June 6, 1933. J. C. GOOSMANN 1,912,443

METHOD AND MEANS FOR PRODUCING SOLIDIFIED CARBON DIOXIDE

Filed Aug. 11, 1928 2 Sheets-Sheet 1

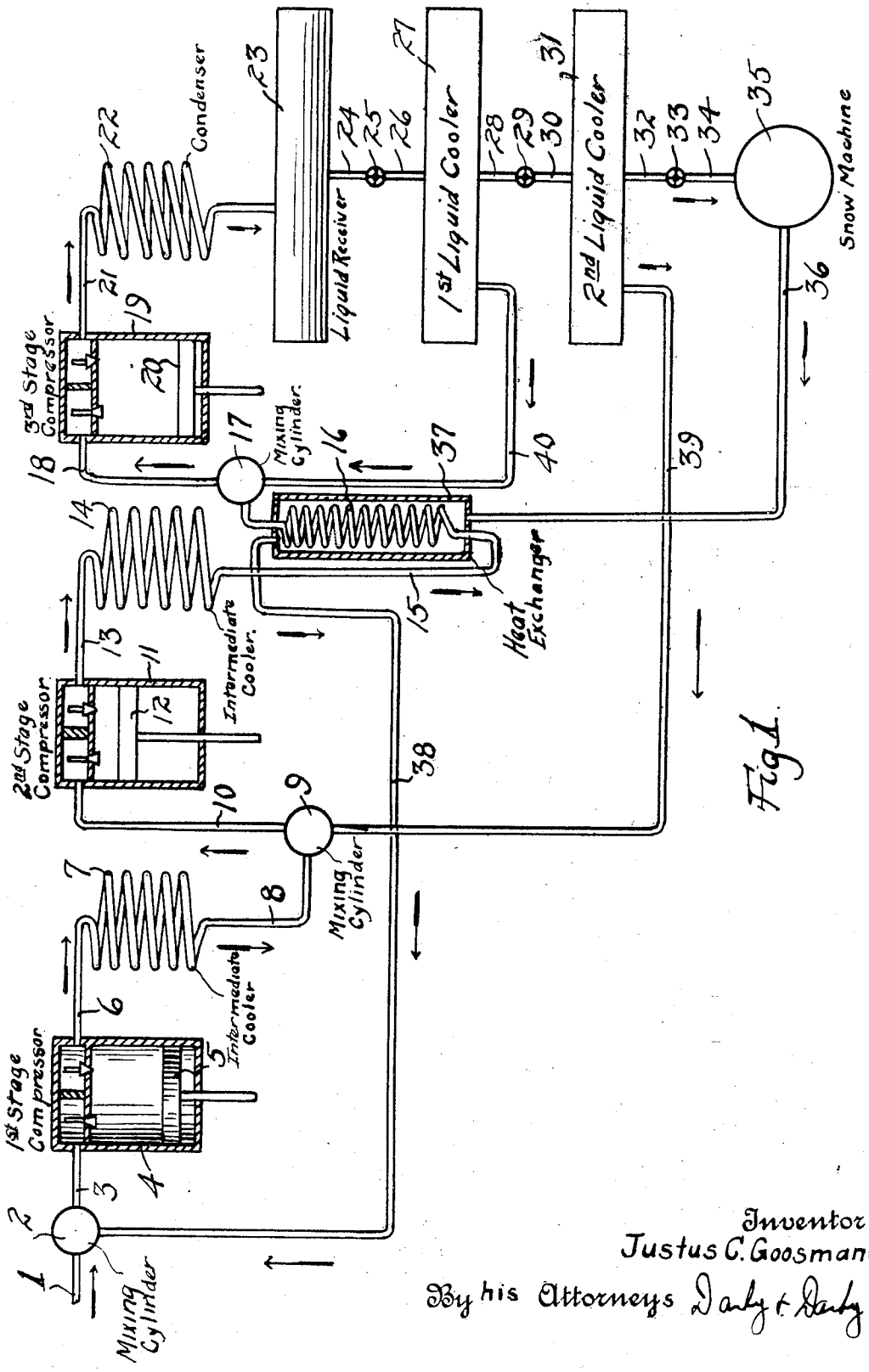


Fig. 1.

