Oct. 23, 1923. 1,471,732

G. A. HORNE

PROCESS AND APPARATUS FOR MULTIPLE STAGE COMPRESSION FOR REFRIGERATION

Filed March 13, 1922 4 Sheets-Sheet 1

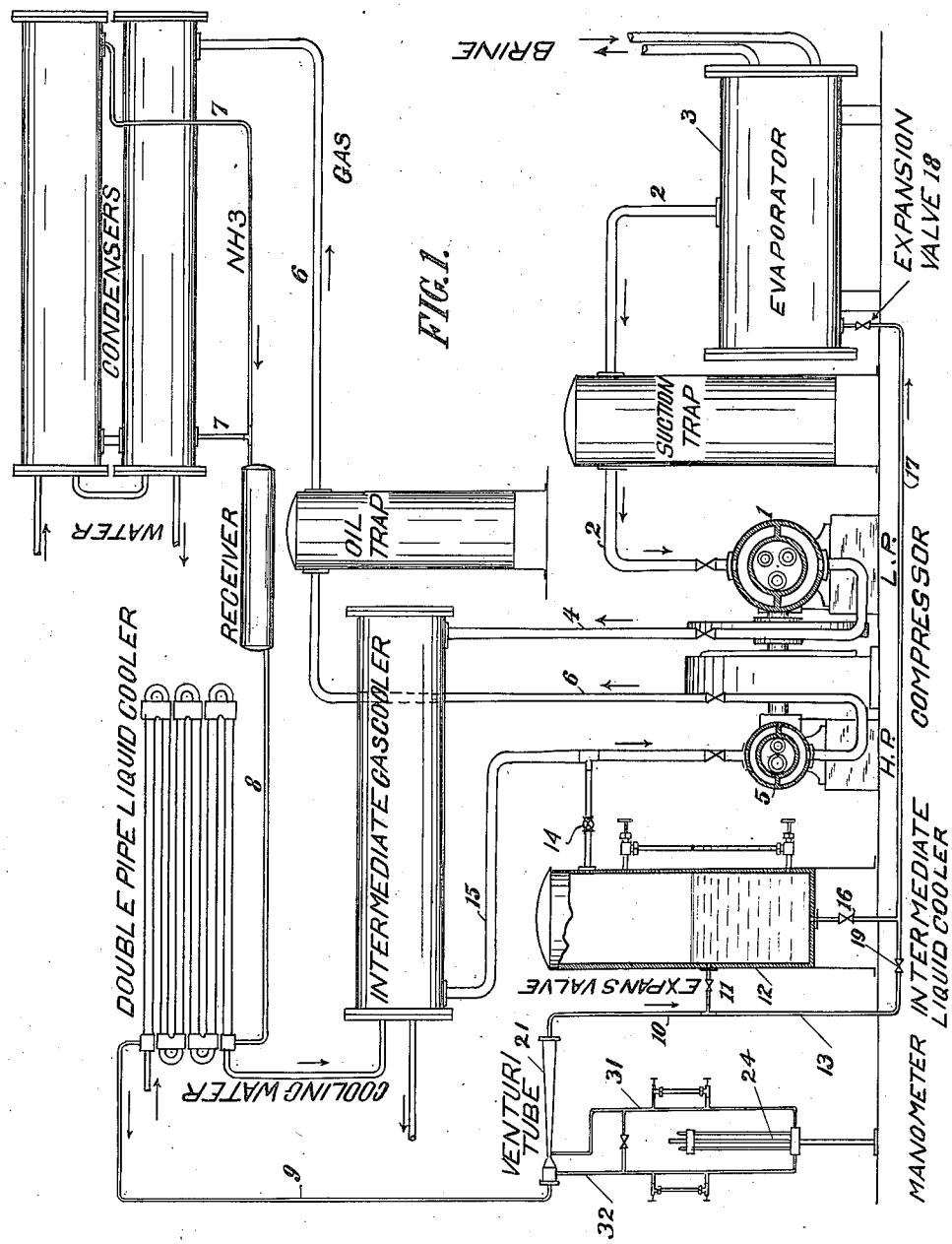


FIG. 1.

