressed and cooled gaseous feed is further cooled and condensed, the condensed portion is combined with the liquid from the first flash cooling stage, and the combined condensed portion and liquid from said first cooling stage are passed to said second cooling stage.

4. The process of claim **1** wherein said gaseous feed comprises natural gas.

5. The process of claim **1** wherein the compressed gaseous feed is cooled to a temperature of around −60° F.

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