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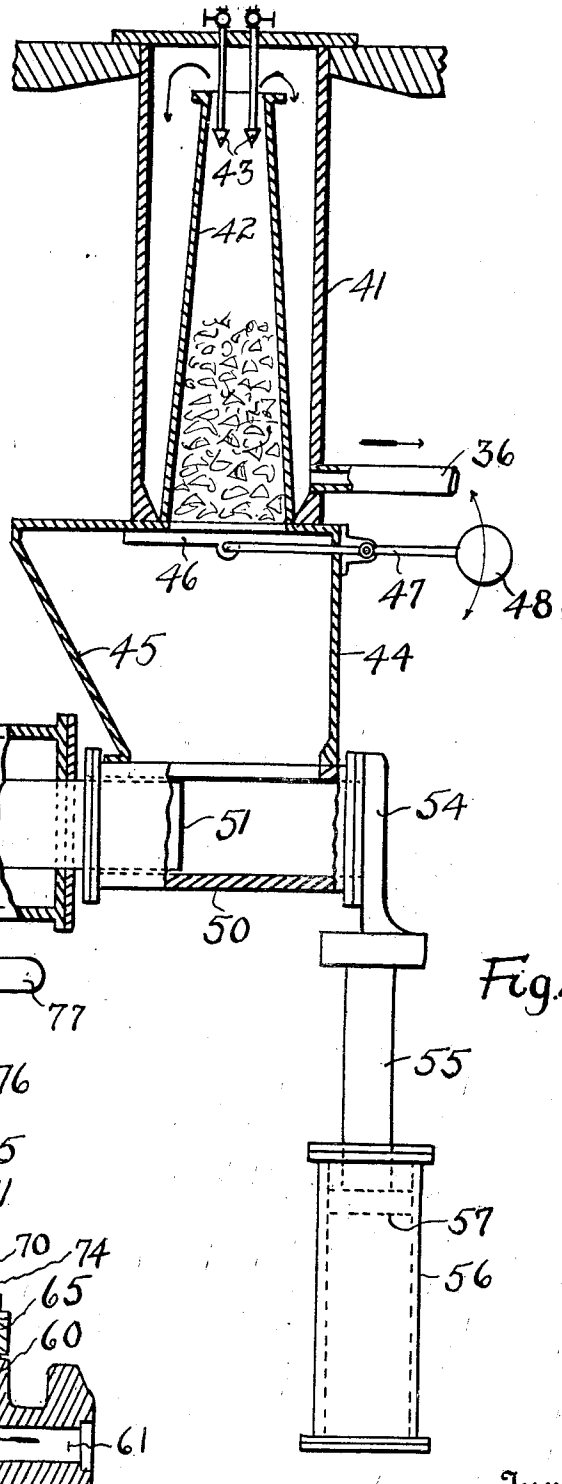


Fig. 2.

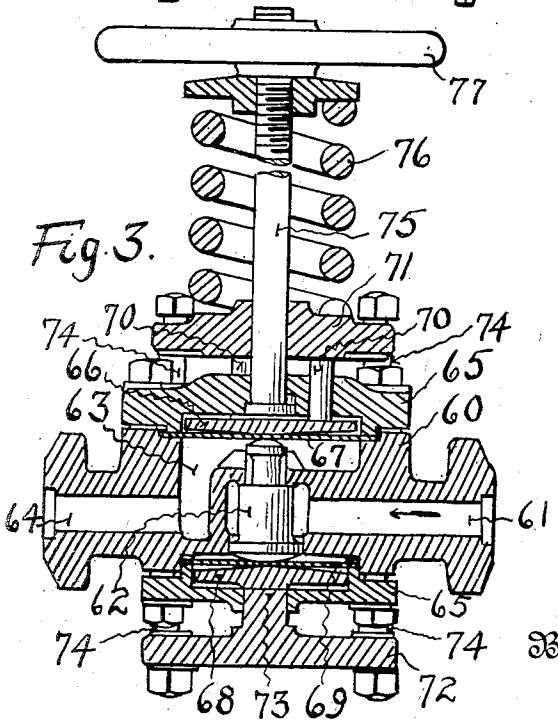


Fig. 3.

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1,912,443

UNITED STATES PATENT OFFICE

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METHOD AND MEANS FOR PRODUCING SOLIDIFIED CARBON DIOXIDE

Application filed August 11, 1928. Serial No. 298,992.

This invention relates to a method and apparatus for producing solid carbon dioxide commonly known as carbon dioxide snow.

One of the objects of this invention is to provide a method and apparatus for use in producing carbon dioxide snow which is simple, economical of manufacture, installation, operation and maintenance and highly efficient in use.

Another object of this invention is the provision of an apparatus for the production of solid carbon dioxide in which gaseous carbon dioxide is converted to a liquid form and subjected to several stages of cooling before its solidification.

A still further object of this invention involves an apparatus of the above type in which the liquid is sub-cooled in several stages by passing it from one container to another through pressure ratio valves.

A still further object of this invention contemplates the formation of liquid carbon dioxide from gaseous carbon dioxide in several stages of compression and cooling the gas between each stage of compression by subjecting it to a counter flow of colder carbon dioxide gas returning from liquid coolers.

Another object of this invention contemplates in the final step of forming carbon dioxide snow by delivering the sub-cooled liquid from a liquid cooler to a snow forming machine.

Further objects of this invention will appear more fully hereinafter.

This invention consists substantially in the combination, construction, arrangement and relative location of parts as well as the procedure employed in connection therewith, all as will be more fully set forth hereinafter, as shown by the accompanying drawings and finally pointed out in the appended claims.

Referring to the drawings in which the same reference numerals will be used throughout the several views to indicate the same or similar parts,

Figure 1 is a diagrammatic view illustrating the apparatus and the association thereof employed in accordance with this invention and by means of which the process thereof is utilized;

Fig. 2 is a vertical cross sectional view of a snow machine in which the carbon dioxide snow is formed in combination with means for compressing the snow into blocks.

Fig. 3 is a vertical cross sectional view of the pressure ratio valve employed in the invention.

This invention pertains to the rational production of solidified carbon dioxide, or carbon dioxide snow at low pressure and the sub-cooling of the liquid CO_2 before solidification by partial evaporation in successive steps, as well as by the employment of heat exchangers for the cooling of the liquid by the cold CO_2 gas returning to the compression apparatus from the next lower pressure liquid cooler in counter current flow.

A short recapitulation of the properties and characteristics of carbon dioxide will no doubt be of help to appreciate the particular "modus vivendi" employed in this method.

The origin of the CO_2 gas does not matter. It may be produced by combustion, from lime kilns during the calcination of lime stone, from alcoholic fermentation, by chemical decomposition or any other source from which carbon dioxide gas may be obtained.

