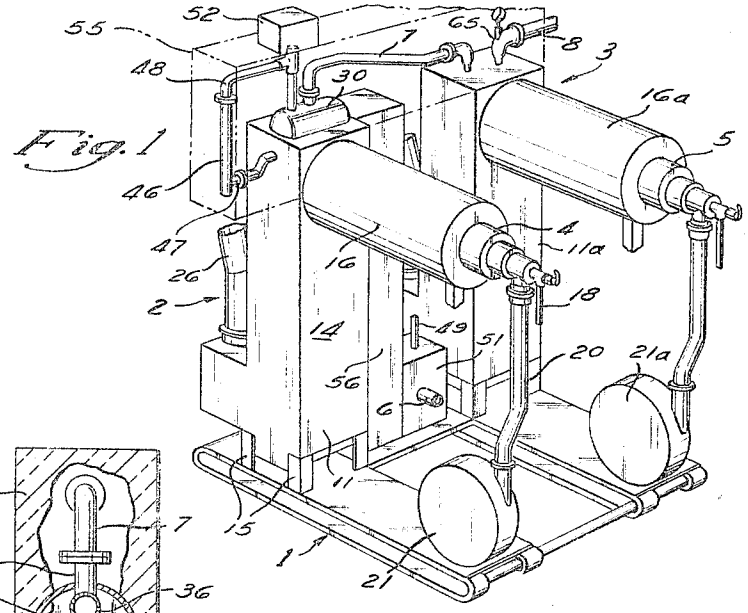
Aug. 30, 1966 T. P. KROEHLE 3,269,367

VAPORIZING APPARATUS AND METHOD

Filed May 18, 1965 3 Sheets-Sheet 1

Fig. 1



