Oct. 16, 1962 L. E. PUTMAN 3,058,317

VAPORIZATION OF LIQUEFIED GASES

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FIG. 1

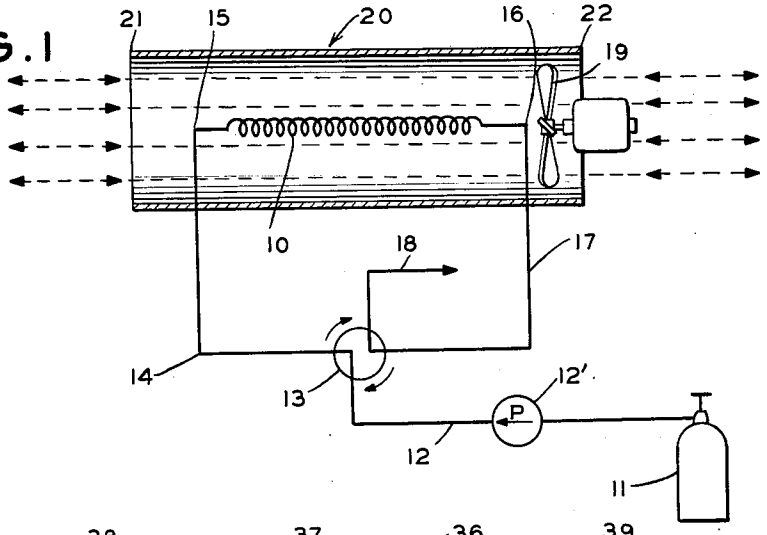


FIG. 2

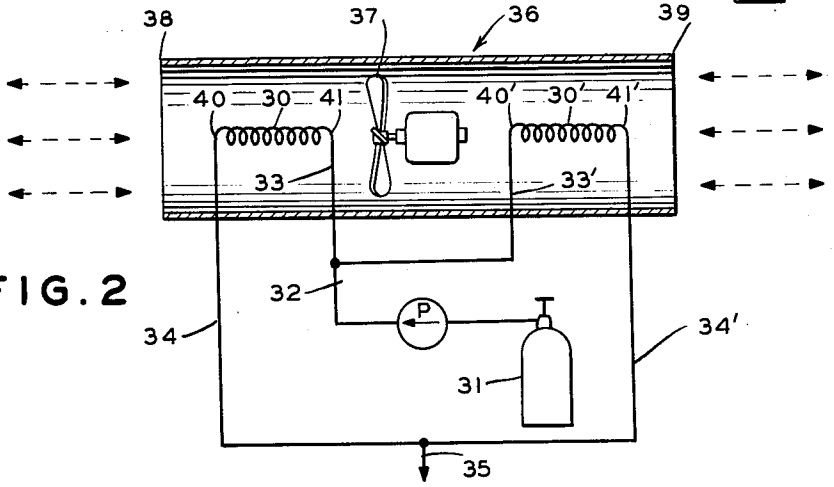


FIG. 3

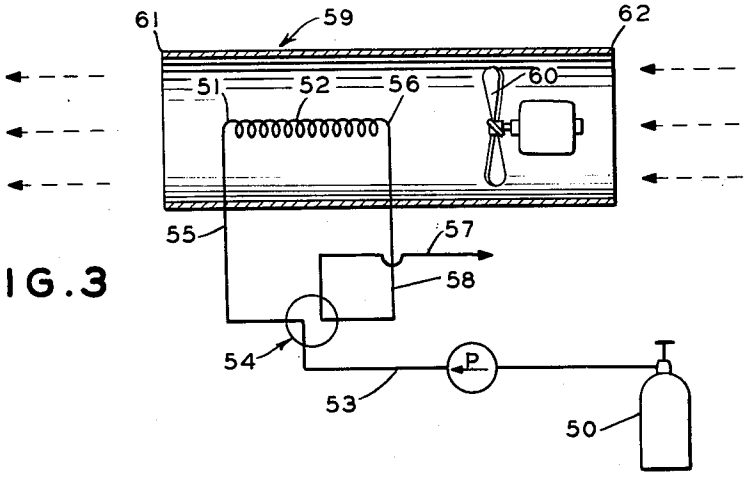


FIG. 4

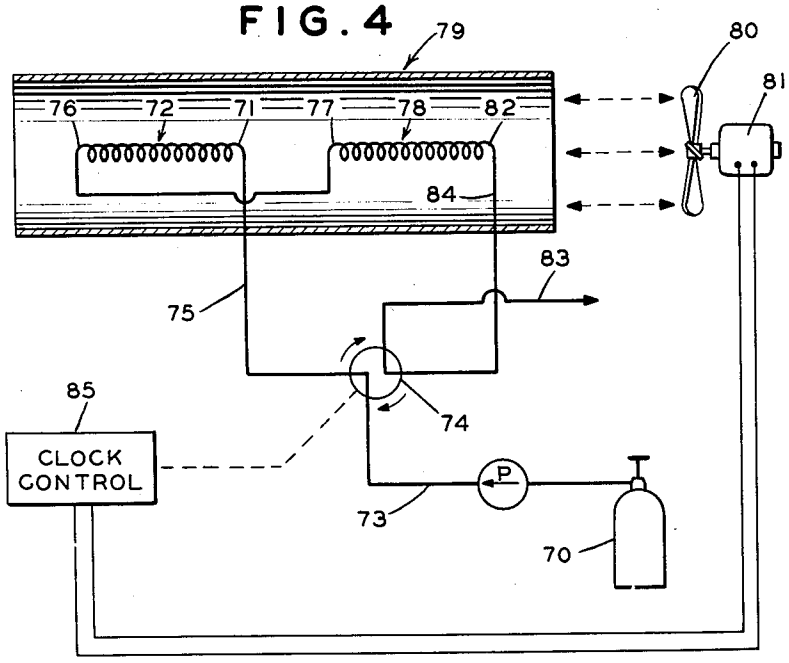
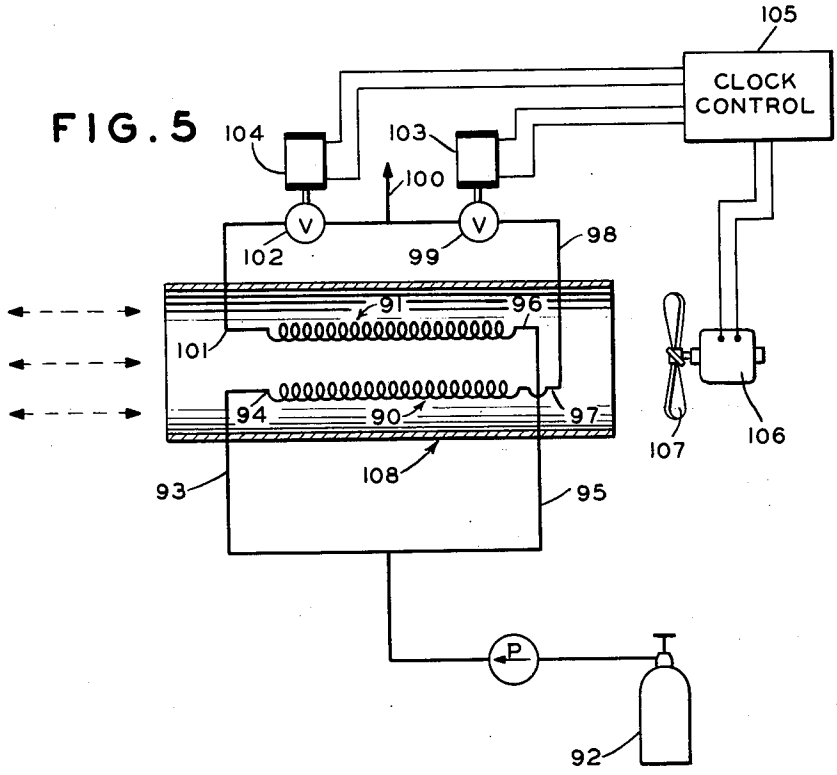