After this gas has been purified to make it suitable for the purpose of solidification and its application, it must be converted from the gaseous in to the liquid state in order to take up the latent heat of a liquid, which afterwards is set free in the evaporation of the greater part of the liquid. When evaporating in suitable containers, with the influx of heat from the outside prevented as much as possible, a temperature is reached which is known as the triple point of carbon dioxide, at which a part of the liquid changes rapidly from the liquid into the solid state.

At this point, or slightly below it, the liquid may be changed into a solid, resembling opaque ice, when the receptacle in which this conversion takes place is maintained at a pressure slightly lower than that of the triple point. But when it is desired to pro-

duce more or less loose CO_2 crystals, resembling snow, the liquid is sprayed into a receptacle of larger volume at a further reduction in pressure, until the container is filled with the same, from which it may be removed and compressed into a hard mass of convenient size and weight for use as a commercial refrigerant, or for any other purpose for which it may be fit and useful.

It is well known that carbon dioxide gas liquefies readily by the joint application of pressure and the cooling action of water.

The pressure is needed to raise the temperature of the gas considerably above that of water of ordinary temperature. At the same time it reduces the gaseous volume to that of a liquid. The temperature of the liquid depends upon the initial temperature of the cooling water as well as upon the efficiency of the condensing or liquefying apparatus.

The average summer temperature of the available water in the United States is below 75° F. which will liquefy CO_2 gas and change it into a liquid of about 85°.

However, there are many localities in the United States and elsewhere where the temperature of the water in summer registers over 85° F. In this case the temperature of the CO_2 leaving the condenser will be 90° and over. At this temperature carbon dioxide cannot be liquefied, in fact the possibility of liquefying it stops at 88° which is known as its critical temperature, hence it leaves the condenser in the form of a compressed and cooled gas, a point which will become of interest later.

In order to appreciate the losses by evaporation which occur when carbon dioxide is taken at condensing temperature and converted into ice or snow at the triple point, it must be borne in mind that the temperature of the medium has to be reduced from that of condensation or liquefaction to the triple point or the temperature of solidification; the former may ordinarily be taken at plus 85°, while the latter is at minus 70° F. The corresponding pressures in practice will then be over 1100 pound gauge, for condensation and 60 pound gauge for solidification. Hence, it is necessary to reduce the pressure approximately 1040 pounds before solidification can possibly take place.

Simultaneously with the reduction in pressure the temperature of the medium is reduced in a strict and definitely defined relation.

For example when the pressure is decreased from 1100 pounds and 85° to that of the atmosphere its temperature will be lowered to minus 110° F. which is 40° lower than the temperature at the triple point or solidification. This peculiar behavior of carbon dioxide in which it differs from other gases explains the fact that it cannot be discharged into a receptacle in the form of a liquid at atmospheric pressure, because it promptly solidifies when the pressure is reduced beyond 60 pound gauge.

But liquid CO_2 can be discharged into a receptacle in which the pressure is maintained constant at a higher pressure than 60 pounds and the temperature which corresponds with it.

Likewise, it is of no consequence whether the CO_2 is obtained from the condenser at a temperature below or above the critical i. e. 88°, so long as the confining pressure corresponds with it.

It has already been pointed out that a reduction in pressure is inevitably accompanied by a definite and corresponding reduction in the temperature of the CO_2. This temperature reduction does not necessarily come from the outside by cooling through a metallic wall, it occurs promptly through its own release or rather by a partial evaporation of a definite percentage of the total weight of the liquid. For instance, if compressed and cooled CO_2 of 90° which is above the critical temperature, and a pressure of 1230 pounds is reduced and released into another receptacle in which a pressure of 350 pounds is maintained, it will immediately liquefy and drop to a temperature of 10°, and if no cooling from the outside occurs, it will sacrifice slightly more than 46% of its weight to attain this reduced temperature.

The CO_2 gas which has thus been generated or released from the remaining 54% of the liquid is still at a pressure of 350 pounds and if returned at this pressure to the corresponding stage of a three stage compressor, a considerable economy will be effected in recompressing and reliquefying it.

On the other hand and assuming that the compressed and cooled CO_2 left the condenser at 90° and was then sub-cooled to 80° in a second condenser or cooler, it will lose less than 40% of its weight in its own temperature adjustment to +10° thus showing that a second condenser or liquid sub-cooler is of economical importance in this process.

However, it is necessary to still further reduce the temperature of the liquid CO_2 before the temperature of solidification is even approached. In order to accomplish this further reduction in pressure and temperature a second liquid cooler may be employed in which the pressure may be reduced to approximately 75 to 100 pound gauge, corresponding with a temperature range of approximately between minus 64° and minus 46° F. which requires a final reduction of only a few atmospheres to reach the region of solidification, which can easily be accomplished in a special solidifying apparatus. This pressure and temperature

reduction again calls for a further loss of approximately 23% out of the previously obtained balance varying between 60 and 54%, depending upon the starting temperature of the CO_2. Hence, the original quantity of the liquid has now been reduced to between 31 and 37% of the original liquid quantity.

To further enhance the economy of the method a heat exchanger may be employed between the second and third stages of compression, utilizing the low temperature of the released vapor at approximately minus 100° to precool the gas leaving the second intercooler and before it enters the third and final compression stage.

The final temperature reduction below the temperature of solidification takes place in a special apparatus in which the CO_2 snow is produced, collected and weighed.