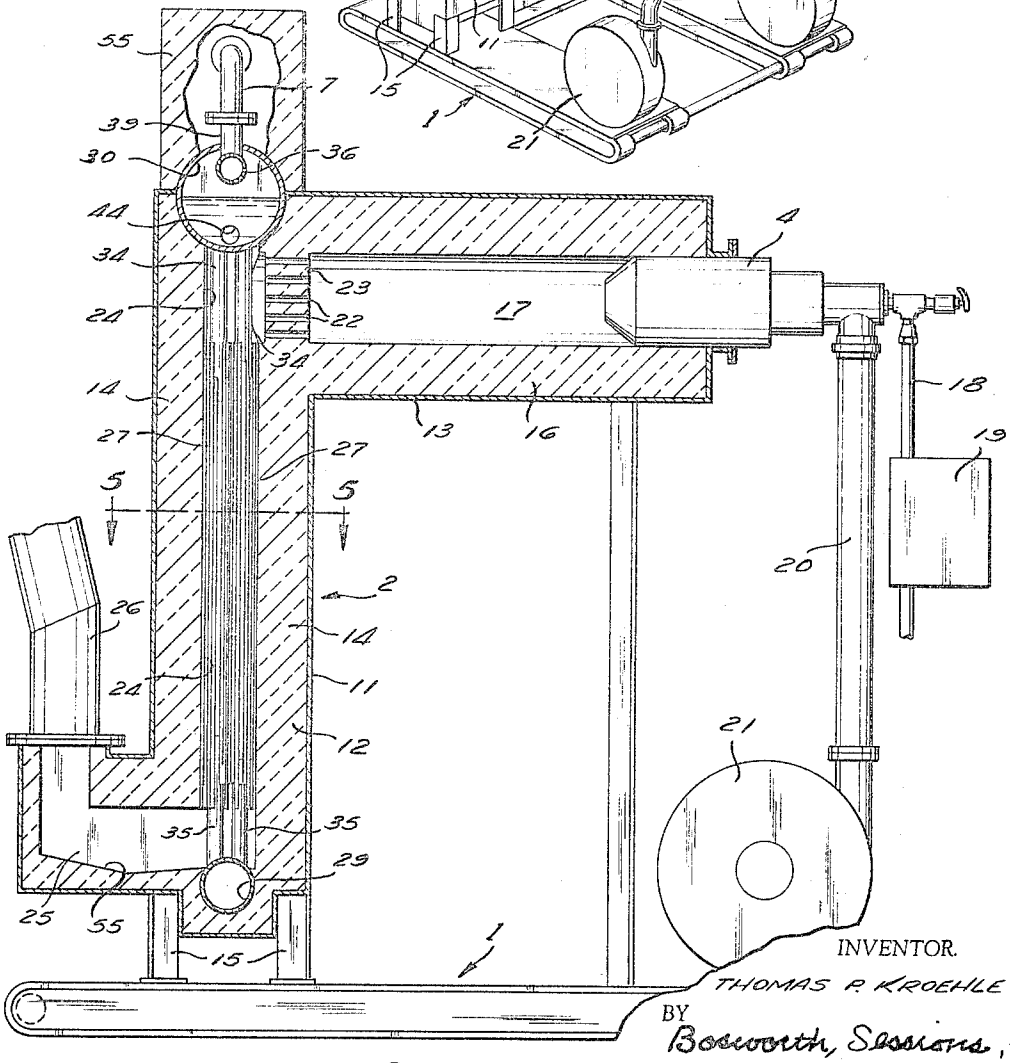


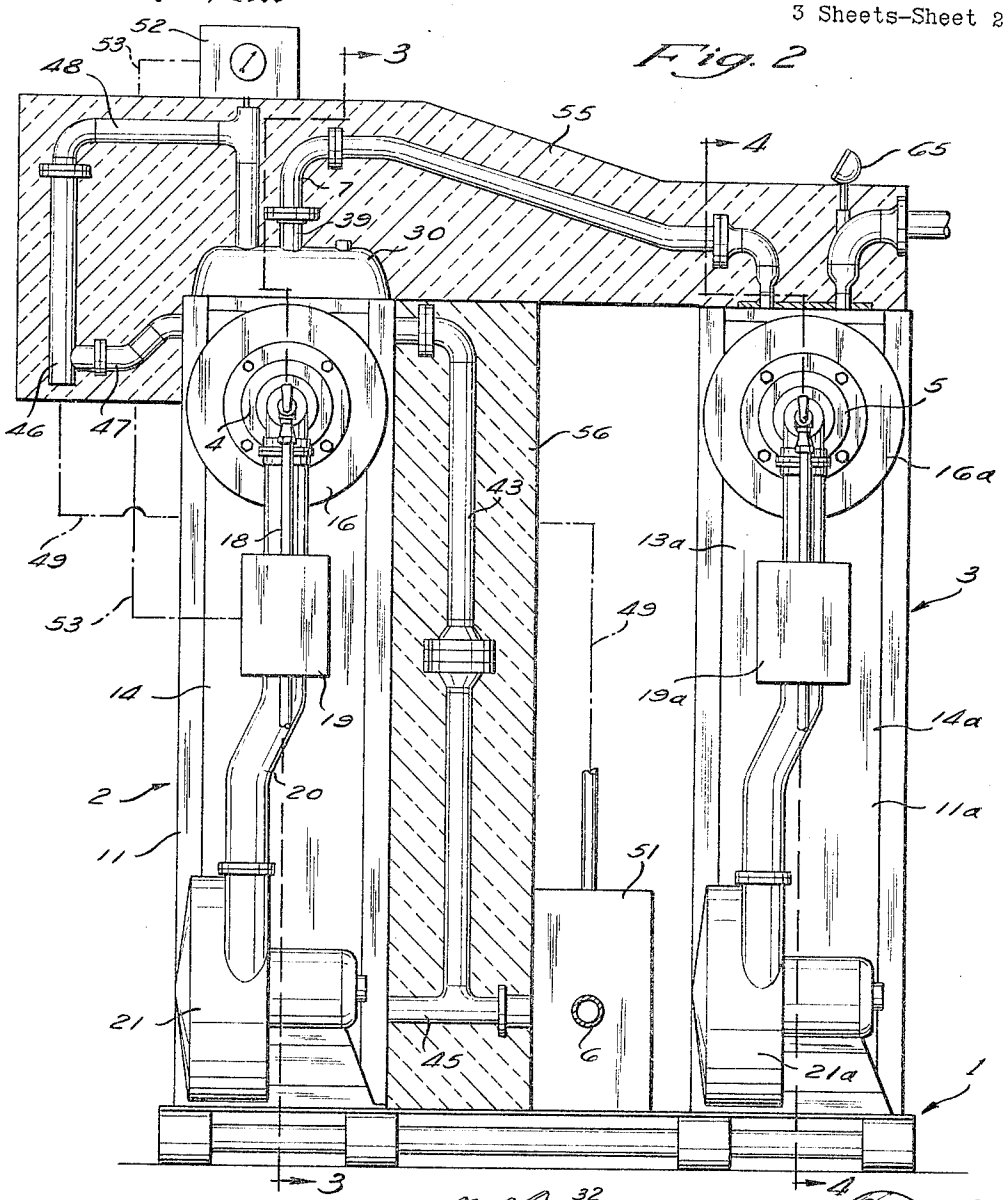
Fig. 3

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VAPORIZING APPARATUS AND METHOD

