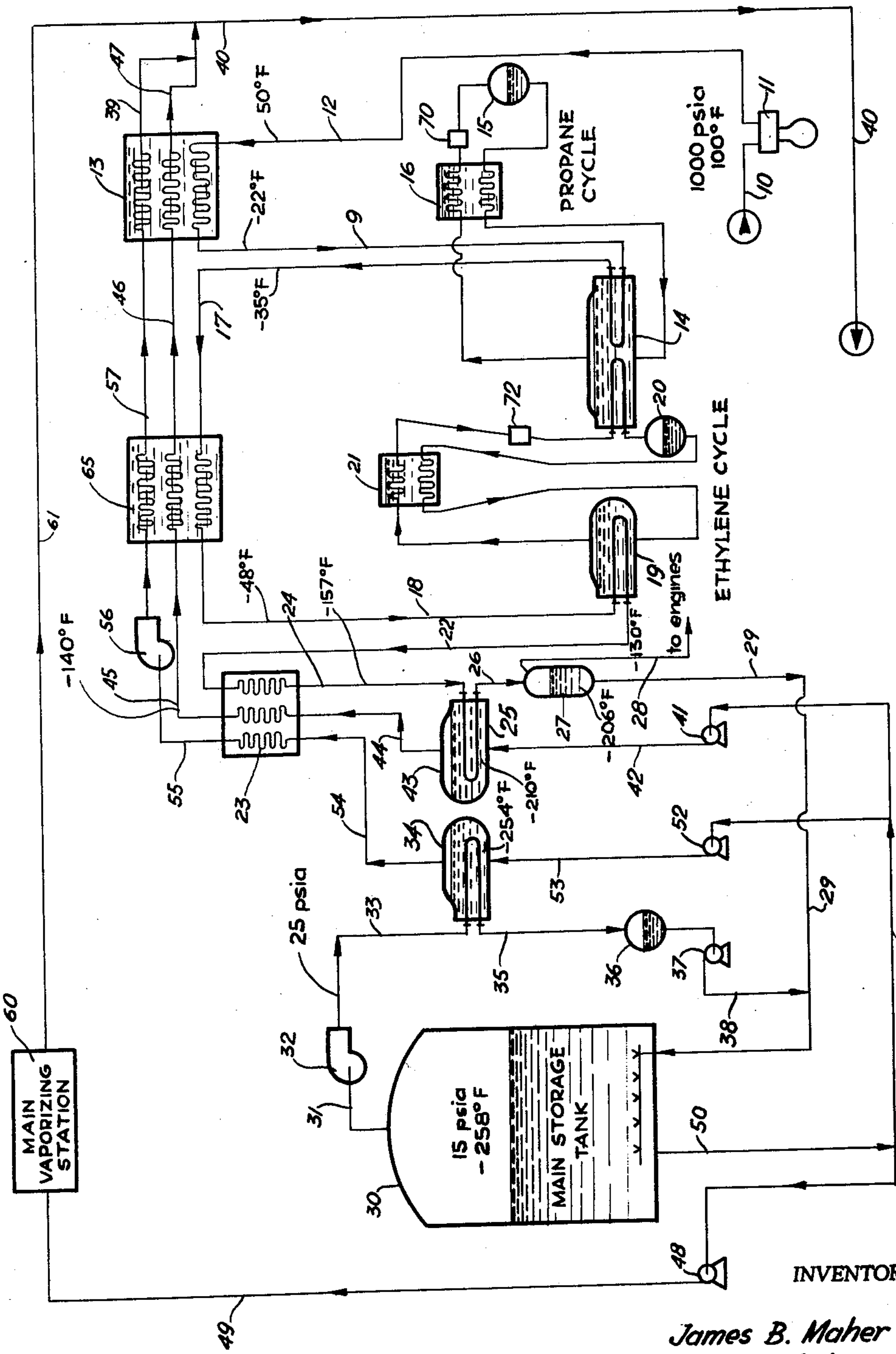
July 20, 1965 J. B. MAHER ETAL 3,195,316