Because of the fact that the losses in liquid weight are great due to the radical drop in the liquid temperature from condensation to solidification the interlocation of means for the economical improvement of the method are of greatest importance of which mixing chambers, inter-coolers and heat exchangers form a prominent part.

Moreover, the return of the spent vapor into the corresponding compression stage of the compression machinery is the means for a considerable economy in the required power for recompression and liquefaction since the work of compression from 100 to 350 pounds is not greater than an equivalent ratio of compression from 350 to 1225 pounds.

Considering that solidification and snow formation takes place at a pressure slightly less than 60 pounds and a temperature lower than minus 70°, it will be found that 10% of the remaining CO_2 evaporates at this stage, leaving a balance of the original weight of 37.5 to 42%. This balance has now been solidified at a pressure of nearly 60 pounds, which must be removed to allow the snow to be handled and compressed at the pressure of the atmosphere.

However, the specific heat of the solidified CO_2 is lower than that of the liquid. This heat has been stated more recently by physicists to be 0.284 hence the loss due to sublimation at a temperature and pressure drop to atmospheric, that is minus 108° entails a further loss of 10%, so that when the solidified CO_2 finally reaches the atmosphere it represents in weight not much over 33% of the original, illustrating the fact that of 3 pounds of liquid CO_2 only about 1 pound has been changed into a solid of snow. It also follows that practically 2 pounds out of 3, or 66% must be recompressed, liquefied and solidified.

Moreover, the total power to effect this change in the process at present employed is roughly 150 h. p. per 1000 pounds per hour of solidified CO_2, which can be reduced to below 100 h. p. in the arrangement contemplated, effecting an operating economy in power alone of approximately 33% and over.

Attention may also be directed at this point to the fact that the weight of liquid CO_2 at constant volume increases materially at the lowering of its temperature. For illustration; liquid carbon dioxide of 86° has a weight per cubic foot of slightly more than 37 pounds. At −5° this weight has increased to nearly 63 pounds. It increases gradually until at −40° it weighs 70 pounds and at −70, its temperature of solidification, 74 pounds.

This material increase in weight per constant volume is assumed by some investigators to be due to the alleged compressibility of liquid CO_2, which seems erroneous. It is evident in the light of numerous investigations by acknowledged scientists that the increase in weight is simply a function of lower temperature.

Reference will now be made to the drawings in which there has been illustrated one form of apparatus employing the principles of this invention.

A pipe 1 leads from any suitable source of carbon dioxide gas to a cylinder or chamber 2 which is called a mixing cylinder. A pipe 3 extends from the mixing cylinder to the first stage compressor having a cylinder 4 and piston 5. This compressor is a well known type and has two opposed valves as has been indicated diagrammatically so that upon the suction stroke of the piston (downward in the figure) the gas is drawn into the cylinder through the left hand valve while the right hand valve is seated. On the compression stroke of the piston (upwardly in the figure) the left hand valve is seated and the right hand valve opens when the gas within the cylinder reaches predetermined pressure for which the valve is set to operate. A pipe 6 extends from the right hand valve chamber to the pipe coil 7 called the intermediate cooler. The pipe coil 7 is intended to be cooled by running water and may be any suitable and well known water cooler in which the gas will flow through the cooling coil and the water surrounding it. The other end of the cooling coil 7 is connected to another mixing cylinder 9 by means of the pipe 8. A pipe 10 connects the cylinder 9 with the cylinder 11 of the second stage compressor in which piston 12 operates. This compressor is the same as the previous one with the exception that the right hand valve is set to operate at a higher pressure. A pipe 13 extends from valve chamber to a second pipe coil 14 also termed an intermediate cooler.

As before the pipe coil 14 is water cooled.

The other end of the pipe coil 14 is connected by means of pipe 15 to another pipe coil 16 within a casing 37. The coil 16 and casing 37 have been termed a heat exchanger. The other end of the pipe coil 16 is connected to another mixing cylinder 17 which is in turn connected through a pipe 18 to the third stage compressor having the cylinder 19 and piston 20. This compressor is similar to the others with the exception that the right hand delivery valve is set at a still higher pressure than either of the other two. The right hand delivery valve chamber is connected through pipe 21 to another pipe coil 22 which is termed a condenser. The coils of this pipe are cooled by water. The other end of the pipe coil 22 is connected to a closed cylinder or chamber 23 termed a liquid receiver. A pipe 24 connects the cylinder 23 with a pressure ratio valve 25 which in turn is connected by pipe 26 to another cylinder 27 termed the first liquid cooler. Cylinder 27 is connected by pipes 28 and 30 through a second pressure ratio valve 29 to another cylinder 31 termed the second liquid cooler. The cylinder 31 is connected through pipe 32, pressure ratio valve 33 and pipe 34 to the snow machine 35 which will be described in more detail later. The snow machine 35 is connected by means of pipe 36 to the casing 37 of the heat exchanger. Another pipe 38 extends from casing 37 to mixing chamber 2. A pipe 39 connects cylinder 31 with mixing cylinder 9 and a pipe 40 connects cylinder 27 with mixing cylinder 17. This completes the general assemblage of apparatus.