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Fig. 2



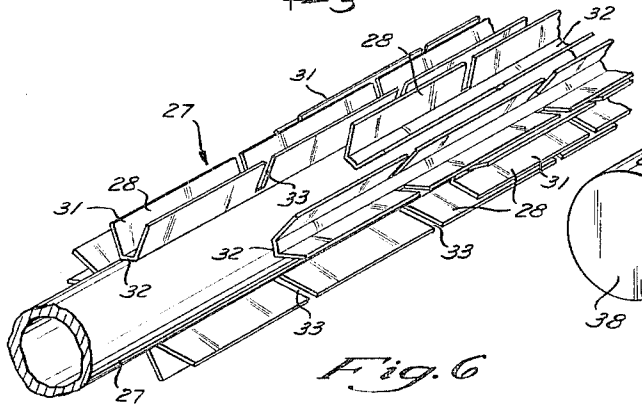


Fig. 6

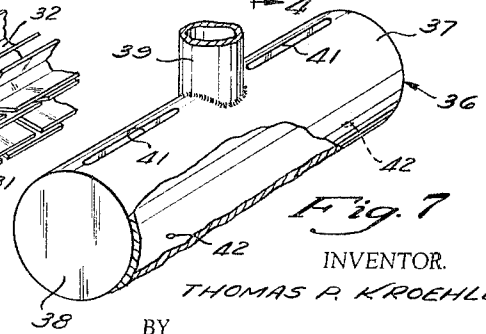


Fig. 7

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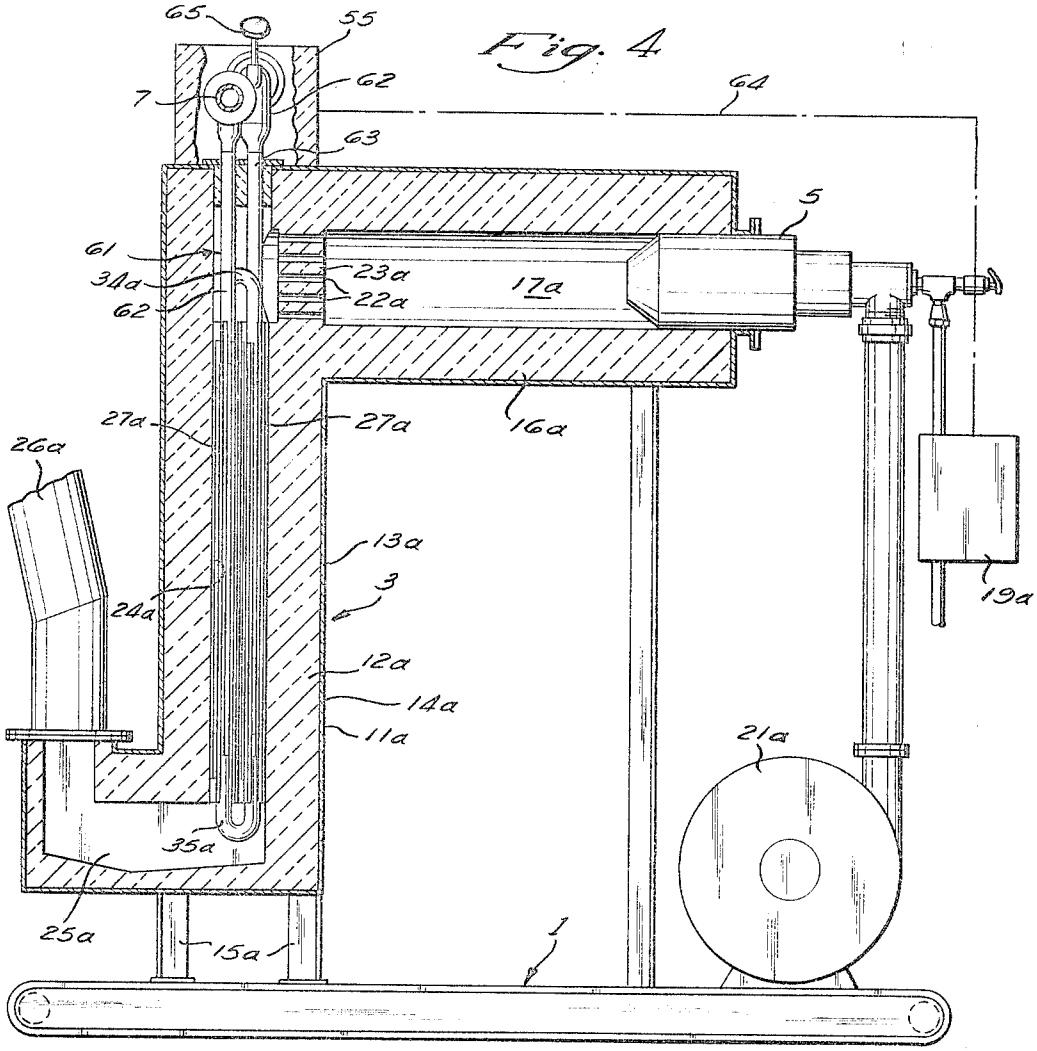
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ATTORNEYS

