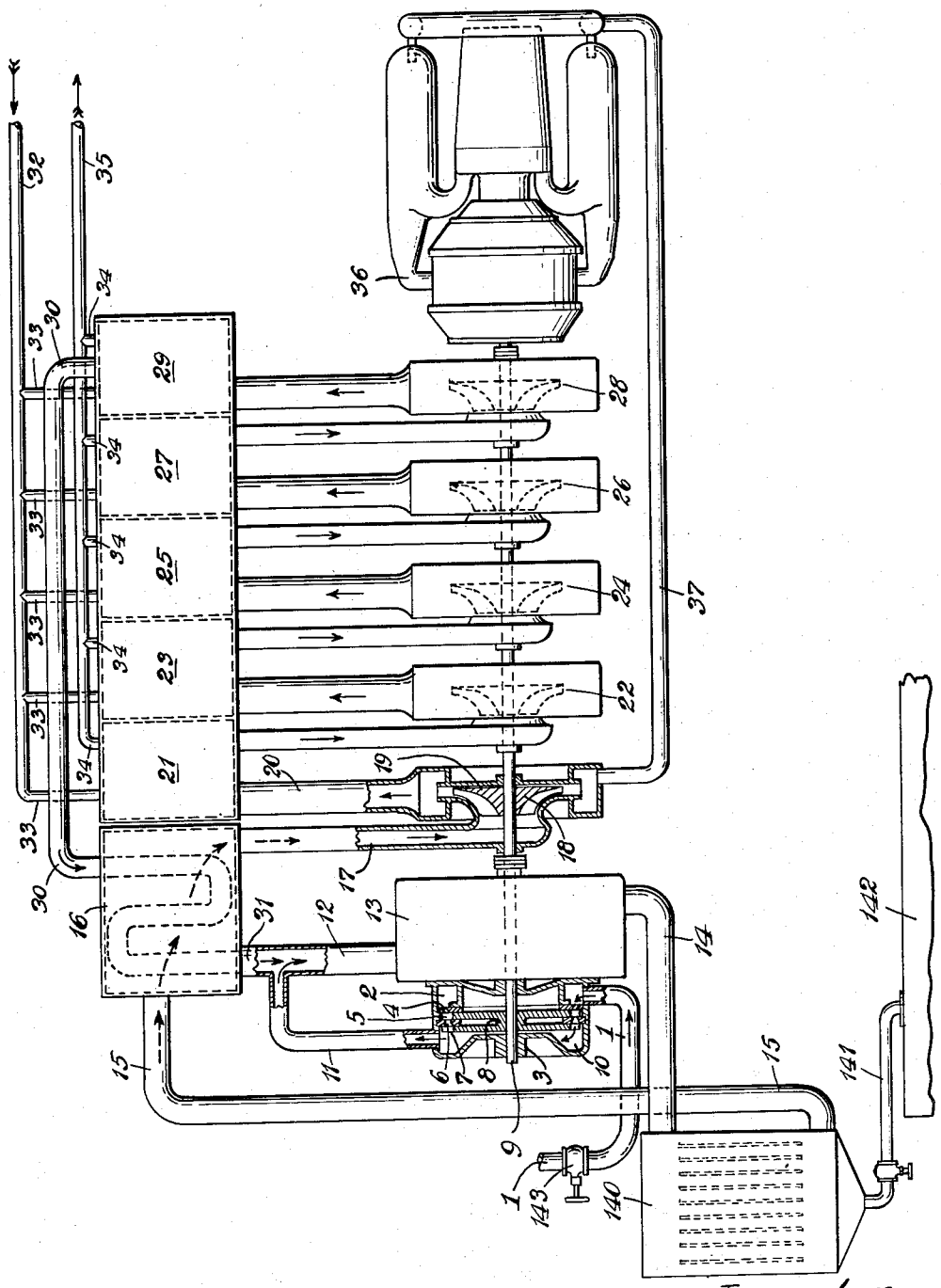
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REGENERATIVE METHOD AND APPARATUS FOR LIQUEFYING NATURAL GAS

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REGENERATIVE METHOD AND APPARATUS FOR LIQUEFYING NATURAL GAS

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This invention relates to improvements in method and apparatus for storing and shipping natural gas and the like and has for one object to provide a regenerative method and apparatus which will make use of the pressure of the natural gas in a well to liquefy the gas.