The snow machine will now be described in detail. The device comprises a closed cylinder 41 within which is supported a conical chamber 42 open at both ends. The cylinder or casing 41 and conical member 42 are united at the bottom to form a tight joint. Projecting through the top of cylinder 41 and a short distance into the conical chamber or member 42, are two pipes formed with nozzles 43 as indicated diagrammatically. These pipes are connected to pipe 34, Fig. 1. The pipe 36 leading into chamber 41 is the same pipe 36 of Fig. 1. Chamber 41 is attached to a casing 44 provided with a sloping side 45. As shown the conical member 42 connects chamber 44 through an opening which is closed by a door or gate 46. The gate 46 is mounted on the pivoted lever 47 which is counterbalanced by the weight 48. As the snow forms on the inside of conical member 42 and rests on the gate 46 it tends to open the gate against the action of weight 48. This weight may be adjusted on arm 47 so as to permit gate 46 to open when any predetermined weight of snow has collected thereon. By reason of the expanding shape of member 42 the snow easily falls into chamber 44 when the gate opens. In view of the fact that the snow as it falls from gate 46 will tend to pile up at the side of chamber 44, the left hand wall thereof is inclined as indicated at 45. Attached to the chamber 44 at the bottom is a cylinder or casing 50 which is open at the top to coincide with the open end of chamber 44. The chamber 50 is of any suitable shape depending upon the shape of the finished block desired. A plunger 51 of the same shape as chamber 50 is adapted to slide therein towards the right under the influence of piston 53 in cylinder 52. The right hand end of chamber 50 is open and arranged to be closed by means of a gate 50 operated by the piston rod 55, piston 57 and cylinder 56.

The pressure ratio valve will now be described.

The valve is shown comprising a member 60 provided with a longitudinal passage 61 opening into an annular chamber surrounding the valve member 62. This valve member as shown comprises two cylindrical parts of different diameters, the upper part being of the smaller diameter and extending through a hole of larger diameter formed in the member 60. This hole is however of smaller diameter than the diameter of the larger portion of valve member 62 so that it is closed by the larger portion seating at the edge thereof. This hole when open connects the annular chamber with another chamber 63, which, in turn, is in communication with passage 64. Secured to the top and bottom of the member 60 are the plates 65 which are recessed to house the disks 66 and 68. The disks 66 and 68 are enclosed within their recesses by means of flexible diaphragms 67 and 69 respectively. Pins 70 extend through holes in the plate 65 and contact at one end with the disk 66 and at the other with the plate 71. A similar plate 72 lies below plate 65 and has a central projection 73 extending through an opening in plate 65 so as to contact with disk 68. The plates 71 and 72 are rigidly secured together in spaced relation at the corners by means of rods 74. A rod 75 having an enlarged end which lies within a recess within plate 65 extends through both plates 65 and 71. The rod 75 is provided with threads at the upper end on which a hand wheel 77 is rotatably supported. A spring 76 lying between the hand wheel and the plate 71 encircles the rod 75.

The valve disclosed in Fig. 3 and described above does not by itself form the subject matter of this invention since it is a well known form of valve of this general type. Other valves which produce this result may equally be used, as for instance, one well known pressure ratio valve which employs but a single diaphragm in its structure. Any valve or float by means of which in use the pressure in cylinder 31 cannot fall below a predetermined value is suitable. The idea

is to provide a valve or means which will prevent a depletion of the liquid in cylinder 31 and an abnormal reduction in pressure therein.

The operation of the apparatus in accordance with the principles of this invention will now be described.

Carbon dioxide gas from any suitable source is supplied at 4 or 5 pounds gauge pressure and at a temperature of 80° F. through pipe 1 to mixing cylinder 2. In this cylinder the gas at 80° F. is mixed with gas at minus 50° F. flowing through pipe 38 from the heat exchanger casing 37. As a result the warm gas being supplied from the source is cooled. The gas mixture is then drawn through pipe 3 on the suction stroke of piston 5 into cylinder 4. The delivery valve of the compressor which is the right hand valve is set to permit the escape of the gas from cylinder 4 when it has reached the pressure in the first inter-cooler of approximately 150 pounds gauge. Thus, on the compression stroke of piston 5, the gas is delivered to pipe 6 at 150 pounds pressure and at a temperature of about 80° F. The gas flows through coil 7 and is cooled so as to be delivered to mixing chamber 9 at about 75° F. Here the gas mingles with gas supplied from cylinder 31 through pipe 39 at a temperature of minus approximately 30° F.

The cool gas mixture flows from cylinder 9 through pipe 10 to cylinder 11 of the compressor on the suction stroke of piston 12. The right hand delivery valve of this compressor delivers gas from the compressor at approximately 400 to 450 pounds gauge, therefore on the compression stroke of piston 12, the gas is delivered through pipe 13 to the coil 14 at the above pressure. The gas flows through coil 14 and is cooled somewhat and then flows through pipe 15 to coil 16 of the heat exchanger from which it flows to cylinder 17 at a temperature near the freezing point of water and mingles in the cylinder with the gas delivered from cylinder 27 through pipe 40 which is at approximately 20° F. The gas mixture is then delivered from cylinder 17 through pipe 18 to cylinder 19 of the third stage compressor on the suction stroke of piston 20. The right hand delivery valve of this compressor delivers the gas therefrom at a pressure of 1000 pounds gauge. On the compression stroke of piston 20 the gas is delivered through pipe 21 at a pressure of 1000 pounds at a temperature of 80° F. to the coil 22 of the condenser. The gas and liquid delivered from the condenser then flows through the liquid receiver 23. The liquid is then permitted to flow from cylinder 23 through the valve 25 into the first liquid cooler. The valve 25 is the valve disclosed in Fig. 3 and is a pressure ratio operated valve by means of which the pressure, which the liquid is under in cylinder 23 is reduced from 1000 pounds gauge in passing through the valve 25 to approximately 400 pounds gauge when it reaches cylinder 27. As a result of this pressure reduction a portion of the liquid is formed into a gas and the remaining liquid is cooled to about 20° F. it having been 80° F. when in cylinder 23. The gas thus collected in cylinder 27 is fed back as explained before through pipe 40 to mixing cylinder 17.