Aug. 30, 1966 T. P. KROEHLE 3,269,367

VAPORIZING APPARATUS AND METHOD

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Fig. 4



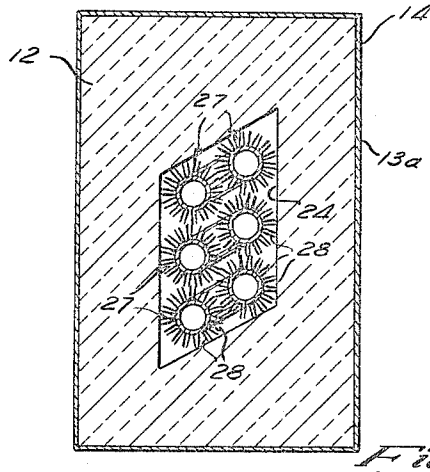


Fig. 5

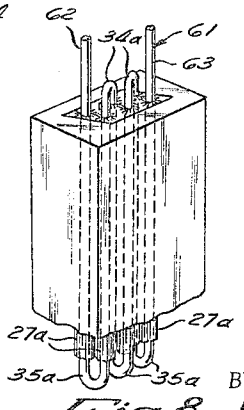


Fig. 8

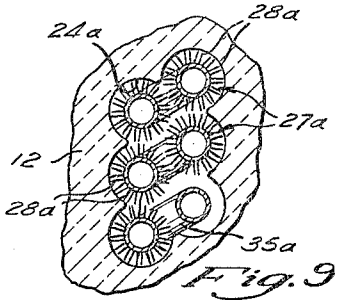


Fig. 9

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United States Patent Office 3,269,367 Patented August 30, 1966

3,269,367

VAPORIZING APPARATUS AND METHOD

Thomas P. Kroehle, Bay Village, Ohio, assignor to Brown Fintube Company, Elyria, Ohio, a corporation of Ohio

Filed May 18, 1965, Ser. No. 463,435
11 Claims. (Cl. 122—448)

This invention relates to method and apparatus for vaporizing liquified gases. This application is a continuation-in-part of application Serial No. 265,206, filed March 14, 1963 by applicant, now abandoned.

For convenience, but not in limitation, the invention will be discussed in connection with the conversion of liquid nitrogen into the gaseous state since it provides particular advantages in such use. In certain applications it is necessary to use substantial volumes of high purity gaseous nitrogen at an accurately maintained temperature of about 65° F. and pressure of about 300 p.s.i.g. (pounds per square inch gauge). The nitrogen is initially stored and supplied in liquid form at a temperature of about —320° F. and at a pressure of about 300 p.s.i.g. The gaseous nitrogen is used at a considerable distance, as much as several hundred yards, from the storage tanks containing the liquid nitrogen. The gaseous nitrogen should be free of droplets of liquified nitrogen to satisfy end use requirements and to prevent localized chilling which could result in deformation or possible cracking of the pipe carrying the nitrogen gas. Furthermore, the temperature and pressure of the gas should be closely controlled to satisfy end use requirements and to minimize undesired expansions or contractions of the pipe. The gaseous nitrogen should be produced at a high and closely controlled rate, and no contaminants should be introduced during the vaporizing operation.

Prior proposals for rapidly producing gaseous nitrogen by applying heat from hot products of combustion to heat exchange means in contact with liquid nitrogen have not satisfied the above requirements. Problems have arisen because ice formed by the freezing of moisture condensed from the ambient air on the heat exchange elements. Other serious problems have occurred because droplets of liquid nitrogen have been discharged into the pipes that carry the gaseous nitrogen.

The general object of the invention is the provision of method and apparatus for converting liquid nitrogen or other liquified gases into dry gas at a desired controlled high rate of production and at accurately maintained temperature and pressure, by means of heat supplied by hot gaseous products of combustion to heat exchange means in contact with the liquified gases, and in contact with vapors of such gases.