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CLOCK CONTROL
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FIG. 5

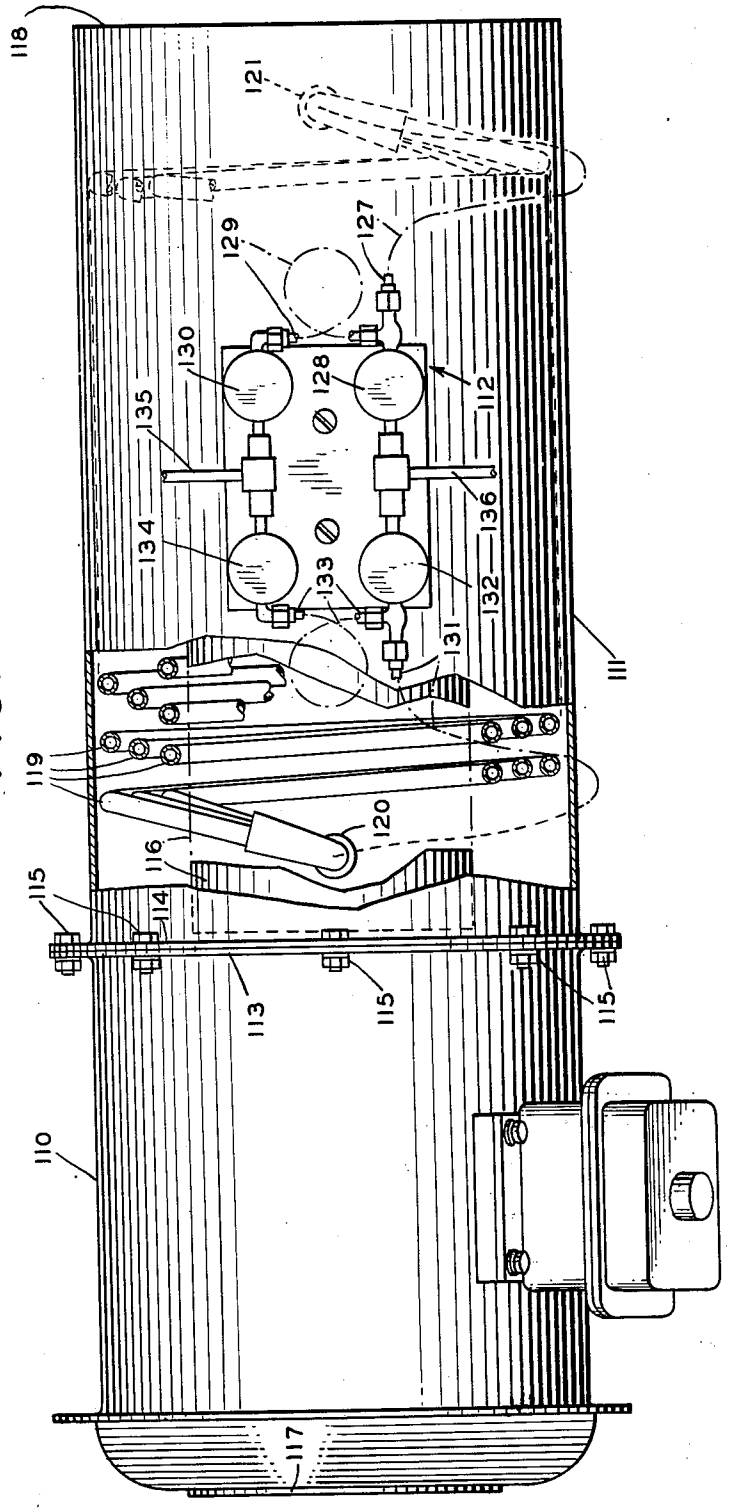

105
CLOCK CONTROL
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VAPORIZATION OF LIQUEFIED GASES

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FIG. 6

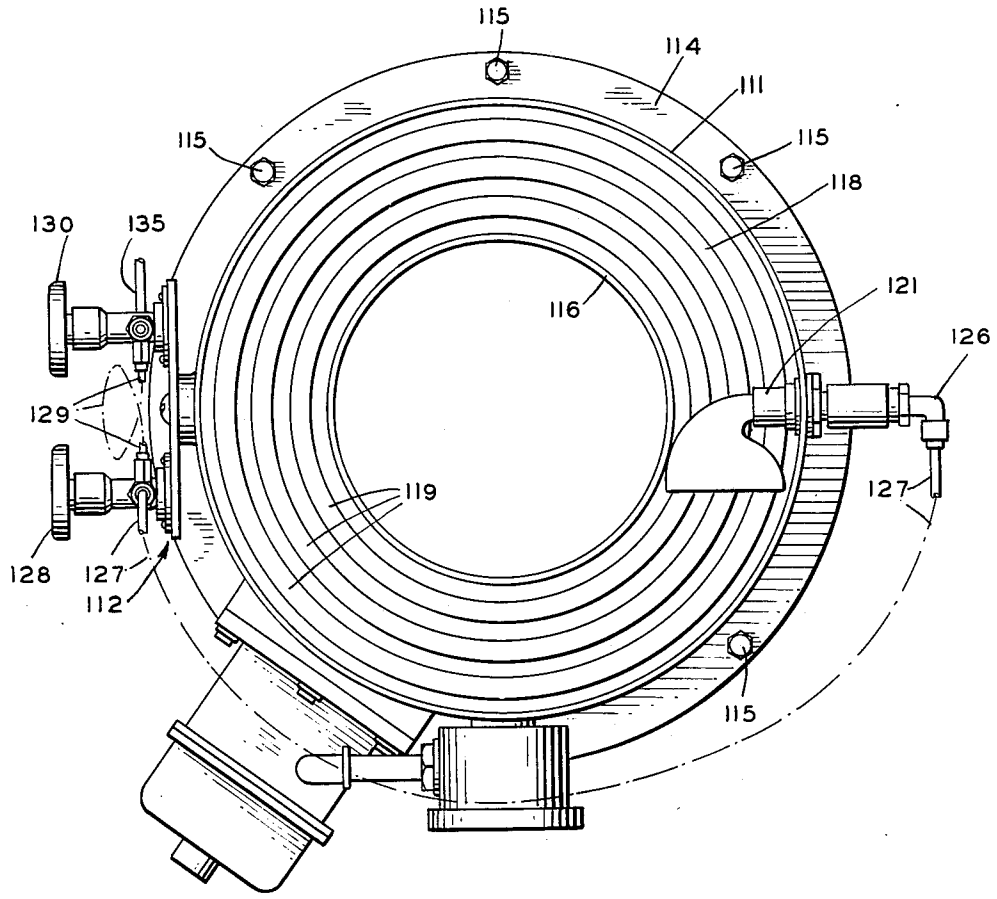


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VAPORIZATION OF LIQUEFIED GASES

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FIG. 7



United States Patent Office 3,058,317 Patented Oct. 16, 1962

3,058,317
VAPORIZATION OF LIQUEFIED GASES

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Filed Mar. 31, 1958, Ser. No. 725,319
14 Claims. (Cl. 62—52)

The present invention relates to the vaporization of liquefied gases and more particularly to the vaporization of liquefied gases having boiling points below the temperature of a gaseous heat source.

The invention is particularly concerned with the vaporization of liquid oxygen, liquid nitrogen and liquid argon by heat-exchange with atmospheric air at ambient temperature and will therefore be described principally in connection with these gases. However, the principles of the invention are in general applicable to the vaporization of any liquefied gas by means of heat-exchange with an impure gas whose temperature is greater than the boiling point of the liquefied gas.

At the present time, most commercial installations for the vaporization of liquefied oxygen, nitrogen or argon employ relatively expensive and complicated methods such as passing the gas through tubes which are externally heated by water or some other medium which is in turn heated by steam or electricity. The power consumption of such heating methods is expensive and the apparatus is complicated.

Attempts have been made to utilize ambient air as a source of heat, but such attempts have either not been successful or have been inefficient with regard to operating costs, plant required, or both. The principal difficulty encountered in the use of ambient air has been the fact that atmospheric air always includes water vapor, carbon dioxide and other gases which, upon contact with the cold surface of the vaporizer and heating coil, rapidly condense out, due to the extreme temperature differences, and the film of condensation so formed, acts as an insulation. Over a period of time the film progresses in thickness and direction to the point where the heat-exchanger surface for all practical purposes becomes non-effective. More or less practical solutions of this problem have been suggested, one of which is to provide a series of two or more vaporizer and warming coils, which can be alternately used, with the intent that while the condensible film is building up on a new surface, the condensed film on the previously used surface will evaporate due to static ambient conditions. This is not practical in temperatures below 5° C. since water vapor which is the primary constituent of the condensed film will not evaporate in sufficient time to allow the use of other than extremely large surfaces in multiples which may be prohibitive from the space or economic standpoint. One variation uses auxiliary methods for removing the relatively poor conductive films of condensed gases, such as electric heating by direct conduction, or indirectly heating the surface by heating the ambient air. Such expedients are, of course, expensive and undesirable.

