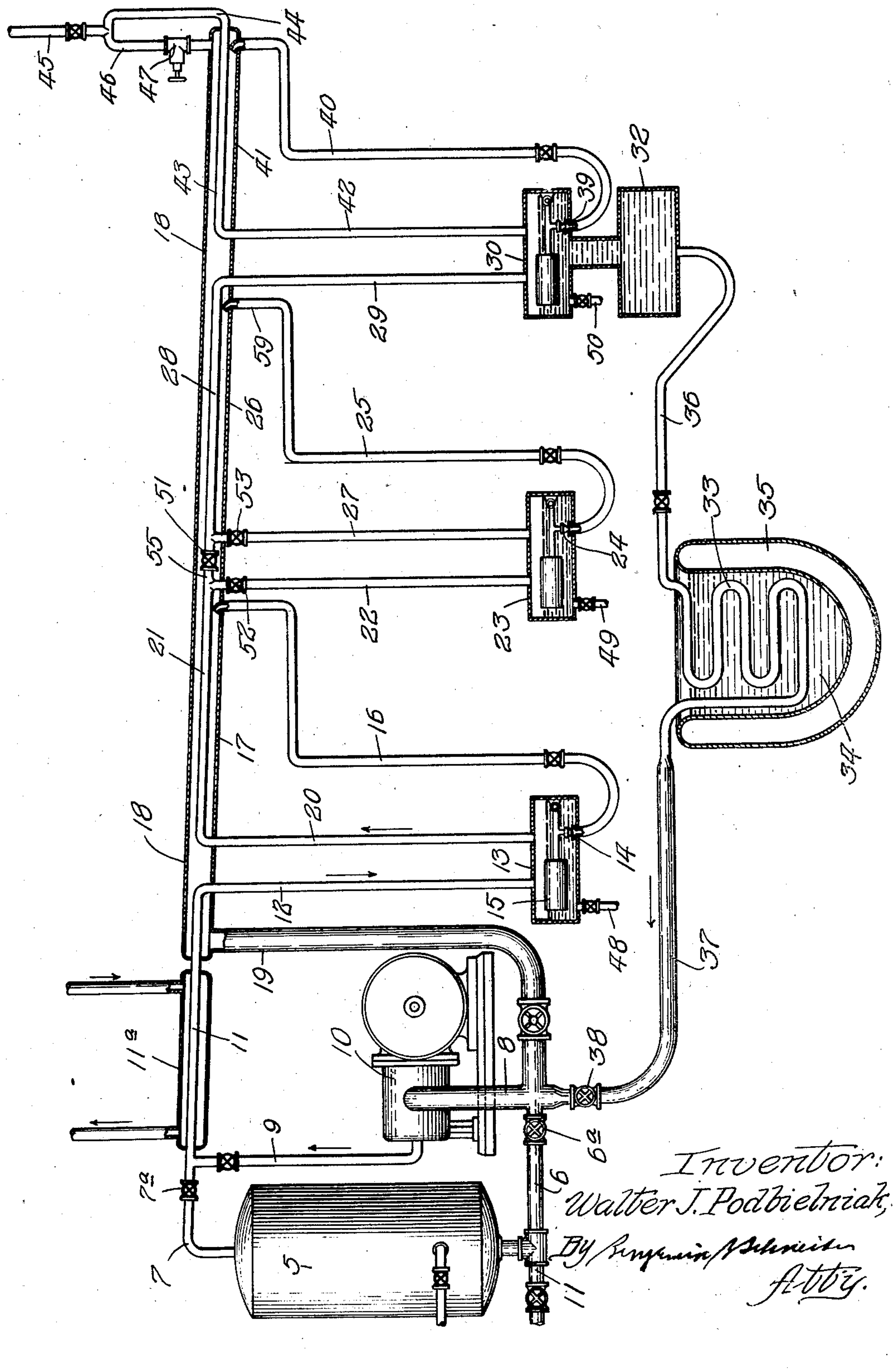
May 26, 1936. W. J. PODBIELNIAK 2,041,725

ART OF REFRIGERATION

Filed July 14, 1934



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Patented May 26, 1936

2,041,725

UNITED STATES PATENT OFFICE

2,041,725

ART OF REFRIGERATION

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Application July 14, 1934, Serial No. 735,096

17 Claims. (Cl. 62—170)

This invention relates to the art of cooling or refrigeration, and more particularly to improvements in processes and apparatus for the attainment of extremely low temperatures and for securing in liquid form the lowest boiling constituent of a complex gas or gas and vapor mixture.