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Filed March 13, 1922 4 Sheets-Sheet 2

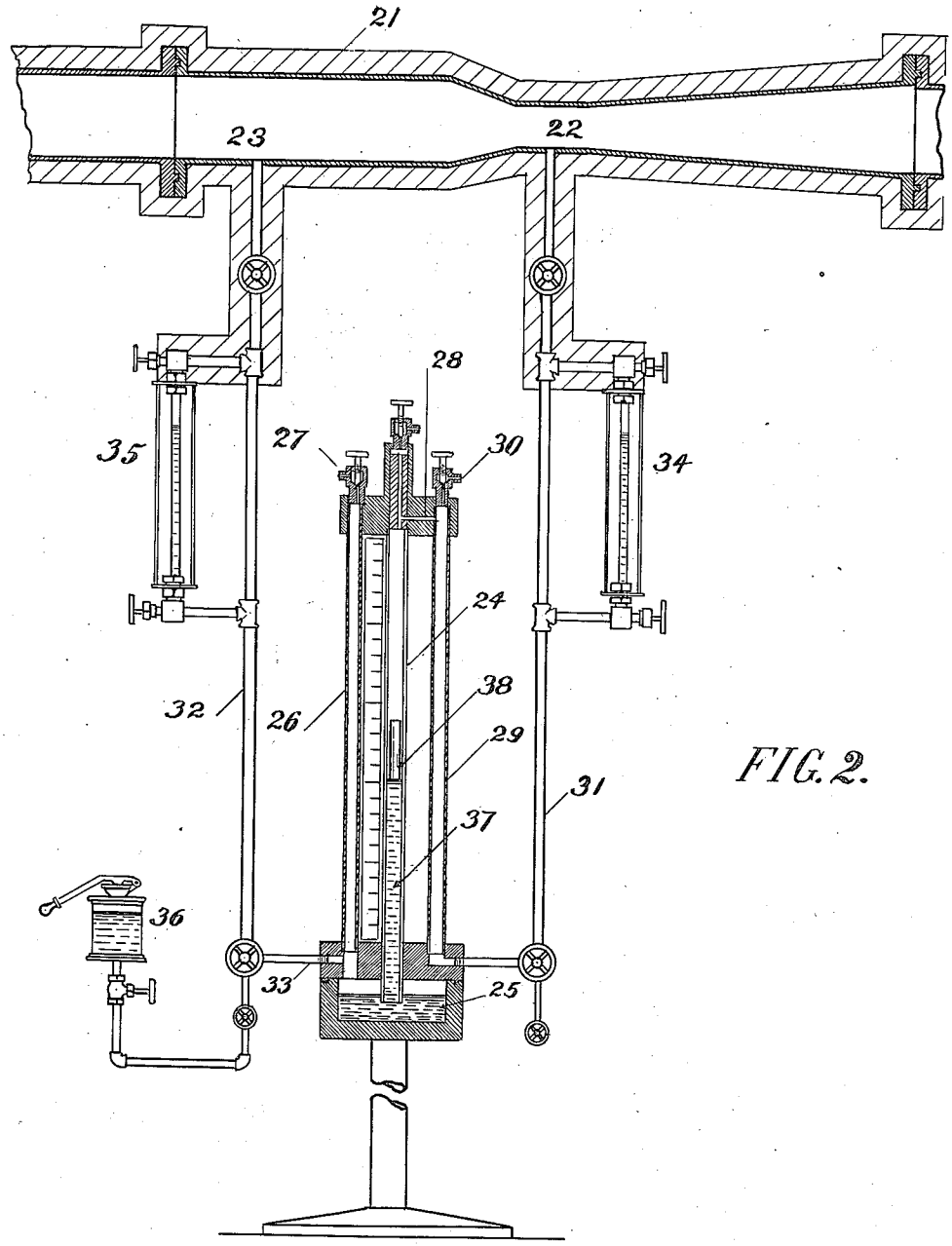


FIG. 2.

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Filed March 13, 1922 4 Sheets-Sheet 3