The liquid is then passed from the pressure of 400 pounds gauge of cylinder 27 through a second pressure ratio valve 29 to cylinder 31 where it reaches a pressure of 100 to 150 pounds gauge and a temperature of approximately minus 35° F. As a result of this second reduction in pressure the remaining liquid is further cooled and more gas is formed which is delivered through pipe 39 at minus 35° F. to mixing cylinder 9.

It may be pointed out here that valve 33 is a pressure control valve for controlling the flow of liquid to the snow machine 35. When the liquid is delivered in cylinder 31 at a pressure of 150 pounds gauge at a temperature of minus 35° F. to the snow machine, it undergoes a considerable reduction in pressure since it is discharged through the nozzle 43 into the chamber of the snow machine which is at approximately atmospheric pressure. In the formation of snow from rapidly expanding liquid, a corresponding amount of gas is formed which flows out of pipe 36 at a temperature of minus 100° F. to the heat exchanger casing 37. This gas is somewhat warmed as it flows over the coils 18 and thus reaches the temperature of about minus 50° F. which is the gas delivered to mixing cylinder 2.

This represents the general cycle of operations and it is pointed out that the temperatures and pressures given are for the purpose of illustration only since it is apparent that other temperatures and pressures will produce useful results. The pressure ratio valve besides forming the function of permitting the reduction in pressure also operates under a condition of balanced pressures. Thus the liquid is delivered to the valve through passage 61 and operates on flexible diaphragm 69 and the larger end of valve 62 causing the valve to open.

The liquid then flows into chamber 63 and passage 64 and operates upon diaphragm 67. Likewise spring 76 through pins 70 and projection 73 exert a pressure on the diaphragms through the agency of disks 66 and 68. As a result should the pressure drop unduly in chamber 63, the valve member 62 will be closed through the agency of spring 76 so that the pressure of the liquid in cylinder 31 never falls below a predetermined value. The area of dia-

phragm 69 exposed to the liquid pressure is less than the area of diaphragm 67 exposed to liquid pressure. The area proportion of these diaphragms is the same as the proportion between the pressure of liquid supplied to passage 61 and the pressure of liquid delivered to passage 64. The tension on spring 76 is adjusted so that under normal operating conditions, valve member 62 is depressed so that the liquid may flow from passage 61 to passage 64. If the liquid pressure in either passage varies beyond the predetermined amount, depending upon the tension on spring 76 the spring acts to close the valve. It may be pointed out here that the plates 71 and 72 firmly united by rods 74 form a rigid cage which moves as a unit under the action of spring 76.

The transformation of the liquid into snow is dependent upon the pressure and the corresponding temperature. Each of these of course is dependent upon the other. The temperature of crystallization is slightly below minus 70° F. and the pressure of crystallization is less than 60 pounds gauge pressure.

In systems heretofore employed the liquid CO_2 has been supplied to the snow machine from the liquid receiver of the condenser at the temperature which it has attained in the condenser which is usually about plus 85° F. Thus, in order to convert that liquid or any part of it into snow it is necessary to reduce the temperature below minus 70°. This means that only a small part of the liquid is actually converted into snow because it is impossible to reduce in the snow machine the temperature of all the liquid to the degree necessary to effect crystallization.

The method of my invention greatly enhances the efficiency of systems of this nature by greatly increasing the amount of snow obtained from a given amount of liquid. For example, in the old systems where the temperature of the liquid in the liquid receiver was approximately plus 85° F. approximately 30% of the liquid is crystallized, that is three pounds of CO_2 will give one pound of snow on the first expansion. In accordance with my invention by the employment of liquid coolers, at least two-thirds of the liquid becomes crystallized that is, out of every three pounds of liquid CO_2, delivered to the snow machine, two pounds of snow are obtained. This advantageous result is obtained for the following reasons: With the liquid going from the receiver of the condenser at about 80° F. to the last liquid cooler where the pressure corresponds to about 150 pounds gauge, and the temperature minus 35° F. to the snow machine, the amount of temperature drop necessary to secure crystallization is much smaller. Therefore, in order to bring the liquid to the crystallization temperature, it is only necessary to reduce the same approximately 35° in my system as compared with 155° in the system of the prior art.

It has already been pointed out that the most important advantage provided in my method will be found in its greatly increased economies, particularly with reference to the saving of power.

Thus it will be seen that I have provided an exceedingly simple and highly efficient method of effecting maximum crystallization of liquid carbon dioxide in a snow machine at controlling pressures and temperatures in the manner disclosed and that I do this in such a way as to eliminate waste and maintain the efficiency of the system, utilizing all beneficial advantages obtained in the prior treatment of gas or liquid in the system.

I am, of course, aware that many changes in the details of construction and relative arrangement of parts, steps and arrangement of steps and temperature and pressure conditions will occur to those skilled in this art and I do not therefore desire to be strictly limited to the disclosure as given for purposes of illustration but rather to the principles and scope of this invention as it is defined in the appended claims.

What I desire to secure by United States Letters Patent is:

1. The method of producing carbon dioxide snow which comprises supplying liquid carbon dioxide under pressure to a receptacle, maintaining the pressure of the liquid at a value where the corresponding temperature is at or near the order of 35° above the temperature of crystallization and finally discharging the liquid from said receptacle to a snow machine where it is solidified.