By operating in accordance with my invention I am enabled to avoid the use of high pressures or of a plurality of compressors, and of bulky, expensive equipment.

In carrying out my invention I can attain exceedingly low temperatures by a simple procedure employing easily obtainable and inexpensive refrigerant or working fluids, usually a mixture of gases and vapors, the composition of which may be readily and easily adjusted as accurately as desired, while the system is still in operation, to give the best results; and at the same time I can secure the most volatile fractions of the mixture as well as other fractions in liquid form.

In carrying out the present invention, one compressor is employed for an operation in a succession of stages or steps with a working fluid mixture as hereinafter described. The mixture of gases is first compressed and then cooled by indirect heat exchange with a readily available cooling medium, such as water, which condenses a high boiling fraction. The liquefied and unliquefied portions are separated and the former expanded (suitably into the suction line) of the compressor, and by heat exchange with the previously unliquefied portion, further reduces the temperature of the latter and condenses an intermediate fraction of the working fluid. This liquefied portion is separated from the remaining unliquefied portion and the steps previously carried out upon the first stage liquefied and unliquefied portions are repeated in cascade procedure for as many stages as are necessary to obtain finally, as a liquefied condensate, the desired low boiling fractions of the mixture necessary to secure the desired low temperature cooling effect on their expansion or use as a refrigerant. By causing this final fraction to expand into the suction of the compressor in exercising its cooling effect, a completely closed cycle may be maintained. The refrigerant or working fluid employed is a mixture of two or more fluids or liquefiable substances, a part or all of which are usually gases or vapors at room temperature and atmospheric pressure, the mixture preferably having a wide range of boiling points. The proportions of the constituents of the mixture in a given instance may be determined by experiment or by physico-chemical calculations or preferably suitable adjustment of its composition may be made during operation. I have found that refinery gas and natural gas, for example, are suitable mixed fluids for use in obtaining by my process temperatures of the order of liquid air, viz., about −160° C. to −170° C. Thus in my process, by using a hydrocarbon mixture comprising methane, ethane, propane, butanes and pentanes, a final temperature of about −170° C. can be secured.

The process of the present invention will be fully understood by reference to the accompanying drawing in which the figure illustrates diagrammatically means suitable for carrying the invention into effect.

In the drawing, the numeral 5 indicates a storage tank for the refrigerant fluid, connected by valved lines 6 and 7 to the suction 8 and to the discharge 9 respectively of a suitable compressor 10, the compressor 10 being power driven from any suitable source. The refrigerant fluid may be introduced into the system or into the storage tank from a suitable source of supply through the valved line 11.

The refrigerant fluid, which may suitably be a fluid mixture such as refinery gas or natural gas, or of either admixed with a light gasoline fraction, of chlorinated hydrocarbons, or the like, containing a plurality of substances and having a range of boiling points, is charged into the storage tank under suitable pressure, say from 100 to 500 lbs. In beginning operations it is withdrawn from the tank by the compressor 10 and forced into the system in which it is handled as hereinafter described, the valves 6*a* and 7*a* in the lines 6 and 7 being closed after operation of the system is initiated, except as it may be necessary to supply additional refrigerant in the system, in which case the valve 6*a* in the line 6 may be opened to the desired extent.

In the refrigerating system proper, the compressor 10 forces the refrigerant fluid through the discharge line 9 into the conduit 11 which is cooled, suitably by a cooling means readily available, such as water at ordinary room temperature, for example, about 20° C., circulated through the cooling jacket 11*a*. It is readily apparent that the conduit 11 may be of any desired form, for example, a coil or helix, in place of the straight conduit as shown.