METHANE LIQUEFACTION SYSTEM

Filed Aug. 2, 1963



INVENTORS

James B. Maher and
James Mair

By Merriam, Smith & Marshall
ATTORNEYS

United States Patent Office

3,195,316
Patented July 20, 1965

3,195,316
METHANE LIQUEFACTION SYSTEM

James B. Maher and James Mair, Chicago, Ill., assignors to Chicago Bridge & Iron Company, Chicago, Ill., a corporation of Illinois

Filed Aug. 2, 1963, Ser. No. 299,506
3 Claims. (Cl. 62—52)

This invention relates to apparatus and methods for storing materials which are normally gases at ambient tempertaures and pressures in the form of liquids. More particularly, this invention is concerned with novel processes and apparatus for liquefying methane, such as in the form of natural gas, and subsequently storing the gas in liquefied form.

Large amounts of methane, usually in the form of natural gas, are used in heating residences, apartments, offices and public buildings as well as in cooking. In addition, industry employs large amounts of the gas in processing operations of a wide variety.

The demand for gas varies seasonally as well as daily. Larger amounts of gas are needed during the winter season in the northern parts of the United States than during the warmer periods of the year. The same is true of the southern parts of the country but to a lesser extent. In addition, the demand for gas varies during the day, with lesser amounts being required during evening hours than during the daylight period. This is because industry employs larger amounts, generally, during the daylight hours and because home consumption is generally greater due to cooking during the daylight and early evening hours than in the nighttime.

Natural gas in distributed by means of pipelines which are usually unable to provide sufficient gas to supply the demand at peak periods.

In many areas of the country, it is necessary to store large quantities of natural gas for the purpose of "peak shaving" to provide the large supply of gas needed during intervals of high demand. It has become a commos practice, since the volume of vapor to be stored would be impracticable, to liquefy the gas near the ultimate area of consumption and subsequently to vaporize and distribute it through the local gas distribution system for ultimate consumption.

The liquefied gas is generally stored in large double-walled insulated tanks at a low temperature which gives a vapor pressure only slightly above atmospheric pressure. An internal vapor pressure of 15 p.s.i.a. with the storage temperature of the liquefied gas being about −258° F. is quite common and representative of the storage conditions.

The natural gas is normally liquified by a cascade refrigeration system followed by isenthalpec expansion, or flashing, into the storage tank. A disadvantage of this system is that large volumes of vapor must be handled by expensive equipment using considerable horsepower.

In the filling of a storage tank, the gas in the pipeline may be about 315 p.s.i.a. and in the consumer distribution header at about 90 p.s.i.a. During normal filling of the storage tank the ratio of gas being stored to gas being distributed as vapor from the tank is about 1 to 1. However, the calorific value of the vapor or distributed gas must be maintained above a specified minimum to meet standards required for the gas.

Maintaining the calorific value of the gas involved in the liquefied vapor flashed to storage temperature is a serious problem since contaminating gases such as nitrogen and carbon dioxide are present in the natural gas in volumes determined by equilibrium conditions. For example, a flow of natural gas carrying 2% nitrogen when compressed to 1000 p.s.i.a., cooled to −206° F., liquefied and flashed to a storage temperature of −258° F., would release vapor carrying about 30% nitrogen. If the resulting vapor is then sent into a distribution system, the calorific value of the distributed gas would be lower, unless suitable steps are taken to correct the calorific content, than the gas fed directly from the pipeline to the distribution system.

Because of the heat-leak problem involved in storage of liquefied gases at low temperatures in insulated storage tanks, it is necessary in controlling the pressure to remove the vapor from the tank and either distribute it into the consumer distribution system or to liquefy it and feed it back into the storage tank. Such storage tanks are built and designed to withstand pressures only slightly above atmospheric pressure and therefore, it is necessary carefully to control the pressure in the tank. It would be prohibitively expensive to erect a large size storage tank which can withstand pressure significantly higher than atmospheric pressure and for this reason the liquefied gas is stored at just slightly above atmospheric pressure but at very low temperatures.