2. Apparatus of the class described, the combination with means for compressing carbon dioxide gas and liquefying it, a container for storing the liquid under a pressure of a value sufficient to retain the temperature of the liquid at about 35° above the temperature of crystallization, means for returning any gas that collects in said container to said compressing and liquefying means and means for discharging the liquid from said container to a snow machine.

3. In an apparatus of the type described, the combination of a plurality of compressors, connections between each of said compressors, including cooling coils and mixing cylinders, a plurality of liquid coolers and a condenser connected in series to the last compressor, connections from said liquid coolers to said mixing cylinders and means connected to the last cylinder in said series for changing the liquid into snow.

4. In an apparatus of the type described, the combination comprising a plurality of

compressors each having an inlet and outlet, connections between said compressors including cooling coils and mixing cylinders, a mixing cylinder connected to the inlet of the first compressor, a plurality of liquid coolers and a condenser connected in series and to the outlet of the last of said compressors, means connected to the last of said liquid coolers for forming the liquid into snow, connections from the last two liquid coolers of said series to said mixing cylinders and a connection for said means forming the liquid into snow to the mixing cylinder connected to the inlet of the first compressor.

5. In an apparatus of the type described, the combination comprising a plurality of compressors each having an inlet and outlet, connections between said compressors including cooling coils and mixing cylinders, a mixing cylinder connected to the inlet of the first compressor, a plurality of liquid coolers and a condenser connected in series and to the outlet of the last of said compressors, means connected to the last of said liquid coolers for forming the liquid into snow, connections from the last two liquid coolers of said series to said mixing cylinders, a heat exchanger in series with the cooling coil and the mixing cylinder connected to the inlet of the last compressor, said heat exchanger comprising a coil and casing, said casing being connected in series with the connection from the means for forming liquid into snow and the mixing cylinder connected to the inlet of the first compressor.

6. In an apparatus of the type described, the combination comprising a plurality of compressors arranged to successively increase the pressure of the gas passing therethrough, means in the connections between each compressor for cooling the gas after each compression, a plurality of receivers and a condenser connected in series to the last compressor, means in the connection between said receivers for reducing the pressure of the liquid as it passes from one receiver to the next and means connected to the last receiver of the series for changing the liquid into snow form.

7. In a device for changing liquid carbon dioxide to snow, the combination comprising a casing, an open ended conical member supported within said casing united with said casing at its lower edge, a chamber attached to the lower edge of the casing, said conical member opening into said chamber, means for closing said opening and means united with said chamber for compressing the snow into blocks.

8. In a device for changing liquid carbon dioxide to snow, the combination comprising a casing, an open ended conical member supported within said casing united with said casing at its lower edge, a chamber attached to the lower edge of the casing, said conical member opening into said chamber, means for closing said opening, said means for closing said opening being adapted to release the snow within the conical member when a predetermined quantity has been formed.

9. In a device for changing liquid carbon dioxide to snow, the combination comprising a casing, an open ended conical member supported within said casing united with said casing at its lower edge, a chamber attached to the lower edge of the casing, said conical member opening into said chamber, means for closing said opening, said means for closing said opening being adapted to release the snow within the conical member when a predetermined quantity has been formed, and means for compressing the snow into blocks, comprising a piston operated plunger and a casing opening into said chamber.

10. In an apparatus for changing liquid carbon dioxide into snow, the combination comprising a casing, an open ended conical member supported in said casing and forming a tight joint with the bottom thereof, means projecting into said casing and conical member for spraying the carbon dioxide liquid, a chamber attached to the lower end of said casing to which said conical member opens, a weight controlled gate for closing said opening, a cylinder attached to the bottom of said chamber and in communication therewith, a plunger slidably operated in said cylinder, means for sliding said plunger, said cylinder being open at the end opposite to that in which the plunger operates, a movable gate enclosing said opening and means for operating said gate.

11. The method of producing carbon dioxide snow which comprises subjecting carbon dioxide gas to sufficient pressure in successive stages of compression to liquefy it, cooling the gas after each compression, confining the liquid in a cylinder, delivering the liquid to other cylinders and simultaneously reducing its pressure before it enters each cylinder, supplying the gas formed at each reduction in pressure of the liquid to the compressed gas after each compression to cool it and forming the liquid from the last cylinder into snow.

12. The method of producing carbon dioxide snow which comprises subjecting carbon dioxide gas to sufficient pressure in successive stages of compression to liquefy it, cooling the gas after each compression, confining the liquid in a cylinder delivering the liquid to other cylinders and simultaneously reducing its pressure before it enters each cylinder, supplying the gas formed at each reduction in pressure of the liquid to the compressed gas after each compres-

sion to cool it and mixing the gas formed during the snow forming operation with fresh gas before the first compression operation to cool it.

13. The method of producing carbon dioxide snow which comprises subjecting carbon dioxide gas to sufficient pressure in successive stages of compression to liquefy it, cooling the gas after each compression, confining the liquid in a cylinder delivering the liquid to other cylinders and simultaneously reducing its pressure before it enters each cylinder, supplying the gas formed at each reduction in pressure of the liquid to the compressed gas after each compression to cool it, utilizing the gas formed during the snow forming operation to cool the gas before the last compression operation and then mixing the gas with fresh gas to cool it before the first compression operation.