Another object of the invention is to provide a method and apparatus wherein gas from a well will be reduced in temperature and liquefied by the use in part of the natural pressure of the gas and by the use in part of some of the gas as a combustible to generate some of the power necessary for liquefaction.

Another object of the invention is to pass the gas under the natural pressure from the well through a work zone wherein the temperature and pressure of the gas will be lowered for the formation of wet gas. Thereafter the wet fraction of the gas will be extracted and the remaining dry gas will be recycled for further liquefaction and extraction.

Another object of the invention is to provide means whereby natural gas under natural pressure from the well will pass through a turbine doing work and generating power, the work done ultimately resulting in such reduction of pressure and temperature that a wet gas results, the wet fraction being then extracted, the remaining gas being then compressed and cooled and recirculated to do further work for the production of a further amount of wet gas.

Another object of the invention is to provide a method and apparatus whereby some of the power required to cool and liquefy the gas results from the reduction in the pressure of the natural gas and other of the work results from the combustion of some of the natural gas. Gas is discharged from a natural gas well at high pressure, frequently above 2000 p. s. i. a. Such gas has in the past been shipped in pipe lines. It has also been shipped at high pressure in tanks of sufficient strength to withstand the pressure but pipe lines are expensive and frequently do not reach to the point where the gas is available. The transportation of gas in tanks at high pressure, owing to the great strength and weight of tank required is especially for the shipment of large quantities of gas prohibitive in cost.

I propose to liquefy the gas at very low temperature and ship and store it in tanks at atmospheric pressure, bleeding off a sufficient amount of vaporized gas from the liquid and discharging it from the tank so as to maintain the tank at substantially atmospheric pressure.

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This makes it possible to store or ship gas in substantial quantities at reasonable cost.

I propose to pass the gas from the well at natural pressure through a work zone, preferably one or more turbines where the high pressure gas will do work with resultant drop in pressure and drop in temperature. The passage of the gas through the work zone will be so organized that when it leaves the zone the gas is at very low pressure and instead of being a dry gas is a wet gas. By wet gas I mean a gas wherein liquid or liquefied gas is mixed with dry gas in the gaseous condition. This wet gas will be conducted to a separator where the wet fraction will be mechanically removed from the gas, the wet fraction being conducted to a storage tank, the remaining dry gas being recirculated through the work zone.

The turbine or work zone will be in a plurality of stages and the gas returning from the separator will be at substantially atmospheric pressure but very cold. This returning gas I propose to pass through a compression zone, preferably comprising a plurality of compressors with a heat extractor or cooler between each compressor so that as the gases pass through the several stages of compression, its pressure is built up to a point at which it can be mixed with the gas passing from one stage to the other of the work zone and may be repassed through the work zone for the production of more wet gas.

The cold gas from the separator will be conducted in heat interchange relationship with the compressed gas so as to reduce the temperature of the compressed gas.

The work zone or the turbine will not generate enough power to liquefy the gas so I propose to burn some of the gas in preferably an internal combustion turbine to furnish the addiitonal power required to operate the compressor system.

The amount of gas supplied at high well pressure to the first work stage will be controlled so as to be just sufficient to compensate for the volume of gas withdrawn from the system as a liquid because it is essential that the volume of gas in the system remain constant. If conditions require variation in the amount of gas admitted to the system from the well, this would result in variation in the amount of power generated especially in the low pressure stage of the turbine. Such variation will be compensated for by varying the amount of gas burned in the internal combustion turbine, the gas received

from the well being also so controlled as to compensate for the amount of gas discharged as gas from the system to support combustion in the internal combustion turbine.