There are provided according to the subject invention, novel processes and apparatus which employ the liquefied product for controlling the vapor pressure in the storage tank as well as processes and apparatus which use the liquified product as a means for lowering the temperature of gas to be stored as a liquid in the tank.

More particularly, there is provided by this invention a mehtod of controlling the pressure in an insulated storage tank holding liquefied methane, such as in the form of natural gas, at close to but slightly above atmospheric pressure, which comprises withdrawing vapor from the tank, increasing the pressure of the withdrawn vapor, feeding the vapor at increased pressure into the tube side of a vessel cooled on the shell side by liquefied methane withdrawn from the tank, liquefying the vapor in the tube side of the vessel, feeding said liquefied methane into the tank and feeding the methane from the shell side of the vessel to a transfer pipe either for use in refrigerating additional supplies of gas to be stored or for distribution to the consumer system.

In another aspect of the subject invention the liquefied natural gas in the storage tank is used for further cooling methane, or natural gas, already brought to a liquid condition but which has a temperature which exerts a pressure substantially above atmospheric pressure, to a temperature considerably lower so that upon flashing into the storage tank, a substantial portion of the gas will be cooled to storage temperature at approximately atmospheric pressure. In this method, incoming natural gas is subjected to the refrigerating action of a cascade system to convert it into a liquid at a temperature which exerts a pressure substantially above atmospheric pressure, after which the so liquefied gas is further cooled by passing it through the tube side of a vessel which is cooled on the shell side by liquefied natural gas withdrawn from the storage tank holding the same at close to, but slightly above, atmospheric pressure, removing the liquefied gas from the tube side of the vessel at a much lower temperature than at which it entered and then flashing the so cooled liquefied gas into the storage tank to further cool it to storage temperature. By "storage temperature" is meant that temperature which gives a vapor pressure close to but slightly above atmospheric pressure.

The invention will now be described in conjunction with the attached drawing in which:

The figure is a flow sheet showing schematically a system of receiving natural gas from a pipeline, its liquefaction and storage in a main storage tank, vaporization of the liquefied gas and distribution to a consumer header.

Natural gas is received from a pipeline at a pressure of about 315 p.s.i.a. and is sent through line **10** to compressor **11** where it is raised to about 1000 p.s.i.a. and

100° F. The natural gas is then conveyed by pipe **12** through heat exchanger **13** where it is cooled, such as to about 22° F. The cooling in heat exchanger **13** is effected by the natural gas removed from the main storage tank and used in the liquefaction process as will be more fully described subsequently. The cooled natural gas from heat exchanger **13** is conveyed by pipe **9** into the tube side of the evaporator-condensor **14**. A closed-loop propane refrigerating cycle is used to cool the natural gas on the tube side of the evaporator **14** to a temperature of about −35° F. In the propane cycle, propane vapor from vessel **14** is compressed by compressor **70**, condensed by cooling water, the condensate collected in receiver **15** and returned to vessel **14** after passing through the heat exchanger **16**.

After the natural gas has been cooled such as to about −35° F. in vessel **14**, it is conveyed by pipe **17** through heat exchanger **65** which is cooled by natural gas removed from the main storage tank. After leaving the heat exchanger **65**, the natural gas is lowered to a temperature of about −48° F. The natural gas is then cooled further by conveying it by pipe **18** through the tube side of evaporator-condenser **19** which is cooled on the shell side by means of ethylene.

In the ethylene cycle, ethylene vapor from vessel **19** is compressed by compressor **72**, condensed by propane in vessel **14**, the ethylene condensate collected in receiver **20** and returned through heat exchanger **21** to vessel **19**.