With a refrigerant fluid mixture as described, and with suitable pressures thereupon at the discharge of the compressor, say about 100 lbs., a portion of the refrigerant fluid will be liquefied by the action of the cooling water in the jacket or chamber 11a surrounding the conduit 11. The resulting condensate, together with unliquefied gas, is discharged through the line 12 into a container or receiver 13 in which the condensate collects. With an initial mixture in the refrigerant fluid of the character described, consisting, for example, of methane, ethane, propane, butanes and pentanes, the liquid in the receiver 13 will consist largely of pentanes with some butanes and perhaps a small amount of propane. With such a mixture, and under the particular conditions hereinbefore set forth, it has been found that the liquid in the receiver 13 may have a temperature of approximately 25° C.

In the receiver 13, a separation of condensate and of unliquefied fluid takes place, and they are separately discharged therefrom. The discharge of the liquefied portion or condensate, while it may be manually controlled if desired, is preferably controlled automatically by means of a valve 14 operated by a float 15, the opening of the valve permitting the liquid or condensate to pass out at reduced pressure through a line 16 into a conduit section 17 of a reduced pressure main or conduit 18. This reduced pressure main or conduit is connected by the valved line 19 with the suction 8 of the compressor 10, the line 18 being, during operation, normally open so that the reduced pressure of the suction of the compressor is maintained throughout the reduced pressure main or conduit 18. In the specific embodiment described, the suction of the compressor and the reduced pressure prevailing in the main or conduit 18 may suitably be in the order of a 20 inch vacuum.

The unliquefied fluid or gases from the receiver 13 pass out through the line 20, from which they enter a conduit section 21 which is within or surrounded by the reduced pressure main section 17. The unliquefied portion of the original refrigerant which is passing through the conduit section 21 is still maintained under the compressor pressure of approximately 100 lbs. per square inch. It is surrounded by the cooled gases resulting from the expansion into the suction main 18 of the liquefied portion, likewise discharged from the container 13, and the cooled gases resulting from this expansion are preferably caused to pass in countercurrent to the flow of the compressed unliquefied portion passing through the conduit section 21. As a result of this interchange, a second portion of the refrigerant fluid is condensed by the cooling action in the conduit section 21, being brought to a markedly lower temperature, say in the order of −50° C. The cooled mixture of condensate and still unliquefied refrigerant fluid from the conduit section 21 pass through a line 22 into a second receiver 23, similar to the receiver 13, in which a similar separation of liquefied fluid or condensate and unliquefied fluid takes place.

From the receiver or container 23, as in the case of the receiver or container 13, the liquefied condensate or gas is discharged through a float controlled valve 24 to a line 25 leading into a section 26 of the reduced pressure main or conduit 18. At the same time, the unliquefied fluid from the container 23 passes out through a line 27 to a conduit section 28 within and surrounded by the section 26 of the reduced pressure main.

The liquefied portion of the condensate collected in the receiver 23 is composed of lower boiling constituents of the original mixture than those contained and separated in the chamber 13, and the unliquefied constituents of the original mixture passing through the line 27 in the conduit section 28 are composed of but the lower boiling or lighter portions of the original mixture. By the expansion of the condensate drawn off from the receiver 23 into the reduced pressure main 18, very low temperatures are secured and the mixed fluids passing through the conduit section 28 countercurrent to the flow of the expanded and cooled gases produced from the condensate in receiver 23 are brought to a very low temperature, say about −100° C. As the unliquefied fluids entering the conduit section 28 are still under the pressure of the compressor, a further and lighter fraction of these fluids are condensed and the cooled mixture of condensate and uncondensed gas passes from the conduit section 28 through the line 29 to a receiver 30. The receiver 30 is of somewhat similar construction to the receivers 13 and 23. However, in a three-stage system as herein described, a larger capacity for stored liquefied products is desired in the third stage, and consequently in the form illustrated, the receiver 30 is connected by a pipe or neck 31 to a reservoir 32.