While I have illustrated my invention as including a high pressure and a low pressure turbine and five compressors with five coolers following each compressor, the number of turbines and compressors and coolers might be varied. While I have illustrated turbines as providing the power, other power means making use of the pressure in the gas and as a result causing cooling of the gas and other power means than the internal combustion turbine might be used without departing from the spirit of my invention.

My invention is illustrated diagrammatically in the accompanying drawing, the well and the receiver being not illustrated.

Like parts are indicated by like characters throughout the specification and drawings.

1 is a conduit conveying gas under pressure from a well to the intake side 2 of the high pressure turbine 3. The gas passes from 2 through nozzles 4, vanes 5, nozzles 6 and vanes 7 on the turbine wheel 8 on drive shaft 9. The spent gas at substantially reduced pressure and substantially reduced temperature is discharged from the exhaust side 10 of the turbine through the duct 11 to the duct 12 which leads to the low pressure turbine 13. The cooled gas at further reduced pressure and temperature is discharged from the turbine 13 through the duct 14. This gas being now a wet gas, that is dry gas with condensed liquefied gas in suspension therein, is conducted by the duct 14 to a mechanical separator 140 where the liquefied gas is separated from the dry gas, the liquefied gas going through a duct 141 to an insulated receiver 142.

The dry gas from the separator returns through the duct 15 through the heat exchanger 16, duct 17 to the compressor wheel 18 in the first stage of compression 19. This raises the temperature and pressure of the gas. Then gas travels through the duct 20 to the cooler 21. This cycle is repeated through the compressor 22, cooler 23, compressor 24, cooler 25, compressor 26, cooler 27, compressor 28, cooler 29.

The gas, by this sequence of compressors and coolers will be brought to such temperature and pressure that when it has passed through the conduit 30 and the heat exchanger 16, it will be discharged through the conduit 31 to meet the gas discharged from the conduit 11, the pressure of the gas discharged through conduit 31 being the same as the pressure of the gas discharged from the conduit 11. The gas from both sources then passes through the low pressure turbine 13.

As a continuous mass of gas passes through both systems, the dry gas continues to recirculate, the wet gas formed by this cycling being gradually deposited and left in the receiver, such process continuing until the receiver is filled with a suitable amount of cold liquid gas.

The compressors raise the temperature of the gas. It is essential that the heat generated by the compressors be removed from the gas. The coolers 21, 23, 25, 27, and 29, are cooled by water or other suitable coolant entering through the pipes 32 and 33 and discharging through the pipes 34 and 35.

The shaft 9 carries the compressor wheels and the additional power needed to operate the compressors comes from a gas turbine 36. The gas to supply such turbine is discharged through the duct 37 from the first stage of compression. Gas is burned in the gas turbine in the usual manner well known in the art, the turbine assisting in driving the shaft 9 to generate the power required to operate the compressors.

143 indicates a control valve to control the rate of flow of gas from the well. It may be manually controlled or automatically; the details of this valve and control forming no part of this invention are not illustrated, except that lever 144 may be connected to any suitable control means.

The use and operation of the invention are as follows:

The action follows what is conventionally called a regenerative process. The gas comes from the well at a high pressure, for example, something about 2000 p. s. i. a., and flows through the high pressure turbine delivering power to the shaft. There is a corresponding reduction in temperature. This new gas from the high pressure turbine exhaust joins the recirculated gas at a lower pressure, for example, 1100 p. s. i. a. and flows through the low pressure turbine. The gas going through the low pressure turbine in turn delivers power to the shaft of the apparatus, as a result is cooled and exhausts in the condition at atmospheric pressure. It then goes to the receiver and the liquid is deposited. The cold dry gas is brought back from the receiver through a heat exchanger where the recirculated gas is cooled on its way to the low pressure turbine. The gas from the receiver having been heated by the transfer of heat from the recirculated gas, then is passed into the compressor units. The gas passes from each compressor stage through a cooler to the next compressor. The compressor cooler system will deliver the compressed gas, for example, to the regenerative heat exchanger at a temperature above the temperature of the exhaust from the high pressure turbine. The regenerative heat exchange will bring the temperature of the compressed gas to a lower temperature and the cooled gas will mix with the exhaust from the high pressure turbine and this mixture will pass through the low pressure turbine for liquefaction.