The natural gas as it leaves vessel **19** has been cooled such as down to about −130° F. It is then conveyed by pipe **22** through heat exchanger **23** where it is further cooled by natural gas removed from the main storage tank. After leaving the heat exchanger **23**, the gas is conveyed by pipe **24** through the tube side of the evaporator-condenser vessel **25** from which it is conducted by pipe **26** into receiver **27**.

Vapors are removed from receiver **27** by pipe **28** and fed to the engines (not shown) used in the system. The vapors removed are somewhat enriched in nitrogen but this is no problem since the engines can readily handle gas containing an appreciable increase in nitrogen. Removal of some of the nitrogen in this way serves to raise the calorific content of the natural gas that is stored in liquefied condition, subsequently vaporized and then distributed.

Liquefied gas is sent from receiver **27** through pipe **29** into the bottom of the main storage tank **30**. There it is flashed to further cool it to a temperature of about −258° F. and a pressure of 15 p.s.i.a.

Vapors formed during the final flash, as well as vapors formed due to heat-leak between the storage tank and its surroundings, plus vapor displaced by the fill, are removed by line **31** and by means of compressor **32** are increaesd to a pressure of about 25 p.s.i.a. The vapors are then conducted by pipe **33** through the tube side of evaporator-condenser vessel **34** where they are liquefied and then conveyed by pipe **35** into receiver **36**. Pump **37** then conveys the liquefied gas from receiver **36** by pipe **38** into the bottom of the main storage tank **30**.

Vessel **34** is cooled by withdrawing liquefied natural gas from the main storage tank **30** by means of pipe **50** and then sending it through pipe **51** to pump **52** where the liquefied gas is pumped through pipe **53** into vessel **34**. The gas leaves the shell side of vessel **34** and is conveyed by pipe **54** into the heat exchanger **23** from which it leaves by pipe **55** which feeds to blower **56**. Blower **56** sends the gas through heat exchanger **65** and by means of pipe **57** it is conveyed through heat exchanger **13** and then by pipe **39** into the line **40** for distribution to a consumer header at a pressure of about 90 p.s.i.a.

Liquid natural gas is also removed from the main storage tank **30** and is conveyed by pipe **50** to pump **41** from which it is conveyed by pipe **42** to evaporator-condenser vessel **43**. The gas leaves vessel **43** by pipe **44**, passes through heat exchanger **23** and exits from it at a temperature of about −140° F. through line **45**. Line **45** conveys the still cool natural gas through heat exchanger **65** from which it is conveyed by pipe **46** through heat exchanger **13** from which it leaves by pipe **47** and is then conveyed to pipe **40** for distribution.

When it is necessary to supply increased amounts of natural gas, the liquid product in the main storage tank **30** can be removed by pipe **50**, conveyed to pump **48** and then to line **49** which feeds it to a main vaporizer station **60** which in turn sends it through pipe **61** into pipe **40** for distribution.

The concentration of nitrogen in the vapor space of storage tank **30** is considerably higher than in the natural gas received from the pipeline so the vapor mixture has a lower calorific content. If vapor was removed from the storage tank and either fed directly into the distribution line **40**, or first used to cool natural gas being liquefied by passing it through vessel **43** and/or heat exchangers **23**, **65** and **13** before feeding it to line **40**, the calorific content would be lower than that of the gas received in the pipeline. This is because the partial pressure of nitrogen at the storage conditions is much higher than the partial pressure of liquefied natural gas.

By withdrawing liquefied natural gas from the main storage tank and using it to cool the product being liquefied, as well as to liquefy vapor withdrawn from the tank to control the pressure therein, the calorific content of the gas after vaporizing is not less, and usually is more, than that of the natural gas originally received from the pipeline.

Although vessels **34** and **43** show vaporization of the liquified gas therein, adequate cooling can alternatively be obtained by passing the gas through the shell side in liquid form. However, this would require a greater flow of gas through the shell side and perhaps increased pressures on the tube sides of these vessels.