The liquid condensate separated and collected in the receiver 30 and the connected reservoir 32 consists of very light constituents of the original refrigerant fluid and are at a very low temperature, say about −100° C. and under substantially the pressure of the compressor. This condensate may be drawn off as required for cooling purposes, and if it is desired to produce much lower temperatures, it may be expanded at the site where cooling is desired. Preferably the gases resulting from expansion are returned to the suction of the compressor 10 so that there will be no loss of refrigerant within the system. For example, in the form illustrated cooling action is desired within a cooling coil 33 within a material or fluid 34 intended to be cooled, the material 34 being surrounded by an insulating vacuum jacket 35. The coil 33 is connected by the valved line 36 to the reservoir 32 and also by a line 37 controlled by valve 38 with the suction 8 of the compressor 10, in which, as hereinbefore noted, a reduced pressure of say a 20-inch vacuum may be maintained. By expanding the condensate from the reservoir 32 into the coil 33 while maintaining the latter under reduced pressure by opening the valve 38 in the line 37, temperatures as low as −170° C. may be secured.

Any excess of fluid condensate collected in the receiver 30 and reservoir 32 may be discharged through the float controlled valve 39 to the lower pressure line 40 connected to the final section 41 of the reduced pressure main or line 18; and excess uncondensed gas may be discharged from the receiver 30 through the line 42 to the conduit section 43 within the reduced pressure main 18, through which the uncondensed gas passes in countercurrent to the expanded and cooled gases from the line 40. The resulting cooled fluids enter a loop 44 provided with a valved vent-line 45, the loop being connected to the reduced pressure main 18 by the line 46 containing a back-pressure regulating valve 47 set at the desired pressure to be maintained on the high pressure side of the system, for example, in the example described, about 100 lbs.

It will be understood that all parts of the system described that are at temperatures below normal atmospheric temperatures will be suitably lagged or insulated to secure the desired operating efficiency.

The present invention has been described in connection with a three-stage system and employing as the initial refrigerant mixture, a material such as refinery gas, natural gas, or mixtures thereof with natural gasoline or like gasoline fractions. As is readily apparent, the specific character of the refrigerant mixture may be varied, it being only necessary that it comprise a series of constituents having a range of condensing temperatures. Mixtures of hydrocarbon gases are particularly desirable, because of the wide range of boiling points of materials available, and of the low cost of such mixtures of which refinery gas and natural gas, previously referred to, and also coal gas, water gas and mixtures thereof with other hydrocarbon gases are examples. Mixtures of chlorinated or fluorinated hydrocarbons may likewise be employed where low inflammability is of importance.

With such mixtures, it is possible to operate in a succession of stages secured primarily by temperature differences, employing the same or substantially the same pressures from the high and low pressure sides of each stage and thus making operation with a single compressor for the entire system possible.

Furthermore, in the operation of the system as described, it is possible to modify the character of the refrigerant mixture within the cycle during operation so as to secure the desired temperature conditions in the various portions thereof and likewise to modify the composition of the refrigerant mixture as desired by the operator. For this purpose, the successive receivers for the liquefied constituents or condensates in the several stages of the cycle may be provided with draw-off lines, and by removing portions from one or more of these receivers at will, the composition of the refrigerant mixture within the cycle may be modified and the temperatures secured controlled. For example, in the system hereinbefore described, the receivers **13**, **23** and **30** may be provided with the valved draw-off lines **48**, **49** and **50** respectively. By maintaining the system in operation for a period in a closed cycle, and during this period, drawing off condensate from one or more of these draw-off lines while introducing only enough refrigerant mixture during the period of adjustment to supply the requirements of the system, the boiling point characteristics and the proportions of constituents of the mixture may be modified as desired by the operator and the temperatures secured in the several stages of operation thereby effectively controlled.

In the operation as described, a mixture of fluids having a wide range of boiling points is employed, as hereinbefore set forth. For example, in a natural gas or mixture of natural gas and natural gasoline suitable for the purpose, the hydrocarbons present may be as follows:

Methane; atmospheric pressure boiling point −160° C.

Ethane; atmospheric pressure boiling point −89.3° C.

Propane; atmospheric pressure boiling point −44.2° C.

Butane; atmospheric pressure boiling point about 0.3° C.

Pentanes; atmospheric pressure boiling point about 36° C.

The mixture of fluids selected may be one containing constituents which can be condensed under the pressures employed by the use of readily available cooling media, such as cold water. Under circumstances wherein a cooler medium, such as refrigerated brine or solidified carbon dioxide is available for the first stage of the operation, as is readily apparent, the heavier constituents of the mixture may be of lower boiling points.