An outstanding feature of this arrangement is in connection with the gas turbine which is also on the same line of shafting. The compressors take considerably more power than the high pressure turbine and the low pressure turbine already mentioned can develop. This additional power is supplied by a gas turbine burning some of the gas. The gas for this turbine will be taken from the circulating system after one of the stages of the compressor units as desired. As shown, the gas is taken after the first stage at for example 60 p. s. i. a. and delivered to the gas turbine but the gas for the turbine has been put through the regenerative cycle and the amount of gas liquefied, which is a percentage, is thereby increased. More gas goes through the low pressure turbine than is handled by the main portion of the compressor unit. The result of this will be a bigger field of liquefied gas per cycle than would be the case if the high pressure and low pressure turbine units were driven by an electric motor for example.

In a sense, if we limit our thinking to one cycle of recirculation the gas used in the gas turbine is waste gas. In order further to illustrate the conception, if there was a sale for gas in a neighboring community, all of the gas not liquefied could be delivered from the receiver to the community gas mains. I am taking ad-

vantage of this idea to use the gas for my own necessary power.

From the receiver of the liquefaction plant the liquid methane may flow into tanks in a barge which are so-to-speak the final receiver and such barge may thereafter be propelled to any suitable point at which the liquefied cold gas may be needed.

I have used the expression "multi-stage turbine." Usually all turbines are multi-stage but that expression in this particular instance is intended to means a turbine wherein one stage at least discharges gas out of the turbine before the gas is returned to the turbine for the next stage. I have shown a high pressure turbine 3 and a low pressure turbine 13. It is the high pressure stage and the low pressure stage that I am referring to when I use the term multi-stage in this connection. The high pressure turbine is smaller than the low pressure turbine. They might be in the same housing but the gas does not go directly from the high pressure stage or stages to the low pressure stage or stages but the exhaust from the high pressure turbine is mixed with an additional supply of gas so that they pass together through the low pressure turbine.

One example of a device such as this would be a situation where the gas supplied to the high pressure was at 2500 pounds pressure. The gas supplied to the low pressure turbine would be at 1000 pounds pressure. The relationship between the weights of gas passing through the two turbines might be that the low pressure turbine would receive twenty-five percent of its gas from the exhaust of the high pressure turbine while seventy-five percent of the gas would be recirculated and supplied to the low pressure turbine from the condensing system. Any weight, for example, we might have five hundred pounds of gas per minute entering the high pressure turbine, would be joined by 1500 pounds of gas per minute recirculating through the system and so going through the low pressure turbine.

The pressure drop and work done in the low pressure turbine results in liquefaction even as the gas is passing through the blades but due to a time lag most of the liquefaction takes place after the gas has been discharged from the blades into a space or receiver at atmospheric pressure.

Only a small part of the gas coming from the well is bled off to supply the combustion turbine. It is bled off after, not before, it is circulated through the high pressure and low pressure turbines and the gas separator because by that arrangement, the pressure value of the gas from the well is not lost and the cooling effect of all the gas is made available before any combustion takes place.

I claim:

1. The method of liquefying natural gas which includes discharging the gas from a gas well at substantially natural well pressure, causing the gas to expand and do work in a primary work zone, with resultant cooling, mixing the spent gas from the primary work zone with an additional supply of gas, at substantially the same pressure, causing the resultant mixture to expand and do work in a secondary work zone, with resultant further cooling and liquefaction of some of the gas, removing the liquid from the dry gas, compressiong the dry gas, cooling it and using it to provide the additional supply of gas for recirculation through the secondary work zone with the spent gas from the primary work zone.