14. A method of producing carbon dioxide snow comprising forming carbon dioxide gas into liquid form in several successive stages of compression, gradually reducing the temperature and pressure of the liquid in several successive stages, utilizing the gas formed in each successive stage of pressure reduction of the liquid in cooling fresh gas at each stage of compression, converting the liquid after its last reduction in temperature and pressure into snow and utilizing the gas formed during the snow forming operation for cooling the fresh gas before its first stage of compression.

15. In the method of producing carbon dioxide snow which comprises subjecting carbon dioxide gas to sufficient pressure to liquefy it, cooling the liquid after compression, confining the cooled liquid in a substantial body under pressure, delivering the liquid to a condition of lower pressure permitting partial evaporation thereof and forming some gas, mixing the gas thus formed with fresh gas to cool it and then compressing it.

16. In the method of producing solidified carbon dioxide which comprises compressing the gas in several stages, cooling the compressed gas after each compression, cooling the gas after final compression to liquefy it, further cooling the liquid while confined in a substantial body by partial evaporation thereof and employing the gas produced during partial evaporation for cooling the fresh gas before its compression.

17. In the method of producing a liquefied gas for later solidification comprising compressing the gas in several stages of compression and pre-cooling the gas between each stage of compression by admixture with a colder gas.

18. In an apparatus of the type described the combination comprising a plurality of compressors, connections between each of said compressors including cooling coils and mixing cylinders, a condenser connected in series with the last compressor, liquid coolers connected in series with said condenser, means connected to the last cooler for solidifying the liquid, and connections from said coolers for delivering the gas formed therein to said mixing cylinders.

19. In the method of producing solidified carbon dioxide the steps of compressing carbon dioxide in a plurality of stages to gradually increase its pressure, liquefying the compressed gas by cooling, cooling the liquid in several stages by effecting changes in pressure and producing gas at pressures of the order of the pressure at the compression stages and mixing the gas formed with new gas at the various stages of corresponding pressures before compression to cool the new gas and prepare the mixture for compression.

20. The method of transforming carbon dioxide from the gaseous to the solid phase, comprising increasing the pressure of the gas in several stages of compression, cooling the compressed gas after each compression and mixing it with a cooler gas, the pressure and temperature conditions at the end of the last compression operation effecting liquefaction of the gas, gradually reducing the pressure and temperature of the liquid thus formed in several successive stages, and finally reducing the pressure and temperature of the liquid below its critical values to effect solidification thereof.

21. In an apparatus of the class described, the combination comprising a plurality of compressors, connections between each compressor, a cooling coil and mixing cylinder in the connections between the first and second compressor and the second and third compressor, means connected to the third compressor for causing the compressed gas to liquefy, a series of tanks connected to said means having connections therebetween including pressure reducing valves, a connection between one of said tanks and one of said mixing cylinders, a connection between another of said tanks and the other of said mixing cylinders, and means connected to the last tank for receiving and solidifying the liquid.

22. In an apparatus of the type described, the combination comprising means for liquefying carbon dioxide gas, a plurality of receivers connected thereto and having connections therebetween, means in said connections for effecting reduction in pressure of the liquid as it flows from one receiver to the other, said means being adapted to prevent a reduction in pressure in each receiver below a predetermined value, means connected to the last of said receivers for forming the liquid into solid form, and means in the connection therebetween for prevent-

ing the depletion of liquid from the last of said receivers.

23. The method of making carbon dioxide ice which consists in compressing carbon dioxide by a series of compressors having intercoolers between them, condensing the compressed fluid after passing through the last compressor, expanding a portion of the fluid to cool the remainder, delivering the cooled fluid to a snow machine, and utilizing the expanded fluid to cool the gas passing to some of the compressors, substantially as set forth.

24. The method of making carbon dioxide ice which consists in compressing carbon dioxide by a series of compressors having intercoolers between them, condensing the compressed fluid after passing through the last compressor, expanding a portion of the fluid to cool the remainder, delivering the cooled fluid to a snow machine, and conducting the expanded fluid back and mixing it with the gas entering some of the compressors to pre-cool this gas, substantially as set forth.

25. In a snow making system a series of compressors having cooling units between them, a condenser, a plurality of liquid coolers, means for expanding a portion of the compressed fluid to cool the remainder of the fluid in the first of said coolers, and means for expanding a portion of the fluid from said first cooler into a second cooler to cool the remaining fluid in said second cooler, and means for conducting the cold fluid from said second cooler to a snow machine, substantially as set forth.

26. In a snow making system a series of compressors having cooling units between them, a condenser, a plurality of liquid coolers, means for expanding a portion of the compressed fluid to cool the remainder of the fluid in the first of said coolers, means for expanding a portion of the fluid from said first cooler into a second cooler to cool the remaining fluid in said second cooler, means for conducting the cold fluid from said second cooler to a snow machine, and means for conducting cold exhaust gas from the snow machine to the intake of one of the compressor units, substantially as set forth.

27. In an apparatus of the type described, the combination comprising a source of liquid carbon dioxide, means connected thereto for cooling the liquid by partial evaporation, means for forming the liquid into snow connected to said cooling means, and means for compressing the gas delivered from said cooling means and snow forming means to a predetermined pressure.

28. Apparatus for preparing carbon dioxide gas for conversion into snow, comprising means for liquefying the gas, a container for storing the liquid, a pipe connection between said means and said container, a pressure ratio valve in said connection, and a gas return pipe connection from said container to said means for returning gas formed in said container to said means for reliquefication.

In testimony whereof I have hereunto set my hand on this 10th day of August A. D., 1928.

JUSTUS C. GOOSMANN.