The manner of achieving this and other objects of the invention will become apparent from the following description of a preferred method and apparatus for practicing the invention, in connection with the accompanying drawings in which:

FIGURE 1 is a perspective of a preferred form of apparatus for practicing the invention, parts being broken away;

FIGURE 2 is an end elevation of the apparatus of FIGURE 1 viewed from the right of FIGURE 1, but to a larger scale;

FIGURE 3 is a vertical sectional elevation of the vaporizer portion of the apparatus along line 3—3 of FIGURE 2;

FIGURE 4 is a vertical sectional elevation along line 4—4 of FIGURE 2 of the heater portion of the apparatus, FIGURE 4 being to the same scale as 2 and 3;

FIGURE 5 is a horizontal section taken along line 5—5 of FIGURE 3;

FIGURE 6 is a perspective to an enlarged scale showing an end portion of one of the finned heat exchanger tubes which may be used in either the vaporizer or heater portions of the apparatus;

FIGURE 7 is a perspective detail to a larger scale than FIGURES 2 and 3, of means for preventing the escape of droplets of liquified gas into the vaporized gas discharging from the vaporizer portion of the apparatus;

FIGURE 8 is a perspective detail, to a smaller scale, showing the configuration of the heat exchanger tubes in the heater portion of the apparatus; and

FIGURE 9 is a section generally corresponding to FIGURE 5 but showing an alternative cross sectional shape.

General arrangement.—In the illustrated apparatus a base **1** supports a vaporizer portion **2** and a heater portion **3**. Vaporizer portion **2** includes a burner **4**, and heater portion **3** includes a burner **5**. Liquid nitrogen supplied through pipe **6** is vaporized in vaporizer portion **2** by applying heat from burner **4**; the resulting low temperature gaseous nitrogen, at a substantially constant predetermined pressure, then passes through pipe **7** to heater portion **3** in which it is raised to a desired predetermined temperature by heat supplied by burner **5**; the vaporized gas at its predetermined temperature and pressure then flows into pipe **8** through which it flows to its end use.

Vaporizer portion.—Vaporizer portion **2**, as shown in FIGURES 1 and 3, comprises a body **11** formed of a known solid cast refractory heat insulating material **12** enclosed in a steel jacket **13**. Body **11** is formed with an upright portion **14** supported by legs **15** from base **1**, and with a lateral portion **16** connected to portion **14** at its upper end.

A generally horizontal combustion chamber **17** extends through lateral portion **16**. Burner **4** is mounted at the free end of lateral portion **16** to discharge into chamber **17**; the burner is a conventional fluid fuel-fired type and is supplied with fluid fuel through supply pipe **18** controlled by valve means **19**, and with combustion air supplied through conduit **20** from conventional rotary air blower **21** supported by base **1**. The combustion chamber **17** communicates through openings **22** in barrier portion **23** with the upper portion of an upright, preferably vertical, heating chamber **24** in the portion **14** of body **11**. The lower end of chamber **24** communicates with a passage **25** discharging into a flue **26**.

Several upright heat exchanger tubes **27**, each having spaced longitudinally extending external fins **28** on its exterior surface, extend through chamber **24**. These tubes are fixed at their lower ends to a transversely extending lower header **29** and at their upper ends to transversely extending upper header **30**; the interiors of the tubes open into the interiors of the headers.

The outer edges of fins **28** on each tube define a periphery generally circular in cross section as shown in FIGURE 5. Preferably, the tubes are arranged in close parallel relation with their peripheries substantially tangential. The upright chamber **24** is shaped in cross section so it approximates the cross section of the resulting tube bundle, so that the hot combustion gases that are the heating gases passing longitudinally of the tube bundle flow in close proximity to the fins on the tubes for efficient heat transfer as shown in FIGURE 5.

The fins **28** preferably form parts of channel-shaped fin members **31**, each formed of two fins **28** and a base portion **32**, as shown in FIGURE 6. The fin members may be formed into such channels and welded to the exteriors of the tubes as disclosed in Patents 2,298,249 and 2,298,250. The fins **28** of fin members **31** preferably have slots **33** extending from the peripheral edges of the fins inwardly into close proximity to their base portions, as in FIGURE 6. These slots, which preferably are

about 1/8" wide and spaced about 4 inches apart through the length of each fin member, prevent wrinkling or cracking of the fins which otherwise could occur due to the large temperature differential between the peripheral edges of the fins, which are heated by the hot combustion gases passing through chamber 24, and the base portions of the fins, which are at a considerably lower temperature because they are welded to the tubes carrying the liquified nitrogen being vaporized. The upper end of each finned tube has a bare portion 34 so that hot gases passing into heating chamber 24 from combustion chamber 19 can flow circumferentially around the tubes into the spaces between the fins. The lower end of each fin tube also has bare portion 35 to permit gases leaving the spaces between the fins to flow circumferentially around the tubes as they travel to passage 25 and flue pipe 26.