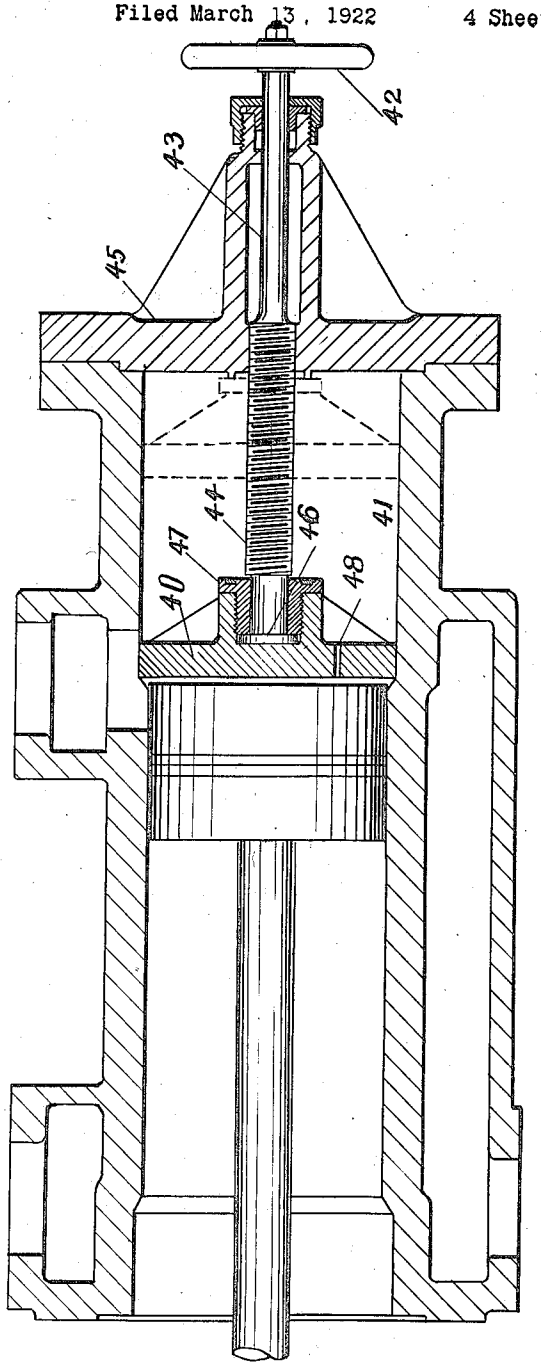


FIG. 3.

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PROCESS AND APPARATUS FOR MULTIPLE STAGE COMPRESSION FOR REFRIGERATION

Filed March 13, 1922 4 Sheets-Sheet 4

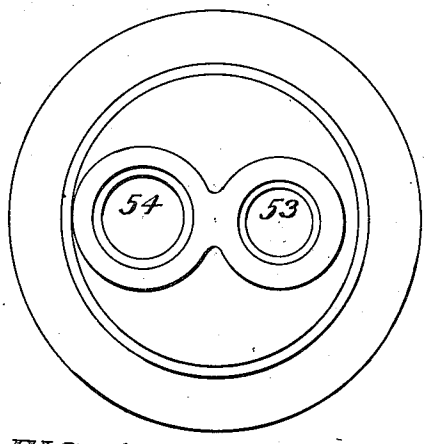


FIG. 4.

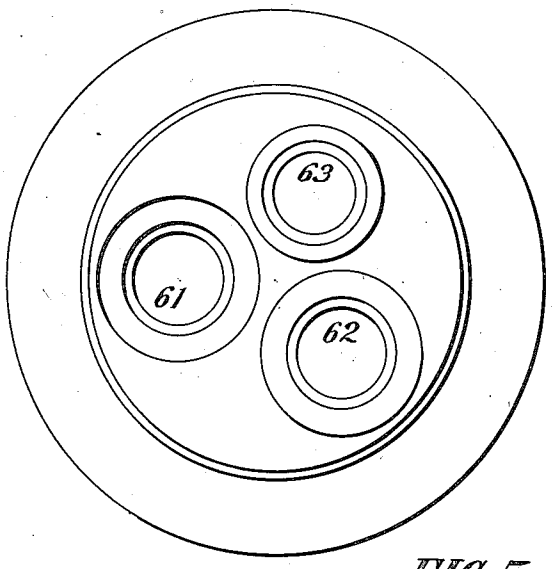


FIG. 5.

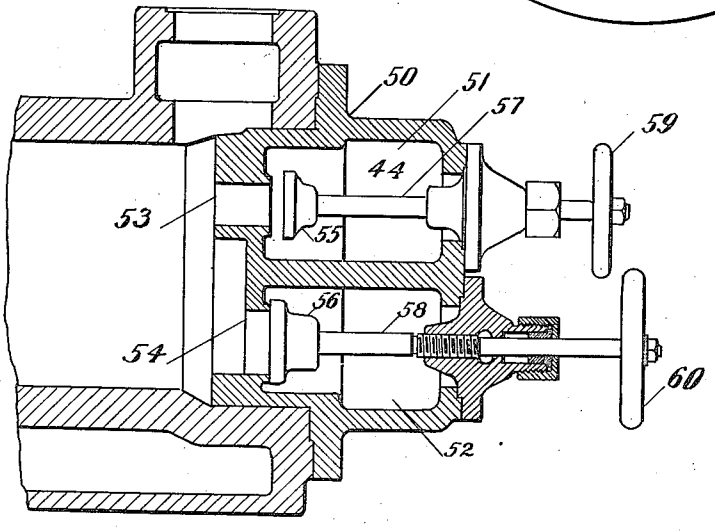


FIG. 6.

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Patented Oct. 23, 1923. 1,471,732

UNITED STATES PATENT OFFICE.

GEORGE A. HORNE, OF PLAINFIELD, NEW JERSEY.