Another attempt to solve the problem has been to provide a heat-exchanger surface with liquid oxygen flowing internally and atmospheric air externally at high volumes and high velocity so that the temperature of the air does not fall below 5° C. Such a method is described in Monroe and Freud Patent 2,729,074 granted January 3, 1956. Even under such conditions condensation of water takes place and provisions have to be made to ensure that the temperature of the ambient air does not fall below its freezing point at atmospheric pressure. Such provisions include heating of the air, directly or indirectly.

The principal object of the present invention has been

to provide a novel and improved method for vaporizing a liquefied gas.

More particularly it has been a principal object of the invention to provide a novel and improved method for vaporizing a liquefied gas through indirect heat-exchange with a warmer gas, which method is efficient both as to operating costs and plant requirements.

Another object of the invention has been to provide a novel and improved method for vaporizing liquefied oxygen, nitrogen or argon through indirect heat-exchange with ambient air.

Other and further objects, features and advantages of the invention will appear more fully from the following description.

In the practice of the invention, a liquefied gas, e.g., oxygen, nitrogen, or argon, is passed through a heat-exchanging device wherein indirect heat-exchange with a stream of ambient atmospheric air is afforded. The process conditions are selected so that condensible gases in the ambient air are deposited on a portion of the heat-exchanger surface during a first part of the heat-exchanging cycle and are deposited on a second portion of the heat-exchanger surface during a second portion of the cycle. During the first part of the cycle, condensed gases are removed from the second portion of the heat-exchanger surface by action of the air flow while during the second part of the cycle condensed gases are removed from the first portion of the heat-exchanger surface by action of the air flow. In this way the net effective heat-exchanger surface is maintained substantially constant irrespective of the ambient air temperatures and the concentrations of condensible gases in the ambient air. It is highly desirable that the invention be carried out so that co-current flow is maintained during both parts of the heat-exchanging cycle since with such flow operation can be maintained regardless of ambient condition and over the largest range of condensible gas in the ambient atmosphere. As used herein, the term "condensible gases" is intended to include also condensible vapors such as water vapor. As explained previously, the process of the invention is applicable to any liquefied gas, for example methane, and to any source of ambient atmosphere having a temperature greater than that of the boiling point of the liquefied gas, provided of course, that the condensible gas concentration in the ambient atmosphere represents only a small portion of the total ambient atmospheric flow.