As shown in FIGURES 3 and 6, the fin members at each end of the finned portion of the tube are arranged in longitudinally staggered relation to form a zone of gradually changing heat transfer area providing a gradual temperature gradient between the cooler completely finned portion of each tube and each warmer bare portion, to reduce thermal shock. The importance of this feature is indicated by the fact that, in the illustrated embodiment, per unit of length, the finned portion of each tube takes up five to six times as much heat as the bare portion of the tube.

In order to prevent the escape of droplets of liquified gas in the vaporized gas leaving the system, a dry pipe 36 is disposed in the upper header 30. The dry pipe, shown in FIGURE 7, comprises a horizontal length of pipe 37 having closed ends 38 and having an upper central outlet 39 that is connected to the outlet pipe 7 of the vaporizer portion of the apparatus as shown in FIGURE 3. Pipe 37 has narrow slots 41 in its top wall portion and circular openings 42 in its bottom wall portion. Gas in the upper portion of the upper header 30 enters the dry pipe 36 through slots 41, reverses direction downwardly and then again reverses direction to flow upwardly through the outlet 39 into outlet pipe 7; the double reversal of direction effectively separates from the vapor being discharged droplets of liquid which pass downwardly through openings 42.

As shown in FIGURES 2 and 3, vaporizer portion 2 also includes a recirculation pipe 43, located outside of the body portion 11 and communicating at its upper end with the interior of upper header 30 through an opening 44 located in the lower portion of the header. The lower portion of pipe 43 communicates with the interior of the lower header 29 through a pipe 45 that is also connected to pipe 6 communicating with a source of liquid nitrogen, not shown.

As apparent from FIGURES 1 and 2, there is associated with upper header 30 a liquid level controller 46 communicating at its lower end with the lower portion of header 30 through pipe 47 and at its upper end with the top of the header through pipe 48. This controller is of a conventional type that measures the deviation of the liquid level in the header from a predetermined level, and transmits control signals accordingly. It is connected by suitable means indicated by broken lines 49 to a controlled valve 51 of conventional design that controls the amount of liquid nitrogen entering the system. Liquid level controller 46 controls the operation of valve 51 to maintain within close limits a predetermined level of liquid nitrogen in the upper header 30. The control system may be of conventional electrical or pneumatic type and requires no further description.

The vaporizer portion 2 also includes a pressure sensitive controller device 52 (FIGURES 1 and 2) for measuring the deviations in gas pressure in the upper header from a preset predetermined pressure and for sending control signals accordingly. Controller device 52 is connected by means indicated by broken lines 53 to control the operation of conventional controllable valve means 19 in the fuel supply line 18 to the burner 4 to increase the supply of the burner fuel of the nitrogen gas pressure in the upper header 30 falls below the preset pressure and to decrease the supply of fuel if the gas pressure increases above the preset pressure, to maintain within close limits the desired preset gas pressure in the upper header. The control system, which may be electrically or pneumatically operated, is conventional and requires no further discussion.

In addition to body 11, all parts of the vaporizer portion that carry the cold nitrogen in either liquified or gaseous form are insulated from the ambient air by conventional thermal insulation diagrammatically indicated at 55 and 56.

The operation of the vaporizer portion 2 is as follows, assuming that it is filled with liquid nitrogen to the predetermined level in the upper header 30 and that all portions of the finned tubes on the lower header are initially filled with liquid nitrogen. When operating at full capacity, the burner 4 produces hot combustion gases at temperatures of 2800° to 3000° F. in the combustion chamber 17. The hot gases pass through the openings 22 in the barrier portion 23, which prevents burner flame from impinging directly on the bare portions of the finned tubes 27, and flow downwardly, giving up heat to the finned tubes before they pass outwardly through lower passage 25 to flue pipe 26, the combustion gases in passage 25 being at approximately 1000° F.

The heat supplied by the hot gases to the finned tubes provides the heat of vaporization necessary to convert a portion of the liquid nitrogen into gas that passes upwardly through the finned tubes. The burner output and the heat transfer area of the tubes 27 are so correlated, and the apparatus is so operated that no more than about 10% to about 20% of the fluid passing through the finned tubes is in the form of gas; this gas is essentially in the form of dispersed bubbles completely surrounded by liquid so that there is no formation of gas-separated solid slugs of liquid that could damage the vaporizer portion or associated equipment. Moreover, by this method of operation, it is possible to obtain a substantially constant heat transfer and boiling rate as the fluid passes upwardly through the finned tubes. This makes it possible accurately to predict metal temperatures and design for maximum efficiency and safety. Since the fluid in the finned tubes consists partly of liquid and partly of gas, its specific gravity is less than that of the liquid (from which the gas has been separated) in the recirculating pipe 43 communicating with the upper and lower headers 29 and 30, with the result that fluid circulated from the lower header upwardly through the finned tubes to the upper header and downwardly from the upper header through the recirculation pipe 43 back to the lower header.