Among other advantages of the described process is the use of small liquid pumps for propelling the liquid natural gas. No low temperature expensive compressors are required to convey the gas to the distribution header. The invention thus permits delivering methane vapor at a high temperature by pumping liquefied methane from a storage tank at close to atmospheric pressure, passing the so withdrawn gas through heat exchangers and vaporizers which vaporize the outgoing gas while cooling a stream of methane incoming to the tank, while generating all of said high pressure by the liquid pump, i.e., without the need of a high pressure, low temperature operating blower.

The described process also uses less horsepower than the classical cascade system for liquifying natural gas. The process of this invention uses about 580 horsepower, while the classical cascade system would use about 825 horsepower, per one million standard cubic feet per day.

Various changes and modifications of the invention can be made and, to the extent that such variations incorporate the spirit of this invention, they are intended to be included within the scope of the appended claims.

What is claimed is:

1. A method of liquefying natural gas and storing the same in an insulated storage tank at close to but slightly above atmospheric pressure, which comprises subjecting incoming natural gas to the refrigerating action of a cascade system to convert it into a liquid at a temperature which exerts a pressure substantially above atmospheric pressure, further cooling the liquefied gas by passing it through the tube side of a first vessel cooled on the shell side of liquefied natural gas withdrawn from a storage tank holding the same at close to but slightly above atmospheric pressure, removing the liquefied gas from the tube side of the first vessel at a much lower temperature than at which it entered and flashing it into said storage tank for storage at a temperature at which the gas gives a vapor pressure close to but slightly above atmospheric pressure, withdrawing vapor from the tank when it reaches a nominal

level, increasing the pressure of the withdrawn vapor, feeding the vapor at increased pressure into the tube side of a second vessel cooled on the shell side by liquefied gas withdrawn from the tank, liquefying the vapor in the tube side of the second vessel, feeding said liquefied gas into the tank, and feeding the gas from the shell side of the second vessel to a transfer pipe.

2. The method of claim 1 in which the gas from the shell side of the first and second vessel is used to cool the gas being liquefied for storage in the tank during cooling by the cascade system to enhance its efficiency.

3. Apparatus for liquefying methane and storing the same for subsequent distribution as a vapor which comprises in combination a cascade means for receiving methane from a pipeline and cooling the same until liquefied with a pressure substantially above atmospheric pressure, a first vessel for receiving the said liquefied methane on the tube side for further cooling it, said first vessel being adapted to be cooled by liquefied methane removed by pipe means communicating with an insulated main storage tank and the steel side of the first vessel, pipe means communicating with the shell side of the first vessel for conveying methane therefrom to means for cooling methane liquefied by the cascade means and then to a vapor distribution line, pipe means for removing liquefied methane from the tube side of said first vessel and conveying it to the main storage tank for flash cooling therein, pipe means communicating with the main storage tank and with means for vaporizing liquefied gas withdrawn from the tank and distributing the vapor to distribution means, pipe means communicating with the vapor space in the tank and with pressure means for removing vapor from the tank and increasing the pressure thereof, pipe means communicating with the pressure means for conveying the vapor into the tube side of a second vessel for liquefaction therein, means for receiving, pumping and conveying liquefied methane from the tube side of the second vessel to the tank, pipe means communicating with the main storage tank and the shell side of the second vessel for withdrawing liquefied gas from the tank and conveying it into the shell side of the second vessel to cool the same, and pipe means communicating with the shell side of the second vessel for removing methane therefrom and conveying it to said distribution means.

References Cited by the Examiner

UNITED STATES PATENTS

2,082,189	6/37	Twomey	62—54
2,582,148	1/52	Nelly	62—23
2,682,154	6/54	Wilkinson	62—54
2,884,763	5/59	Faulk	62—54
2,960,837	11/60	Swenson et al.	62—9

ROBERT A. O'LEARY, *Primary Examiner.*