PROCESS AND APPARATUS FOR MULTIPLE-STAGE COMPRESSION FOR REFRIGERATION.

Application filed March 13, 1922. Serial No. 543,450.

To all whom it may concern:

Be it known that I, GEORGE A. HORNE, a citizen of the United States, residing at Plainfield, county of Union, and State of New Jersey, have invented a certain new and useful Process and Apparatus for Multiple-Stage Compression for Refrigeration, of which the following is a specification.

This invention relates more especially to processes of refrigation in which the compression of a refrigerant, such for example, as ammonia vapor is compressed by successive stages from a relatively low pressure under which it is formed in the evaporator to a relatively high pressure under which it is condensed within the condenser.

The primary object of my invention is to provide an improved process and apparatus for compressing the refrigerant vapor whereby the refrigerating process may be carried out in a more effective manner and a greater degree of economy secured than has heretofore been possible in well known processes of refrigeration.

One of the objects of the present invention is to eliminate heat from the refrigerant between successive stages of compression by means of a cooling medium such as water, other than the said refrigerant.

My improved process furthermore contemplates a super-cooling of the condensed liquid refrigerant below its critical temperature of boiling in connection with its passage thru a Venturi tube whereby an accurate operating control of the refrigerating process is made possible by a direct and continuous metering of the liquid refrigerant.

Another object of invention contemplated by this process is to reduce the pressure and corresponding temperature of the liquid refrigerant from the pressure and temperature to which it is subjected in the condenser down to a pressure and temperature corresponding to the pressure and temperature of the gaseous refrigerant between successive stages of compression and the mixing of the gaseous refrigerant arising from this expansion with the partly compressed gaseous refrigerant between its successive stages of compression.

Another object is to provide suitable means for adapting a Venturi meter to be employed in a refrigerating system in which a volatile fluid is employed at or near its critical temperature of boiling.

Another object is to provide suitable means for reducing the pressure of the entire body of liquid refrigerant to the pressure existing between successive stages of compression.

Another object is to provide suitable means for regulating the relative capacities of high and low pressure compression cylinders for the purpose of properly proportioning the ratio of cylinder volumes.

Other and further objects will appear in the specification and be pointed out in the appended claims, reference being had to the accompanying drawings which exemplify my invention in a preferred embodiment.

In the drawings:—

Figure 1 is a diagrammatic plan view of compound compression refrigerating apparatus for carrying out my improved process of refrigeration;

Figure 2 is a diagrammatic side elevation of the Venturi meter on an enlarged scale, parts being broken away and parts shown in section;

Figure 3 is an axial section of the H. P. cylinder at its head end showing the preferred arrangement of clearance compartments;

Figure 4 is an end elevation of the H. P. cylinder showing a modified construction of the clearance compartments, the valves and valve housing caps being removed;

Figure 5 is an end elevation of the low pressure cylinder with the valve caps and valves removed;

Figure 6 is an axial section on an enlarged scale of the high pressure cylinder at its head end showing the modified arrangement of clearance compartments parts being shown in plan.

According to the present invention, multiple stage compression may be applied in two or more stages. In the embodiment of my invention shown on the drawings, suitable apparatus is illustrated for carrying out my invention in a refrigerating process including a compound compression of the gaseous refrigerant. Referring first to Figure 1 of the drawings, a gaseous refrigerant is drawn into the low pressure cylinder thru pipe 2 from the evaporator 3 having first passed thru a suction trap to remove any entrained liquid. In the low pressure cylinder the gaseous refrigerant is compressed and passed thru a pipe 4 to an intermediate gas cooler which is cooled by a heat exchange into water. In this intermediate gas