The pressures, composition of the refrigerant fluid and number of stages employed may all be varied as desired. In the description hereinbefore given, variations in the nature of the refrigerant mixture and control of its composition in the operation has been indicated. In a system such as that herein described, it is readily apparent that a stage of the operation can be eliminated, if desired. For example, a by-pass connection **55** may be provided between the conduit sections **17** and **26**, a valve **51** being provided in the by-pass connection, this valve being normally closed when all of the stages hereinbefore described are in operation. When it is desired to eliminate a stage of operation, such as the second stage in the example given, the valve **51** in the by-pass **55** is opened, and suitable valves **52**, **53** and **54** provided in the lines **22** and **27** and **25** respectively are closed.

It is readily apparent that the invention is not limited to the specific procedure described hereinbefore, and that the form of the parts of the apparatus and their proportions, diagrammatically illustrated in the drawing, may be varied in accordance with the requirements of the system and of engineering design. The pressures prevailing in the high pressure and low pressure side of the system as well as the composition of the refrigerant fluid may likewise be varied as desired.

I claim:

1. In the art of cooling, subjecting a gaseous mixture having a range of boiling points, to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, expanding the separated initial condensate to said lower pressure stage, cooling the uncondensed compressed portion of the gaseous mixture by the gases resulting from the expanding of the said initial condensate, thereby condensing a further portion of the compressed gaseous mixture, effecting separation of the resulting condensate from the remaining uncondensed compressed gases, and repeating the steps of expansion of the condensate and cooling of the uncondensed compressed gas thereby, and returning the gases from expansion of the condensates for recompression to the high pressure stage.

2. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, and the condensate separated from the remaining portion of the compressed gaseous mixture.

3. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, the condensate separated from the remaining portion of the compressed gaseous mixture, combining and returning the gases from the expansion of the condensates for recompression to the high pressure stage, thereby securing a closed cycle of operation.

4. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, the condensate separated from the remaining portion of the compressed gaseous mixture, and transferring the final condensate to a locus of cooling.

5. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separting the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, the condensate separated from the remaining portion of the compressed gaseous mixture, combining and returning the gases from the expansion of the condensates for recompression to the high pressure stage, thereby securing a closed cycle of operation, and withdrawing a portion of condensate from said closed cycle, thereby modifying the composition of the gaseous mixture within the cycle.

6. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, the condensate separated from the remaining portion of the compressed gaseous mixture, and transferring the final condensate to a locus of cooling, expanding said final condensate and combining and returning the gases from the expansion of the several condensates for compression to the high pressure stage, thereby securing a closed cycle of operation.

7. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, the condensate separated from the remaining portion of the compressed gaseous mixture, transferring the final condensate to a locus of cooling, expanding said final condensate and combining and returning the gases from the expansion of the several condensates for compression to the high pressure stage, thereby securing a closed cycle of operation, and withdrawing a portion of condensate from said closed cycle, thereby modifying the composition of the gaseous mixture within the cycle.

8. In the art of refrigeration, the steps which comprise subjecting a gaseous mixture of hydrocarbons of the character found in natural gas, refinery gas and the like to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling hydrocarbons from the mixture, separating the resulting condensate from the uncondensed portion of hydrocarbon gases while maintaining the uncondensed portion at the said high pressure, expanding the separated condensate to said low pressure stage, cooling the uncondensed compressed portion of the gaseous mixture by the gases resulting from the expanding of the condensate, thereby condensing a further portion of the mixture of gaseous hydrocarbons, and returning said expanded gases for recompression to the high pressure stage.

9. In the art of cooling, subjecting a mixture of gaseous hydrocarbons of the character found in natural gas, refinery gas, and the like, to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling hydrocarbon constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous hydrocarbon mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation, and the condensate separated from the remaining portion of the compressed gaseous mixture.

10. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the re-

sulting initial condensate fom the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with a consequent partial condensation of the compressed gases, the condensate separated from the remaining portion of the compressed gaseous mixture, combining and returning the gases from the expansion of the condensates for recompression to the high pressure stage, thereby securing a closed cycle of operations.