The invention will now be described in greater detail with reference to the appended drawings, in which:

FIG. 1 is a schematic illustration of one form of heat-exchanger system for carrying out a preferred method in accordance with the invention;

FIG. 2 is a schematic illustration of another form of heat-exchanger system for carrying out a modified method in accordance with the invention;

FIG. 3 is a schematic illustration of still another form of heat-exchanger system for carrying out a further modification of the invention;

FIG. 4 is a schematic illustration of another form of heat-exchanger system for carrying out another modification of the invention;

FIG. 5 is a schematic illustration of another form of heat-exchanger system for carrying out still another modification of the invention;

FIG. 6 is a side elevational view of a practical form of apparatus for practicing the invention; and

FIG. 7 is an end view of the apparatus shown in FIG. 6.

Referring now to the drawings, and more particularly to FIG. 1, the heat-exchanger apparatus, which may be termed a "vaporizer-warmer," is illustrated in the form of a coil 10 through which flows liquefied gas from a source 11, which might be, for example, a tank. Lique-

fied gas from the source **11** flows to the coil **10** through a feed line **12**, a four-way valve **13** and another feed line **14**. A pump **12'** may be inserted in the feed line **12** to build up the liquefied gas to any desired pressure. With the four-way valve **13** in the position shown, the liquefied gas will be delivered to the left end of the coil **10**, which is designated as point **15**. The right end of the coil **10**, which is designated as point **16**, is connected to four-way valve **13** through a line **17**. With the four-way valve **13** in the position shown, the line **17** is connected through the valve to a discharge line **18**.

The liquefied gas from the source **11** may be at high- or low pressure as desired. In general, the higher the pressure of the liquefied gas source the more advantageous it will be for the liquefied gas to flow internally of the heat-exchanger coil **10**, although the choice of internal or external flow will also depend an other factors such as economy, ease of maintenance and similar criteria. The pump **12'** may be used to provide a suitable high pressure,

Ambient atmosphere at any desired pressure is forced by suitable means, such as a fan **19**, over the vaporizer-warmer coil **10**. A shroud or housing **20**, open at the ends, is disposed about the coil **10** and serve to direct and control the ambient flow over the coil **10**. The open left end of the shroud **20** is designated **21**, while the open right end of the shroud **20** is designated **22**. The ambient atmosphere, which will generally be atmospheric air, enters the shroud **20** at point **22**, contacts the coil **10** at point **16**, loses contact with the coil **10** at point **15**, and exits from the shroud **20** at point **21**, or vice versa depending upon the direction of rotation of the motor driving the fan **19**.

In this, the preferred form of the invention, co-current flow of air and liquefied gas is maintained at all times. Thus, during a first part of the operating cycle, air enters the shroud at point **21**, flows along the coil **10** from point **15** to point **16** and leaves the shroud **20** at point **22**. At the same time, liquefied gas is delivered to the coil **10** at point **15** and the warmed and vaporized gas exits from the coil **10** at point **16**. Since the temperature of the liquefied gas will be lowest at the point of delivery to the vaporizer-warmer coil, the temperature difference between ambient air and liquefied gas will be greatest at point **15**. This temperature difference is so large that the condensible gases in the ambient air freeze out on the exchanger surface, starting at point **15**. As the condensate builds up on the exchanger surface adjacent the point **15**, the transfer of heat between the liquefied gas and the ambient air at this point will become less efficient, resulting in the zone of freeze-out extending in the direction of point **16**.

After a period of time, which can be predetermined, the exchanger surface will be covered with a sufficient thickness of condensate to prevent the portion of the exchanger surface between the point **15** and the middle of the coil **10** from functioning as an effective heat-exchanger surface, so that the major portion of the vaporizing and warming of the liquefied gas will then occur in that of the coil **10** nearest the point **16**. The buildup of condensate is a function of time depending upon such variables as relative flows of liquefied gas and ambient atmosphere, amount of condensible in the ambient atmosphere, and total surface are available in the vaporizer-warmer **10**.

The liquefied gas leaving the vaporizer-warmer **10** and delivered to the line **18**, will have been vaporized and heated to within a few degrees of the temperature of the ambient atmosphere.

Ambient atmosphere leaving the shroud at the point **22** will be essentially free of all condensibles since they have been frozen out on the surface of the vaporizer-warmer **10**. As the buildup of condensibles on the exchanger surface proceeds, a point will be reached at which the effective heat-exchanger surface is reduced so far (because of the insulating layer of condensibles) that the vaporized and warmed gas leaving the system at point **16** is at a colder temperature than permissible.

At this time the flow of liquefied gas from the source **11** is directed to the point **16** instead of the point **15** by reversing four-way valve **13**. Such reversal of the four-way valve **13** will interconnect lines **12** and **17** on the one hand and lines **14** and **18** on the other hand. Thus the liquefied gas enters the vaporizer-warmer at a point which has little or no condensed vapor or gas on its surface, i.e., the righthand portion of the vaporizer-warmer. This righthand portion will be at substantially maximum effectiveness in affording heat-exchange because it has little or no condensed gas or vapor on its surface. At the same time, the direction of flow of air is changed so that the fan **19** directs air through the shroud **20** from point **22** to point **21**, thus maintaining co-current flow.

The liquefied gas delivered at point **16** will be warmed and vaporized as it passes through the vaporizer-warmer **10** toward point **15**. Condensible gas in the ambient air will start freezing out and depositing on the exchanger surface at a point **16** since this is now the point of greatest temperature difference between the liquefied gas and the ambient air. As the layer of condensed gas on the exchanger surface builds up to provide insulation, the point of maximum temperature difference will move toward the left in FIG. 1, i.e., toward the point **15**.

As the ambient air flows over the right-hand part of the exchanger surface, condensible gases contained therein are deposited on the exchanger surface, as described, so that when this air reaches the left-hand part of the exchanger surface it will have lost at least a major part of its condensible gas content and will certainly be unsaturated. As this unsaturated air passes over the previously deposited condensibles on the left-hand part of the exchanger surface, i.e., that part between the center and point **15**, the previously deposited condensibles tend to and do diffuse or evaporate into the air, cleaning the heat exchanger surface which had been coated during the first portion of the cycle. The second portion of the cycle is, of course, that portion in which both the liquefied gas and the ambient air travel from right to left in FIG. 1.