The amount of liquid nitrogen supplied to the system is controlled by the level of the liquid in the upper header as described above. In the event that gas is discharged from the vaporizer portion at a rate greater than the rate of production of gas by the evaporation of liquid nitrogen, the pressure in the upper header 30 will tend to fall below the preset predetermined pressure. When this occurs, the pressure sensitive control 52 and valve means 19 increases the supply of fuel to the burner 4 and the rate at which heat is supplied to the finned tubes, thus increasing the rate of vaporization of the liquid nitrogen. When the gas pressure in the upper header increases above the predetermined pressure, the amount of fuel supplied to the burner is decreased with a consequent reduction in the rates of combustion and of vaporization. The result is that the pressure in the upper header is maintained substantially constant within reasonably close limits.

The apparatus is so designed and operated that when the burner 4 is full on, the heat supplied to the system is sufficient to prevent ice formation on the outsides of the finned tubes. Even if the moisture in the combustion

gases tends to freeze because of lower combustion gas temperatures at the lower ends of the finned tubes when the burner is operating at a lower rate, any ice that tends to accumulate will form between the fins on the outside of the lower portion of one or more finned tubes. Should ice form, the new free flow area available for flow of combustion gases is decreased, but since a substantially constant mass flow of gas is maintained for a given set of burner operating conditions, the combustion gas velocity increases, causing an increase in the rate of transfer of heat from the combustion gases to the fins. Furthermore, the design is such that per unit of finned length on each finned tube **27**, the heat transfer area provided by the fins **28** is substantially greater, preferably at least twice as great, as the heat transfer area provided by the extension surface of the tube in the absence of the fins; consequently, then if a layer of ice should form on the tube between the fins, the major portions of the depth and the heat transfer area of the fins are at all times exposed to combustion gases, so that the major portion of the heat transfer area is not reduced by ice formation. These factors tend to prevent formation of ice, but if it does form, they limit the ice to a relatively thin layer on the tube and base portions of the fins which layer ordinarily is less than about ⅛" thick. When the ice melts due to an increase in combustion rate, the downward flow of combustion gases aids gravity in moving the resulting water downwardly to the bottom of the unit from which it is easily removed either by being carried away in the flue gases or, if necessary, by draining from passage **25** which, as shown in FIGURE 3, preferably is formed with a sump portion **55** for such purpose.

Nitrogen in the gaseous state, wholly or practically free of any droplets of liquid nitrogen, is discharged from the vaporizing portion at a substantially constant pressure and in an amount closely responsive to calls on the vaporizing portion **2**. The temperature of the nitrogen gas leaving this portion depends primarily on the pressure in the upper header **30**. If this pressure is atmospheric pressure, the temperature of the leaving gas will be about —320° F.; if the pressure is about 150 p.s.i.g. the temperature will be about —270° F.; and if the pressure is about 300 p.s.i.g. the temperature will be about —250° F.

Heater portion.—When, as is usually the case, the end use for which the gas is supplied requires the gas to be at considerably higher temperature than that at which it is discharged from the vaporizing portion, it is necessary to heat the gas to the desired temperature. The heater portion **3** of the illustrated apparatus (see (FIGURES 1 and 4 is designed to accomplish this. It is similar to the vaporizer portion **2** in having a main body **11***a* formed of cast refractory material **12***a* enclosed in a sheet metal housing **13***a*. Main body **11***a* comprises an upright portion **14***a* supported by legs **15***a* and connected at its upper end to a lateral portion **16***a* defining a combustion chamber **17***a* having burner **5** at its free end. The burner **5** and combustion air supply blower **21***a* may be similar to, and preferably for standardization are identical to, the corresponding parts of vaporizer portion **2**. The combustion chamber **17***a* at its end remote from the burner has a barrier portion **23***a* with openings **22***a* that permit hot combustion gases but not flames to pass. The hot combustion gases pass downwardly through an upright heating chamber **24***a* and outwardly at the bottom of the unit through passages **25***a* to flue pipe **26***a*.

Disposed in heating chamber **24***a* are several tubes having finned portions **27***a* which for standardization are identical to the finned tubes **27** of vaporizer portion **2** as to tube diameters, numbers of fins **28***a*, size and spacing of fin slots **33**, heat transfer areas per unit of length, and staggering of the fin members on each tube to provide zones at the ends of the finned portions which result in gradual temperature gradients and reduce thermal shock between the completely finned portions of each tube and the bare portions **34***a* and **35***a* thereof.