2. The method of liquefying natural gas which includes discharging the gas from a gas well at substantially natural well pressure, causing the gas to expand and do work in a primary work zone, with resultant cooling, mixing the spent gas from the primary work zone with an additional supply of gas, at substantially the same pressure, causing the resultant mixture to expand and do work in a secondary work zone, with resultant further cooling and liquefaction of some of the gas, removing the liquid from the dry gas, compressing the dry gas, cooling it and using it to provide the additional supply of gas for recirculation through the secondary work zone with the spent gas from the primary work zone, controlling the rate at which gas is discharged from the well to compensate for the liquid removed from the dry gas.

3. The method of liquefying natural gas which includes discharging the gas from a gas well at substantially natural well pressure, causing the gas to expand and do work in a primary work zone, with resultant cooling, mixing the spent gas from the primary work zone with an additional supply of gas, at substantially the same pressure, causing the resultant mixture to expand and do work in a secondary work zone, with resultant further cooling and liquefaction of some of the gas, removing the liquid from the dry gas, compressing the dry gas, cooling it and using it to provide the additional supply of gas for recirculation through the secondary work zone with the spent gas from the primary work zone, burning some of the dry gas to furnish power to compress the dry gas.

4. The method of liquefying natural gas which includes discharging the gas from a gas well at substantially natural well pressure, causing the gas to expand and do work in a primary work zone, with resultant cooling, mixing the spent gas from the primary work zone with an additional supply of gas, at substantially the same pressure, causing the resultant mixture to expand and do work in a secondary work zone, with resultant further cooling and liquefaction of some of the gas, removing the liquid from the dry gas, compressing the dry gas, cooling it and using it to provide the additional supply of gas for recirculation through the secondary work zone with the spent gas from the primary work zone, using the cold dry gas to cool the compressed dry gas before it is mixed with the spent gas from the primary work zone.

5. In combination, a high pressure and a low pressure turbine rotor, housings therefor, valve controlled means for supplying high pressure gas to the intake side of the high pressure rotor housing, means for conducting spent gas from the exhaust side of said housing to the intake side of the low pressure rotor housing, a liquid separator, means for conducting gas from the exhaust side of the low pressure rotor housing to the separator, means for withdrawing liquid gas from the separator, a rotary compressor, means for conducting dry gas from the liquid separator to the intake side of the rotary compressor, a cooler, means for conducting gas from the discharge side of the rotary compressor through the cooler to the intake side of the low pressure rotor housing.

6. In combination, a high pressure and a low pressure turbine rotor, housings therefor, valve controlled means for supplying high pressure gas to the intake side of the high pressure rotor housing, means for conducting spent gas from the ex-

haust side of said housing to the intake side of the low pressure rotor housing, a liquid separator, means for conducting gas from the exhaust side of the low pressure rotor housing to the separator, means for withdrawing liquid gas from the separator, a rotary compressor, means for conducting dry gas from the liquid separator to the intake side of the rotary compressor, a cooler, means for conducting gas from the discharge side of the rotary compressor through the cooler to the intake side of the low pressure rotor housing, a heat exchanger through which cold gas from the liquid separator passes on its way to the rotary compressor to additionally cool the gas on its way from the cooler to the intake side of the low pressure rotor housing.

7. In combination, a high pressure and a low pressure turbine rotor, housings therefor, valve controlled means for supplying high pressure gas to the intake side of the high pressure rotor housing, means for conducting spent gas from the exhaust side of said housing to the intake side of the low pressure rotor housing, a liquid separator, means for conducting gas from the exhaust side of the low pressure rotor housing to the separator, means for withdrawing liquid gas from the separator, a rotary compressor, means for conducting dry gas from the liquid separator to the intake side of the rotary compressor, a cooler, means for conducting gas from the discharge side of the rotary compressor through the cooler to the intake side of the low pressure rotor housing, a prime mover adapted to burn some of the dry gas discharged from the separator to furnish power to operate the compressor and a driving connection between the turbine rotors, the compressor and the prime mover.

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