When the buildup of condensibles on the exchanger surface reaches a level in which the vaporized gas discharged at the point **15** is at a colder temperature than permissible, the four-way valve **13** is reversed again to its original position so that liquefied gas will be delivered to the point **15** and the direction of air flow is also reversed so that air will flow from point **21** to point **22**. This initiates the first portion of a new cycle. In this new cycle, ambient air passing over the right hand portion of the exchanger surface will pick up condensibles from this portion of the exchanger surface because the ambient air will have lost at least a substantial proportion of its condensible gas content from having first flowed over the lefthand portion of the exchanger surface which is now the coldest portion. The operation is continued with the direction of flow of the liquefied gas and ambient air being reversed as necessary.

Since in FIG. 1 co-current flow is maintained at all times, both portions of the cycle may be of equal duration. In general, the cycle portion times may be selected as desired provided that each cycle portion is of sufficient duration to permit substantially complete cleaning of condensible gases deposited during the preceding cycle portion. The changeover from one cycle portion to the next may be effected manually or automatically and may be initiated by the passage of a predetermined time, observation of the temperature of the warmed and vaporized gas, or observation of the condensible buildup on the vaporizer-warmer surface. The use of co-current flows of approximately equal masses minimizes the power cost for moving the ambient air and also permits the use of a minimum size heat-exchanger surface since the

cycle duration can be made quite short. This is of particular importance where equipment should be small in size.

While it is preferable to maintain co-current flow of the liquefied gas and ambient air and this condition should be used to provide the best results and the greatest efficiency, satisfactory results can generally be achieved without maintaining co-current flow. An arrangement in which the direction of flow of the ambient air only is reversed is illustrated in FIG. 2. In FIG. 2, the vaporizer-warmer is divided into two sections 30 and 30'. Liquefied gas from a source 31 flows through feed line 32 and feed lines 33 and 33' to the coils 30 and 30'. the other ends of the coils 30 and 30' are connected through delivery lines 34 and 34', respectively, to the vaporized gas discharge line 35. A shroud or housing 36, open at both ends, is provided around the coils 30 and 30' to direct and control the flow of ambient air set up by a fan 37. The fan 37 is reversible so that it can direct ambient air from point 38 to point 39, or from point 39 to point 38. The lefthand end of coil 30 is labeled 40 while the righthand end thereof is labeled 41. Similarly, the lefthand end of coil 30' is labeled 40' while the righthand end thereof is labeled 41'.

During a first part of each cycle, the fan 37 is caused to direct air from right to left, i.e., from point 39 toward point 38. Air passing over the coil 30' will contain condensible gas which will freeze out on the coil 30'. This same air will then pass over the coil 30; but since a major portion of its condensible gas content will have been deposited on the coil 30', this air will be able to absorb condensibles and hence will be able to clean the surface of the coil 30 of condensible gas deposited thereon during the second part of the preceding cycle. When the condensible gas deposited on the coil 30' exceeds a desired amount so that the temperature of the vaporized gas delivered through the tube 34' is too low, the direction of air flow is reversed. This results in cleaning action on the surface of coil 30 and a deposition of condensibles on coil 30'. In other words, while one section of the vaporizer-warmer is having a layer of condensibles built up thereon, the other section is being cleaned by the air which has been stripped of condensibles by the first section. The ambient air entering the shroud 36 at 38 or 39, as the case may be, and then passing over the adjacent vaporizer-warmer coil section 30 or 30', is relatively free of condensibles by the time it reaches the other section of the vaporizer-warmer coil 30' or 30, as the case may be, and will absorb condensibles from the latter.

In the case of FIG. 2, the two portions of the cycle may be of identical durations if the two vaporizer-warmer sections afford equal exchanger surface areas. The time duration of each portion of the cycle will be limited by the length of time required to build up a layer of condensation on either section of the vaporizer-warmer to the point where the vaporized and warmed gas leaving that section becomes too cold due to the condensibles on the coil surface destroying the effectiveness of the heat-transfer surface.

An operation in which the direction of air flow only is reversed, as described in connection with FIG. 2, is especially desirable when it is more economical and practicable to maintain a one-way flow of liquefied gas, such as in a very high-pressure system—cycle control of a very high-pressure fluid being difficult.

Referring now to FIG. 3, there is illustrated an arrangement in which only the direction of flow of the liquefied gas is changed. Liquefied gas from a source 50 is delivered to the lefthand end (point 51) of vaporizer-warmer coil 52 through delivery line 53, a four-way valve 54 and a delivery line 55. The vaporized and warmed gas discharged from the righthand end (point 56) of vaporizer-warmer coil 52 is delivered to discharge line 57 through a line 58 and the four-way valve 54. By reversing the four-way valve 54, liquefied gas may be delivered to the righthand end of coil 52 and the vaporized and warmed gas may be discharged through the line 55 to the line 57. Ambient air is directed through a shroud or housing 59 and over the coil 52 by a fan 60. The fan 60 causes the air to enter the shroud at point 62 and to leave at point 61.

In the first portion of each cycle, liquefied gas enters the vaporizer-warmer 52 at point 51, resulting in a deposit and buildup of condensibles on the exchange surface starting at the point 51 and moving progressively toward the right in FIG. 3. When the buildup of condensibles results in too low a temperature of the vaporized and warmed gas discharged at the point 56 the direction of flow of the liquefied gas is reversed, resulting in a deposition of condensibles at the righthand end of the exchanger surface and a cleaning of the lefthand portion of the exchanger surface.

By properly sizing the exchanger surface area, mass flows and cycle times, the unit shown in FIG. 3 will operate indefinitely. Since the flow is not co-current during both portions of the cycle, care should be taken to maintain a relatively large flow of ambient air in proportion to the fluid being vaporized since during the counter-current flow portion of the cycle, the removal of condensibles from the frozen portion of the heat exchanger is accomplished by a much less driving force. This is to say that the air flowing from 62 to 61 contains a maximum of condensibles when the warmed and vaporized gas exists at point 56 and the removal of condensibles for the zone nearest point 56 is done only by the difference between degree of concentration possible in ambient air and the degree actually present. During the other portion of the cycle a substantial proportion of the condensibles are frozen out of the air before it passes over the surface to be cleaned, thus making the cleaning easier. It is unlikely that the air available will be saturated with respect to water and carbon dioxide, which are the major condensible constituents, so that, assuming that the air is not saturated with these constituents, the only precaution that should be taken is to provide a relatively longer cycle time for the counter-current flow. Alternatively, a larger exchanger surface may be used for the counter-current flow, as by unequal division of the exchanger surface between the two portions of the cycle. Another alternative, but which would be difficult to control under varying ambient conditions, is to provide a greater flow rate of ambient air during the counter-current flow than during the co-current flow.