cooler a large portion of the heat of compression is removed. From the intermediate gas cooler the ammonia vapor or other refrigerant passes thru pipe 15 to high pressure cylinder 5 of the compound compressor. After being compressed the ammonia vapor passes thru pipe 6 and the oil trap to the condensers. The ammonia vapor or other refrigerant is condensed to a liquid in the usual manner and drains thru pipe 7 into the receiver. From the receiver the liquid ammonia or other liquid refrigerant passes thru a pipe 8 to a double pipe liquid cooler, the liquid refrigerant passing thru the inside pipe while the cooling water is being passed thru the annular space surrounding said inside pipe. Said refrigerant liquid is thus cooled several degrees below its critical temperature and then passes thru pipe 9 and a Venturi meter tube which is connected to a manometer arranged and connected in a peculiar way as hereinafter described. From the Venturi tube, the liquid refrigerant is conveyed by a pipe 10 to an intermediate liquid cooler into which it discharges thru an expansion valve 11. The liquid ammonia or other refrigerant is here reduced from the condenser pressure to the intermediate pressure and its temperature correspondingly lowered. As shown in Figure 1, the intermediate liquid cooler is connected by an equalizing pipe line 14 to the connection pipe 15 and thereby to the high pressure cylinder 5. All the liquid ammonia or other refrigerant is thus cooled in the intermediate liquid cooler to its critical temperature corresponding to the intermediate pressure. Said intermediate cooler is provided with a gauge glass to enable the height of the liquid therein to be seen at all times. Connected to the intermediate liquid cooler is a valve 16 from which a pipe 17 leads to the low pressure expansion valve 18 for controlling the admission to the evaporator. That portion of the liquid ammonia which is evaporated in the intermediate liquid cooler, due to the cooling of itself in the pressure reduction at expansion valve 11, passes thru equalizing line 14 and mixes with the main body of the partly compressed gaseous refrigerant as it passes thru pipe 15 to the high pressure cylinder 5. In my system the intermediate gas cooler provides a means of rejecting heat directly and I can show a direct thermal gain of from 7 to 12% depending upon conditions and a corresponding reduction in power required to operate the compressor. To the best of my knowledge and belief an intermediate gas cooler utilizing a cooling medium derived from a source outside of the system, has never before been used in refrigerating machinery. Furthermore, in the intermediate liquid cooler all the liquid is expanded directly into an open vessel and reduced therein to the critical temperature corresponding to the intermediate pressure, and a gas evaporated in so cooling the liquid is released at a comparatively high pressure and only requires compressing again in the H. P. cylinder.

In order to carry on a refrigerating process in the most effective and economical manner, it is essential to know how much liquid ammonia is being supplied at any given time, and to be able to regulate the flow of liquid refrigerant. As far as I am aware, no suitable means have even been employed in refrigerating systems for directly measuring the flow of highly volatile fluids which have very low boiling points as is the case with anhydrous ammonia. According to the present invention a Venturi meter tube may be used for this purpose and in connection with a manometer connected thereto in the manner to be presently described, may be readily made to indicate the flow of liquid ammonia in a system of this character. In order to utilize this means of measuring volatile fluids, it is necessary to pre-cool the liquid to be measured several degrees below its critical temperature or the temperature corresponding to the boiling point at the pressure at which it exists. This is for the reason that any liquid passing thru the Venturi tube is slightly reduced in pressure as it passes thru the throat of the Venturi tube. If the liquid be not super-cooled a certain amount of evaporation takes place as the liquid passes thru the throat and this interferes with the operation and also prevents a correct reading of the manometer. The cooling of the liquid ammonia or other refrigerant is accomplished in the double pipe liquid cooler as heretofore described.

As shown in Figure 2, the Venturi tube 21 is provided with a restricted throat 22, the pressure difference between the throat 22 and the unrestricted cross-section 23 of said Venturi tube providing means for measuring the flow of a liquid when the interior diameters of these portions of the tube are known. A manometer tube 24 has its lower end dipped into a mercury bath 25, the space above said bath being in open communication with a tube 26 having a valve controlled outlet 27 at its upper end. The upper end of the manometer tube 24 is in open communication thru a port 28 with the upper end of a tube 29 provided with a valve controlled outlet 30. A pipe 31 connects the lower end of tube 29 with the contracted throat 22 of the Venturi tube. A pipe 32 which is connected above to the unrestricted portion 23 of the Venturi tube, is provided with a branch 33 which communicates with the mercury bath chamber and lower end of tube 26. Connected to the pipes 31 and 32 are gauge glasses 34 and 35 for indicating the height of an interposed body of oil in the pipes 31 and 32, said body

of oil constituting a pressure transmitting medium between the highly volatile liquid and the mercury bath 25. An oil pump 36 may be connected up with this apparatus for maintaining equal weights of oil in the pipes 31 and 32 and the respective connections so as to enable the mercury in the manometer tube 24 to accurately indicate the difference in pressures between the points 22 and 23 of the Venturi tube. For this purpose, the height of the mercury column 37 is indicated by a float 38. The ammonia being lighter than the oil rests upon the top of the oil in each of said tubes 31 and 32 so that the differential pressure which would otherwise be exerted by the column of ammonia directly upon the mercury bath is thus exerted thru the interposed columns of oil. The oil is carried at the same height in each leg, so that the difference in specific gravity between the oil and the liquid being metered will not affect the reading. I have found by exhaustive tests that the measurement of anhydrous ammonia by the use of this method of super-cooling and the employment of oil pressure transmission to the manometer is extremely accurate. Whereas the flow of the liquid thru a meter tube by the use of pumps sometimes causes a pulsation, the metering of anhydrous ammonia in my apparatus is absolutely without pulsation.

As above mentioned the metering of the liquid ammonia is an essential feature of my system for two reasons.