11. In the art of cooling, subjecting a mixture of gaseous hydrocarbons of the character found in natural gas, refinery gas and the like, to compression from a low pressure stage to a high pressure stage, cooling the hydrocarbon mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations upon the separated portions of the gaseous hydrocarbon mixture, in each of which the condensate from the preceding cooling stage is expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with consequent partial condensation, the condensate separated from the remaining portion of the compressed gaseous hydrocarbon mixture, combining and returning the gases from the expansion of the condensates for recompression to the high pressure stage, thereby securing a closed cycle of operations, and withdrawing a portion of condensed hydrocarbons from a selected one of said succession of operations, thereby modifying the composition of the gaseous hydrocarbon mixture within the cycle.

12. Apparatus for producing a cooling medium from a gaseous mixture comprising a compressor for compressing the mixture from low pressure to high pressure, a conduit section receiving the high pressure gases, means for cooling said conduit section, thereby condensing part of said gases, a receiver into which the cooled gases and condensate are discharged and separated from each other, said receiver being under said high pressure, and a series of subsequent stages following said receiver, each comprising a conduit section receiving separated gases under high pressure from the preceding separating receiver, means for expanding separated condensate from the same preceding receiver to the low pressure side of the compressor and for contacting the resulting cooled gases with said conduit section containing the separated gases under high pressure, to cool and partially condensate the latter, and a receiver under said high pressure for receiving the cooled gases and condensate from said cooled conduit section and separating them for transmission to the subsequent stage of apparatus.

13. Apparatus as set forth in claim 12 where means for withdrawing condensate are provided for each of the separating receivers, whereby selected portions of said condensates may be withdrawn and the composition of the gaseous mixture within the apparatus is thereby modified.

14. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture, in each of which the condensate from the preceding cooling step is expanded to the low pressure stage, the uncondensed compressed gases at the pressure of the high pressure stage cooled by the resulting expanded gases with resulting partial condensation, and the condensate separated from the remaining portion of the compressed gaseous mixture, transferring the final condensate to a locus of cooling, and compressing gas from said locus of cooling to said high pressure stage.

15. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate form the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the said high pressure, carrying uncondensed gas from said separating step and the condensate from said step in parallel operative flow from the zone of separation, expanding the separated initial condensate to said lower pressure stage, cooling the uncondensed compressed portions of the gaseous mixture by the gases resulting from the expanding of said initial condensate, thereby condensing a further portion of the compressed gaseous mixture, effecting separation of the resulting condensate from the remaining uncondensed compressed gases, carrying forward uncondensed compressed gases from the second separation and the condensate therefrom in parallel operative flow and repeating the steps of expansion of the condensate and cooling of the uncondensed compressed gas thereby, and combining and returning the gases from expansion of the condensates to the high pressure stage for recompression.

16. In the art of cooling, subjecting a gaseous mixture having a range of boiling points, to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at the same high pressure, carrying uncondensed gas from said separating step and the condensate from such step in the same direction, expanding the separated initial condensate to said lower pressure stage, cooling the uncondensed compressed portion of the gaseous mixture by the gases resulting from the expanding of the said initial condensate while flowing the expanded gases in the contrary direction to the direction of flow of the compressed mixture, thereby condensing a further portion of the compressed gaseous mixture, effecting separation of the resulting condensate from the remaining uncondensed compressed gases, and repeating the steps of expansion, carrying the second condensate and the remaining uncondensed gases in the same direction, expanding the condensate and cooling the uncondensed gas by counter-flow action of the expanded compressed gases, and combining and returning the gases from expansion of the condensates for recompression to the high pressure stage.

17. In the art of cooling, subjecting a gaseous mixture having a range of boiling points to compression from a low pressure stage to a high pressure stage, cooling the mixture to condense higher boiling constituents thereof, separating the resulting initial condensate from the uncondensed portion of the gaseous mixture while maintaining the uncondensed portion at said high pressure, conducting a succession of operations on the separated portions of the gaseous mixture in each of which a condensate is obtained from the preceding cooling step and maintained separate from other condensates until expanded to the low pressure stage, the uncondensed compressed gases cooled by the resulting expanded gases with resulting partial condensation and the condensate separated from the remaining portion of the compressed gaseous mixture, and combining and returning the gases from expansion of the condensates for recompression to the high pressure stage.

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