Another exchanger arrangement in which co-current flow can be maintained is illustrated in FIG. 4. In FIG. 4, liquefied gas from a source 70 is supplied to the righthand end 71 of a vaporizer-warmer coil section 72 through a feed line 73, a four-way valve 74 and a feed line 75. The liquefied gas discharged at left end 76 of coil 72 is conducted to left end 77 of another vaporizer-warmer coil section 78. The sections 72 and 78 are axially spaced within a shroud or housing 79 which serves to direct and control the flow of air from a fan 80 over the exchanger surfaces. The fan 80 is powered by a reversible electric motor 81. Vaporized and warmed gas discharged from right end 82 of coil section 78 is delivered to discharge line 83 through a line 84 and four-way valve 74.

During a first portion of each cycle, liquefied gas is conducted from right to left in coil 72 and then from left to right in coil 78. At this time the fan 80 is powered to force air from left to right in the shroud 79 so that condensibles from the ambient air are deposited on the coil 72 and are removed from the coil 78. A cycle-timing control which may be operated by a clock mechanism 85 reverses the four-way valve 74 and also reverses the electric motor 81 so that liquefied gas will flow from right to left in coil section 78 and thence from left to right in coil sections 72 while ambient air will be di-

rected from right to left in the shroud 79. During this second portion of the cycle, condensibles from the ambient air will be deposited on the coil section 78 and will be cleaned from the coil section 72.

Another exchanger arrangement in which co-current flow can be maintained is illustrated in FIG. 5. Referring to FIG. 5, the vaporizer-warmer is formed by two separate coils 90 and 91 which are axially coincident but laterally spaced from each other. In practice, the coils 90 and 91 may be wound close to each other. Liquefied gas from a source 92 is conducted through a feed line 93 to left end 94 of coil 90 and through a feed line 95 to right end 96 of coil 91. Vaporized and warmed gas from the right end 97 of coil 90 is delivered through a line 98 and a valve 99 to discharge line 100. Similarly, vaporized and warmed gas from the left end of coil 91 is delivered to the discharge line 100 through a line 101 and a valve 102. The valves 99 and 102 are controlled by solenoids 103 and 104, respectively, which are in turn controlled by clock-control mechanism 105. The clock mechanism 105 also controls a reversible electric motor 106 which drives fan 107. The fan 107 forces air from right to left or left to right within a shroud or housing 108 provided around the vaporizer-warmer coils 90 and 91.

The valves and solenoids 99—103 and 102—104 are arranged so that when one valve is open the other is closed, and vice versa. With the valve 99 open, liquefied gas passes through coil 90 from point 94 to point 97. At this time valve 102 is closed so that no flow occurs through the coil 91. Air passing from left to right through the shroud 108 vaporizes and warms the liquefied gas in the coil 90, deposits condensibles from left to right on the coil 90 and removes condensibles from the coil 91 which had been deposited thereon during the latter portion of the preceding cycle. Similarly, air passing from right to left in the shroud 108 vaporizes and warms the liquefied gas in the coil 91, deposits condensibles on the coil 91 and removes condensibles from the coil 90 which had been deposited thereon during the latter portion of the preceding cycle. It will be observed that when gas and air flow occur from left to right frosting and depositing occur from left to right, and vice versa.

It is particularly desirable that the invention be carried out so that during each cycle portion the ambient air first sweeps over the coldest area of the heat-exchanger surface and then over the area to be cleaned. In this way a maximum amount of the moisture in the air will be frozen out on the cold surface and the air will have a maximum capacity for picking up moisture from the warmer surface due to the concentration difference driving force, which to some extent is independent of temperature.

A practical form of apparatus for carrying out the method of the invention is illustrated in FIGS. 6 and 7. The apparatus of FIG. 6 comprises three principal sections, these being a fan and motor section contained in a housing 110, a heat-exchanger section contained in a housing 111, which also serves as the air directing shroud, and a liquid inlet-gas outlet manifold 112 mounted on the housing 111. The housings 110 and 111 are provided with flanges 113 and 114, respectively, which may be bolted together with bolts 115.

The housing 110 contains a reversible electric motor and a fan arranged to blow ambient atmospheric air through the housing 111 in either direction, the air passing in the annular space between the housing 111 and a core 116, which may be a hollow cylinder closed at one or both ends. The fan may draw air in through a port 117 at the left end of the housing 110 and exhaust the air through the annular opening 118 at the right end of the housing 111, or draw in air through the opening 118 and exhaust the air through the port 117, depending upon the direction of fan rotation.

A three-section annular heat-exchanger coil 119 is mounted on the core 116 within the housing 111. The coil is wound in three sections of different diameter and which are connected together by headers at each end, the headers terminating in fluid connections 120 and 121, respectively. The three coil sections are thus connected in parallel so that fluid entering at 120 continuously progresses toward the exit at 121, or vice versa. Thus, even though the individual turns of the coil sections are disposed generally perpendicular to the direction of air flow, the direction of flow of the fluid contained in the coil is parallel to the direction of air flow. As illustrated, the three layers or sections of the coil 119 are spaced from each other and the individual turns are spaced from each other to permit adequate air flow therebetween and thus to afford an extended heat-exchanging surface for indirect heat-exchange between the air and the liquefied gas.

As best shown in FIG. 7, the end 121 of coil 119 is connected to a bushing 122, which is connected through a washer 123 to a coupling 124. A reducer bushing 125 is threaded into the coupling 124. A nipple 126 serves to connect a tubing 127 to the bushing 125. A similar connection is afforded for the coil end 120.

The tubing 127 is connected to the outlet of a valve 128 carried on the manifold 112 and also, through a tubing 129, to the inlet of a valve 130 also carried on the manifold 112. Similarly, the coil end 120 is connected through a tubing 131 to the outlet of a valve 132 and, through a tubing 133, to the inlet of a valve 134, both valves being mounted on the manifold 112. The outlets of valves 130 and 134 are connected to high-pressure gas outlet tube 135, while the inlets of valves 128 and 132 are connected to high-pressure liquefied gas inlet tube 136.

By opening valves 128 and 134, liquefied gas will enter the coil 119 at end 121 and will travel toward end 120, being warmed and vaporized as it progresses. By the time the gas is discharged into the outlet tube 135 it should be only a few degrees below the ambient air temperature. A reverse direction flow of gas can be provided by opening valves 130 and 132 instead of valves 128 and 134. The valves may conveniently be solenoid-operated under time or temperature control in order to afford automatic transfer from each cycle portion to the next.