First—to provide means of a controlled and uniform feeding of the evaporator or expansion coils with the liquid refrigerant.

In any compression system it is obvious that the volume of vapor handled for a given machine at constant speed is constant. For uniformity of operation it is desirable to maintain the volume of the vapor as uniform as possible.

This uniformity is expedited by maintaining a uniform liquid level in the evaporator which in turn is made possible by a controlled and practically uniform feeding of the evaporator.

Second—this means of metering the liquid ammonia is entirely novel in showing directly the actual capacity of the refrigerating system. With an accurate knowledge of specific heats and latent heats and specific volumes of refrigerants in common use, the weight of such refrigerant being handled in the system allows the direct calculation of the refrigerating output.

Another essential and novel feature of my system is an arrangement of clearance compartments used on the cylinders of my compressor. The preferred embodiment of this feature is shown in axial section in detail on Figure 3. Compressor cylinders are made somewhat larger than ordinarily would be required, thus providing for a clearance compartment in the cylinder itself. A secondary piston 40 is provided as shown which is adjustable to any point in the compartment 41. When the secondary piston is entirely closed, the same becomes equivalent to the head of the cylinder proper. When it becomes necessary to regulate the actual volumes delivered by either the high or low pressure cylinder the secondary pistons in the respective cylinders may be moved by the hand wheel 42 to any desired piston. Said wheel 42 is mounted on a stem 43 which is provided with an enlarged threaded portion 44 threaded into the head plate 45 of the cylinder. An enlargement 46 on the inner end of stem 43 interengages with a ring nut 47 which screws into the piston 40. It is thus evident that perfect adjustment of cylinder volumes and corresponding correct intermediate pressures are obtainable for any condition of suction and condenser pressures. A small hole 48 is drilled through the secondary piston to allow the gradual equalization of pressures on both sides of same. This allows an easier operation of the secondary piston and also provides against an undue pressure which might result from any accumulation of liquid refrigerant in the compartment. The ideal ratio of cylinder volumes is extremely important in giving most efficient results in a compound refrigerating system.

I have demonstrated practically that there is a definite intermediate pressure for given suction and condenser pressures where the highest efficiency of the compressor is obtained. There are two factors that have to be considered in determining the ideal intermediate pressure:

First dividing of the work done in the two stages so that the ratio of compression for each stage is the same.

Second the question of lowest intermediate pressure consistent with the first factor mentioned, which taken together with this factor will produce the highest over all efficiency in the entire process. This is for the reason that the lower the intermediate pressure the greater the gain in cooling the liquid in the intermediate liquid cooler or in other words the lower will be the temperature of the liquid delivered to the evaporator. The proper cylinder ratios will also give the lowest discharge temperature to the gas entering the condenser which reduces the work of the condenser and lessens the work in pumping condensing water.

I show another arrangement in Figures 4, 5 and 6 for accomplishing similar results. This arrangement can easily be adapted to any compressor of ordinary design and while it does not give the fineness of adjust-

ment shown on Figure 3, above described, it carries out the same idea and serves to illustrate another means of applying the broad principle of controlling the ratio of cylinder volumes. As shown in Figures 4, 5 and 6, a plurality of compartments are provided in each of the cylinder heads for the high and low pressure compressors. According to Figures 4 and 6, the high pressure cylinder has a cylinder head 50 provided with compartments 51 and 52 which may be placed in communication with the piston chamber thru valve openings 53 and 54 which may be closed by separately movable valves 55 and 56 carried by valve stems 57 and 58. Said stems 57 and 58 are provided with hand wheels 59 and 60 to permit these valves to be opened or closed at will. In the particular embodiment shown in Figure 5, the low pressure cylinder head is provided with valve openings 61, 62 and 63 corresponding to compartments which may be opened or closed by suitable valves (not shown). When the valves 55 and 56 are closed, the entire volume of the H. P. cylinder is discharged thru the regular compressor valves. When valve 55 is open, a volume of gas equivalent to the capacity of compartment 51 is admitted thru port 53 into compartment 51. In a similar manner valve 56 may be operated to admit gas to compartment 52, the displacement volumes of the high and low pressure cylinders being thus regulated.

$$\frac{V}{v}=0.82\sqrt{\frac{R}{r}}$$

where V equals the volumes of the low pressure cylinder, v equals the volumes of the high pressure cylinder and R equals discharge pressure in pounds per square inch, absolute, and r equals low pressure suction in pounds per square inch, absolute. By opening the clearance compartment on either cylinder a certain portion of the gaseous refrigerant is allowed to pass in and out of the pocket and thus reduce the actual volume of gas delivered by the cylinder. This operation does not perceptibly effect the efficiency of the cylinder but it decreases the capacity and with pockets of correct proportions, practically any desired ratio of $\frac{V}{v}$ may be obtained. The arrangement of compartments in Figure 6 provides for a reduction in volume of approximately 25% of the cylinder volume per revolution.

To illustrate the practical use of my clearance compartment in the every day use of refrigerating apparatus where pressure ratio change, I cite as follows:—

$$\frac{V}{v}=2.85$$

satisfying the above formula where

$$\frac{R}{r}=12$$

A test conducted with clearance compartment all closed under conditions of $\frac{R}{r}$ equals 8, the indicated horsepower per ton of refrigeration was 1.4. On the second test by opening of certain compartments on the low pressure cylinder, the above formula for $\frac{V}{v}$ was satisfied for the relation

$$\frac{R}{r}=8$$

and in this test with other conditions being similar, the indicated horsepower per ton of refrigeration was 1.12. In the range of ordinary refrigerating practice $\frac{R}{r}$ varies from 6 to as high as 13 and it is thus obvious that any compressor with given cylinder sizes cannot operate efficiently without means for regulating the displacement volumes of the high and low pressure cylinders.

In order to permit the double compression with its intermediate cooling of the gaseous refrigerant to be carried on without using the intermediate liquid cooler, a by pass 13 is provided with a normally closed valve 19 which may be opened when desired to cut out the intermediate liquid cooler. At the same time the expansion valve 11 and hand valve 16 which are normally open, are closed. A normally open valve 14 in the equalizing pipe extending between the intermediate liquid cooler and the pipe 15, is also closed when it is desired to cut out the intermediate liquid cooler.

I claim:—

1. The combination with a refrigerating system comprising an evaporator, means for compressing a refrigerant, and means for condensing said refrigerant. of a Venturi meter connected up in said system, and means interposed between said refrigerant-condensing means and said Venturi meter for supercooling all of the condensed refrigerant to a temperature below the critical temperature of boiling corresponding to the lowest pressure attained by said refrigerant in the Venturi meter whereby evaporation due to reduction in pressure in the Venturi tube is prevented.

2. The process of refrigeration consisting in partially compressing a refrigerant in its gaseous state, in cooling the partially compressed refrigerant, in finally compressing the cooled partially compressed refrigerant, in condensing the same, and in expanding the condensed refrigerant to the pressure substantially the same as that of the partially compressed refrigerant.

3. In a refrigerating system, the combination of an evaporator, means for compressing a refrigerant, means for condensing said refrigerant, a Venturi meter, and means connected to said Venturi meter for super-cooling said refrigerant to a temperature below the critical temperature of boiling corresponding to the lowest pressure attained by the refrigerant in the Venturi meter whereby evaporation due to reduction in pressure in the Venturi tube is prevented.

4. The process of refrigeration which consists in partially compressing a refrigerant in its gaseous state, in cooling the partially compressed refrigerant, in completing the compression of the partly compressed refrigerant, in condensing said refrigerant, in super-cooling all of the condensed refrigerant to a temperature below its boiling point corresponding to the lowest pressure attained while it is being metered, in metering the super-cooled condensed refrigerant, in reducing the temperature of the refrigerant to that corresponding to the partially compressed refrigerant, and in adding the gaseous refrigerant arising from reduction in pressure last mentioned, to the partially compressed refrigerant.

5. The combination with a refrigerating system including refrigerant-evaporating means, refrigerant compressing means, and refrigerant condensing means, of a meter, and means for super-cooling the condensed refrigerant to a temperature below its boiling point corresponding to the lowest pressure attained during its passage thru said meter, said super-cooling means and meter being connected up in series within the refrigerating system.

6. In a refrigerating system, an evaporator, a low pressure compressor connected to said evaporator, a high pressure compressor provided with connections extending from the low pressure compressor, a condenser connected to said high pressure compressor, and a liquid refrigerant expansion cooler in which the entire body of liquid refrigerant is expanded to a pressure corresponding to that in the connection between the low pressure and high pressure compressors, said liquid cooler being connected to said condenser, said liquid refrigerant expansion cooler having a liquid connection with said evaporator and a vapor connection with said connection extending between the low pressure and high pressure compressors.

7. A refrigerating system comprising an evaporator, means for compressing refrigerant from said evaporator, means for condensing said compressed refrigerant, and a Venturi tube interposed between said condensing means and said evaporator, a manometer connected to the large and small diameters of said Venturi tube for measuring variations of pressure therein, and means interposed between said condensing means and said Venturi tube for supercooling all of the condensed refrigerant to a sufficient degree to prevent evaporation during the variation of pressure in said Venturi tube.