The apparatus illustrated in FIGS. 6 and 7 is of the same type as that illustrated in FIG. 1 in that it affords reversible flow for both liquefied gas and air. This permits co-current flow during both cycle portions, which is the preferred mode of carrying out the invention.

In one embodiment of the apparatus shown in FIGS. 6 and 7, the air flow was approximately 3450 s.c.f.m. The coil 119 was made of tubing having an outside diameter of ½ inch and a wall thickness of 0.082 inch. The coil length was 250 feet affording an exchanger surface area of approximately 33 square feet. The apparatus was used to charge a tank with gaseous oxygen. The liquid oxygen source included a pump which caused the delivered gas to reach a pressure of 3000 p.s.i.g., the starting pressure with the gas tank empty being 0 p.s.i.g. With a half cycle (each cycle portion) time of approximately 30 minutes, the oxygen gas delivery was approximately 2000 s.c.f.h. The liquefied oxygen was delivered at approximately —297° F., while the gaseous oxygen was discharged from the exchanger at about 10° F. below ambient air temperature.

It is desirable that the air temperature not change appreciably in passing over the exchanger surface, since efficiency of operation will be maximized. By "not appreciably" is meant a temperature change of not more than about 10° F. Larger air temperature changes, for example, 50° F., can be accommodated, but at reduced efficiency.

It is particularly desirable that the invention be carried out so that during each cycle portion the ambient air first sweeps over the coldest area of the heat-exchanger surface and then over the area to be cleaned. In this way a maximum amount of the moisture in the air will be

frozen out on the cold surface and the air will have a maximum capacity for picking up moisture from the warmer surface due to the concentration difference driving force, which to some extent is independent of temperature.

While the invention has been described in connection with specific steps, specific illustrations and specific uses, various modifications thereof will occur to those skilled in the art without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of a gaseous heat source, comprising the steps of passing said liquefied gas over one face of an extended heat-exchanging surface of a heat-exchanger device, passing a relatively warm gas from said heat source over the other face of said heat-exchanging surface in indirect heat-exchange with said liquefied gas to vaporize and warm the latter, permitting condensible gases contained in said relatively warm gas from said heat source to freeze out on a first zone of said heat-exchanger surface which is the coldest zone during a first portion of each cycle, permitting condensible gases contained in said relatively warm gas from said heat source to freeze out on a second zone of said heat-exchanger surface which is the coldest zone during a second portion of each cycle, utilizing said relatively warm gas from said heat source to evaporate previously frozen out condensibles from said second zone during said first portion of each cycle, utilizing said relatively warm gas from said heat source to evaporate previously frozen out condensibles from said first zone during said second portion of each cycle, and periodically reversing the direction of flow of said liquefied gas and said relatively warm gas to effect transfers between said first and second portions of cycle, said relatively warm gas during each portion of each cycle contacting first the coldest zone of said heat-exchanger surface.

2. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over one face of an extended heat-exchanging surface, of a heat-exchanger device, passing ambient air over the other face of said heat-exchanging device in indirect heat-exchange with said liquefied gas to vaporize and warm the latter, said air and said liquefied gas being passed along said surface in one direction during a first portion of each cycle and in the opposite direction during a second portion of each cycle whereby said air contacts first the coldest zone of said surface, permitting condensible gases contained in said air to freeze out on the coldest zone of said surface during each portion of each cycle, utilizing said air during each portion of each cycle to evaporate condensible gases frozen out on the coldest zone of said surface during the preceding cycle portion, and peridically reversing the direction of flow of said liquefied gas and said air, the time duration of each portion of each cycle being selected so that the condensible gases frozen out on said exchanger surface during the preceding cycle portion are substantially completely evaporated.

3. The process set forth in claim 2, in which said liquefied gas is selected from the group consisting of oxygen, nitrogen and argon.

4. The process set forth in claim 2, in which the time duration of each cycle portion is not greater than the time required for the temperature of said vaporized and warmed gas to fall below a predetermined value.

5. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over one face of an extended heat-exchanging surface of a heat exchanger device, passing ambient air over the other face of said heat-exchanging surface in indirect heat-exchange with said liquefied gas to vaporize and warm the latter, the relative mass flows and velocities of said liquefied gas and said air being selected so that the temperature of said air does not change appreciably during said heat-exchange, said air and said liquefied gas being passed along said surface in one direction during a first portion of each cycle and in the opposite direction during a second portion of each cycle whereby said air contacts first the coldest zone of said surface, permitting condensible gases contained in said air to freeze out on the coldest zone of said surface during each portion of each cycle, utilizing said air during each portion of each cycle to evaporate condensible gases frozen out on the coldest zone of said surface during the preceding cycle portion, and periodically reversing the direction of flow of said liquefied gas and said air, the time duration of each portion of each cycle being selected so that the condensible gases frozen out on said exchanger surface during the preceding cycle portion are substantially completely evaporated.

6. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of a gaseous heat source, comprising the steps of passing said liquefied gas over one face of an extended heat-exchanging surface of a heat-exchanger device, passing a relatively warm gas from said heat source over the other face of said heat-exchanging surface in indirect heat-exchange with said liquefied gas to vaporize and warm the latter, said liquefied gas and said relatively warm gas being passed along said surface in one direction during a first portion of each cycle and in the opposite direction during a second portion of each cycle whereby said relatively warm gas contacts first the coldest zone of said surface, permitting condensible gases contained in said relatively warm gas to freeze out on the coldest zone of said surface during each portion of each cycle, utilizing said relatively warm gas during each portion of each cycle to evaporate condensible gases frozen out on the coldest zone of said surface during the preceding cycle portion, and periodically reversing the direction of flow of said liquefied gas and said relatively warm gas, the time duration of each portion of each cycle being selected so that the condensible gases frozen out on said exchanger surface during the preceding cycle portion are substantially completely evaporated.

7. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over one face of each of two axially spaced axially extended heat-exchanging surfaces of a heat-exchanging device, said liquefied gas passing along said surfaces in opposite directions, passing ambient air over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said ambient air passing first along one of said surfaces and then along the other of said surfaces during a first portion of each cycle, said ambient air passing first along the other of said surfaces and then along said one surface during a second portion of each cycle, permitting condensible gases including water vapor and carbon dioxide contained in said air to freeze out on said one surface during said first portion of each cycle and on said other surface during said second portion of each cycle, utilizing said air passing along said one surface during said second portion of each cycle and along said other surface during said first portion of each cycle to evaporate from said surfaces condensible gases frozen out on said respective surfaces during the preceding cycle portion, and periodically reversing said direction of flow of said air and said directions of flow of said liquefied gas so that the ambient air entering said heat-exchanger device at all times contacts first the coldest zone of said surfaces, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged warmed and vaporized gas to fall below a predetermined value.