8. In a refrigerating system, an evaporator, a low pressure compressor connected to said evaporator, an intermediate gas cooler connected to said low pressure compressor, a high pressure compressor connected to said intermediate gas cooler, a condenser connected to said high pressure compressor, a liquid refrigerant cooler in which the entire body of the liquid refrigerant is expanded to a pressure substantially corresponding to the pressure in said intermediate gas cooler, said liquid refrigerant cooler being connected to said condenser, and provided with a connection for vaporized refrigerant leading to the connection between said intermediate gas cooler and said high pressure compressor, and a connection extending from said liquid refrigerant cooler to said evaporator.

9. In a refrigerating system, the combination with an evaporator, of a low pressure compressor, a high pressure compressor, an interediate gas cooler provided with connections with said low pressure and high pressure compressors respectively, a condenser connected to said high pressure compressor, an intermediate liquid cooler interposed between said condenser and said evaporator, a connection for vapor leading from the intermediate liquid cooler to said connection from the intermediate gas cooler to said high pressure compressor, and an expansion valve in the connection between said condenser and said intermediate liquid cooler whereby all of the condensed refrigerant is reduced to the pressure and corresponding temperature of the partially compressed refrigerant passing thru said intermediate gas cooler.

10. The combination with a refrigerating system including an evaporator, means for compressing and condensing refrigerant from said evaporator, and a Venturi meter, of means for cooling all of the condensed refrigerant to a temperature substantially below the critical temperature of boiling corresponding to the lowest pressure attained in the Venturi meter, and means for conveying the refrigerant passing thru said Venturi meter to said evaporator.

11. A refrigerating system comprising an evaporator, means for compressing refrigerant from said evaporator, means for condensing said compressed refrigerant, a Venturi tube interposed between said condensing means and said evaporator, a manometer connected at opposite ends to the large and

small diameters respectively of said Venturi tube for measuring variations of pressure therein, and means interposed between said condensing means and said Venturi tube for supercooling all of the condensed refrigerant to a sufficient degree to prevent vaporization in the liquid refrigerant under the variation of pressure in said Venturi tube, said manometer being provided with connections extending between said Venturi tube and opposite ends of said manometer, said connections containing non-volatile fluids as pressure-transmitting mediums.

12. In a refrigerating system, the combination with an evaporator, of low pressure and high pressure compressors connected in series with said evaporator, a condenser connected to said high pressure compressor, means for connecting said condenser to said evaporator, and means for varying the displacement volume of each of said compressors whereby the work of compression may be equally divided between said compressors.

13. In a refrigerating system, an evaporator, a low pressure compressor connected thereto, an intermediate gas cooler, a connection leading from said compressor to said gas cooler, a high pressure compressor, a connection leading from said gas cooler to said high pressure compressor, and means for connecting said high pressure compressor to said evaporator including an intermediate liquid cooler, said intermediate liquid cooler being provided with an expansion valve for reducing the pressure of the compressed refrigerant and a connection extending from said liquid cooler to the connection between said gas cooler and high pressure compressor for vapor derived from said refrigerant passing said expansion valve.

14. In a refrigerating system, the combination with an evaporator, of a low pressure compressor cylinder connected to said evaporator, said compressor cylinder being provided with an adjustable wall for varying the displacement volume thereof, a high pressure compressor cylinder provided with an adjustable wall for varying the displacement volume thereof and a condenser connected to said high pressure cylinder and provided with connections leading to said evaporator.

15. In a refrigerating system, the combination with an evaporator, of low pressure and high pressure compressors connected in series with said evaporator, means connected to said high pressure compressor for condensing a refrigerant, means for varying the displacement volume of each of said compressors whereby the work of compression may be equally divided between said compressors, means for connecting said condensing means to said evaporator, a Venturi meter connected up in said system between said condensing means and said evaporator, and means interposed between said condensing means and said Venturi meter for supercooling all of the condensed refrigerant to a temperature below the critical temperature of boiling corresponding to the lowest pressure attained in the Venturi meter whereby evaporation due to reduction in pressure in the Venturi tube is prevented.

16. In a refrigerating system, the combination with an evaporator, of a low pressure compressor cylinder, connected to said evaporator, said compressor cylinder being provided with an adjustable wall for varying the displacement volume thereof, a high pressure compressor cylinder provided with an adjustable wall for varying the displacement volume thereof, a condenser connected to said high pressure cylinder and provided with connections leading to said evaporator, a Venturi meter connected up in said connections between said condenser and evaporator, and means interposed between said condenser and said Venturi meter for supercooling all of the condensed refrigerant to a temperature below the critical temperature of boiling corresponding to the lowest pressure attained in the Venturi meter whereby evaporation due to reduction in pressure in the Venturi tube is prevented.

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