8. The process set forth in claim 7, in which said liquefied gas is slected from the group consisting of oxygen, nitrogen and argon.

9. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over one face of each of said two axially spaced axially extended heat-exchanging surfaces of a heat-exchanging device, said liquefied gas passing along said surfaces in opposite directions, passing ambient air over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said ambient air passing first along one of said surfaces and then along the other of said surfaces during a first portion of each cycle, said ambient air passing first along the other of said surfaces and then along said one surface during a second portion of each cycle, the relative mass flows and velocities of said liquefied gas and said air being selected so that the temperature of said air does not change appreciably during said heat-exchange, permitting condensible gases contained in said air to freeze out on said one surface during said first portion of each cycle and on said other surface during said second portion of each cycle, utilizing said air passing along said one surface during said second portion of each cycle and along said other surface during said first portion of each cycle to evaporate from said surfaces condensible gases frozen out on said respective surfaces during the preceding cycle portion, and periodically reversing said direction of flow of said air and said directions of flow of said liquefied gas so that the ambient air entering said heat-exchanger device at all times contacts first the coldest zone of said surfaces, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged warmed and vaporized gas to fall below a predetermined value.

10. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of a gaseous heat source, comprising the steps of passing said liquefied gas over one face of each of two axially spaced axially extended heat-exchanging surfaces of a heat-exchanger device, said liquefied gas passing along said surfaces in opposite directions, passing a relatively warm gas from said heat source over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said relatively warm gas passing first along one of said surfaces and then along the other of said surfaces during a first portion of each cycle, said relatively warm gas passing first along the other of said surfaces and then along said one surface during a second portion of each cycle, permitting condensible gases contained in said relatively warm gas to freeze out on said one surface during said first portion of each cycle and on said other surface during said second portion of each cycle, utilizing said relatively warm gas passing along said one surface during said second portion of each cycle and along said other surface during said first portion of each cycle to evaporate from said surfaces condensible gases frozen out on said respective surfaces during the preceding cycle portion, and periodically reversing said direction of flow of said relatively warm gas and said directions of flow of said liquefied gas so that the relatively warm gas entering said heat-exchanger device at all times contacts first the coldest zone of said surfaces, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged warmed and vaporized gas to fall below a predetermined value.

11. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over one face of each of two axially extended heat-exchanging surfaces of a heat-exchanger device, said liquefied gas passing along said surfaces in opposite directions, passing ambient air over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said surfaces being disposed in the same axial position but laterally spaced from each other with respect to the direction of air flow therealong, permitting flow of said liquefied gases along one of said surfaces only during a first portion of each cycle and along the other of said surfaces only during a second portion of each cycle, causing the direction of flow of said air during each portion of each cycle to be the same as the direction of flow of said liquefied gas, permitting condensible gases contained in said air to freeze out on the surface past which liquefied gas is flowing during each portion of each cycle, and utilizing said air flowing along the surface past which liquefied gas is not flowing during each portion of each cycle to evaporate therefrom condensible gases frozen out thereon during the preceding cycle portion, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged vaporized and warmed gas to fall below a predetermined value.

12. The process set forth in claim 11 in which said liquefied gas is selected from the group consisting of oxygen, nitrogen and argon.

13. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of available ambient air, comprising the steps of passing said liquefied gas over the face of each of two axially extended heat-exchanging surfaces of a heat-exchanger device, said liquefied gas passing along said surfaces in opposite directions, passing ambient air over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said surfaces being disposed in the same axial position but laterally spaced from each other with respect to the direction of air flow therealong, the relative mass flows and velocities of said liquefied gas and said air being selected so that the temperature of said air does not change appreciably during said heat-exchange, permitting flow of said liquefied gases along one of said surfaces only during a first portion of each cycle and along the other of said surfaces only during a second portion of each cycle, causing the direction of flow of said air during each portion of each cycle to be the same as the direction of flow of said liquefied gas, permitting condensible gases contained in said air to freeze out on the surface past which liquefied gas is flowing during each portion of each cycle, and utilizing said air flowing along the surface past which liquefied gas is not flowing during each portion of each cycle to evaporate therefrom condensible gases frozen out thereon during the preceding cycle portion, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged vaporized and warmed gas to fall below a predetermined value.

14. A cyclic process for vaporizing and warming a liquefied gas having a boiling point below the temperature of a gaseous heat source, comprising the steps of passing said liquefied gas over one face of each of two axially extended heat-exchanging surfaces of a heat-exchanger device, said liquefied gas passing along said surfaces in opposite directions, passing a relatively warm gas from said heat source over the other face of each of said heat-exchanging surfaces in indirect heat-exchange with said liquefied gas, said surfaces being disposed in the same axial position but laterally spaced from each other with respect to the direction of relatively warm gas flow therealong, permitting flow of said liquefied gases along one of said surfaces only during a first portion of each cycle and along the other of said surfaces only during a second portion of each cycle, causing the direction of flow of said relatively warm gas during each portion of each cycle to be the same as the direction of flow of said liquefied gas, permitting condensible gases contained in said relatively warm gas to freeze out on the surface past which liquefied gas is flowing during each portion of each cycle, and utilizing said relatively warm gas flowing along

the surface past which liquefied gas is not flowing during each portion of each cycle to evaporate therefrom condensible gases frozen out thereon during the preceding cycle portion, the time duration of each cycle portion being not greater than the time required for the temperature of the discharged vaporized and warmed gas to fall below a predetermined value.

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CERTIFICATE OF CORRECTION

Patent No. 3,058,317 October 16, 1962

Laurel E. Putman

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 19, for "pressure," read -- pressure. --; line 23, for "serve" read -- serves --; line 59, after "that" insert -- half --; line 63, for "are" read -- area --; column 6, line 75, for "sections" read -- section --; column 9, lines 57 and 58, for "peridically" read -- periodically --; column 11, line 7, strike out "said", second occurrence; line 9, for "heat-exchanging" read -- heat-exchanger --; column 12, line 27, for "the" read -- one --.

Signed and sealed this 5th day of March 1963.

(SEAL)
Attest:

ESTON G. JOHNSON
Attesting Officer

DAVID L. LADD
Commissioner of Patents