The finned portions **27***a* of the tubes are closely spaced in a bundle so that the generally circular cross section defined by the outer peripheries of the fins are in generally tangential relation, and the cross sectional shape of heating chamber **24***a* approximates the cross section of the tube bundle. FIGURE 5 can also illustrate the cross sectional arrangement of tubes **27***a* in heater chamber **24***a*. FIGURE 9 shows that chamber **24***a* can be shaped in cross section so it very closely conforms to the cross section defined by the tube bundle for even more greatly increased heating efficiency. Obviously, the chamber **24** of the vaporizer portion can also be so shaped.

The finned portions **27***a* of the tubes are interconnected in series to provide a single long tube **61** of sinuous configuration, shown in FIGURES 4 and 8. The inlet **62** and outlet **63** of this single long tube are both at the top of the apparatus. Nitrogen gas at the low temperature at which it is discharged from the vaporizer unit **2** enters the inlet end of this sinuous tube **61** at the upper end of the apparatus, passes downwardly through the first finned portion **27***a* of the tube, then through a bare U-shaped section **35***a* to an adjacent finned portion **27***a*, upwardly through such section, through another curved section **34***a* at the upper end, to another finned portion **27***a* adjacent the first finned portion of tube downwardly through such section, and so on, so that in the apparatus illustrated the nitrogen gas passes alternately downwardly and upwardly for a total of six times before it is discharged. The same advantages of inhibiting icing at low burner rates are provided in this heater portion **3** as in the vaporizer portion **2**, and the same advantages in removal of water from melting ice are also provided because of downward flow of heating gas.

In heater portion **3**, the rate of combustion of burner **5** is controlled by conventional controllable valve means **19***a* connected by conventional means indicated by broken lines **64** to a conventional temperature sensitive controller **65** designed so that when the temperature of the nitrogen gas leaving heater portion **3** drops below the preset temperature, the flow of fuel to the burner is increased to increase the amount of heat supplied to the nitrogen gas passing through the finned tubes to raise its temperature, and when the temperature of the heated gas increases to above the preset temperature, the fuel flow is decreased to decrease heat supplied to the gas passing through the finned tubes. The temperature of the outlet gas is thus controlled within close limits.

The rate of gas flow through heater portion **3** is controlled by the demand on the apparatus as a whole for gaseous nitrogen.

The sinuous configuration of the finned tube provides several advantages. Since the finned tube lengths are connected in series, the gas velocity through each length is considerably greater than if they were connected in parallel, with an accompanying increase in the rate of transfer of heat to the gas in each tube length. Furthermore, since the gas abruptly changes direction several times, any droplets of liquid that might have escaped into the heater portion **3** from the vaporizer portion **2** are separated from the gas at it passes through the tube and are vaporized immediately and completely upon contacting the heated tube walls.

Summary.—The above apparatus thus makes it possible rapidly to convert low temperature liquid nitrogen or other liquified gases directly from the liquid state to the gaseous state by the application of hot combustion gases resulting from fired units, heat exchange means in contact with the liquified gases and with vapors of such gases, without the necessity of using intermediate heat exchange fluids or other expedients heretofore employed. The apparatus is rugged, simple in operation, less costly in construction and more effective and economical in initial costs and operating expenses than other types of apparatus for the same purpose. While the invention has been disclosed as used in vaporizing liquid nitrogen

gas at certain illustrative temperatures and pressure, it may be used at other pressures and temperatures, and also may be employed to convert to the gaseous state liquified gases other than nitrogen, and to deliver gases at any of a wide range of temperatures and pressures.

Those skilled in the art will appreciate that changes and modifications can be made in the invention without departing from the spirit and scope thereof. The essential features of the invention are defined in the appended claims.

What is claimed is:

1. Apparatus for vaporizing a low temperature liquified gas by hot gaseous combustion products comprising: a gas-containing system including conduit means comprising a heat-transfer wall adapted to have one side thereof exposed to liquified gas and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing substantially increased heat-transfer area, means for supplying liquified gas to said conduit means, and means for removing gaseous gas from said conduit means; a heating system comprising a source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the pressure of gaseous gas produced in said conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to vaporize liquified gas in said conduit means and inhibit formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products.

2. Apparatus for vaporizing a low temperature liquified gas by hot gaseous combustion products comprising: a gas-containing system including conduit means comprising a heat-transfer wall adapted to have one side thereof exposed to liquified gas and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing extended heat-transfer surfaces that per unit of length of said wall provide a heat-transfer area at least twice as great as that of a like wall having no projections, means for supplying liquified gas to said conduit means at a first location therein, and means for removing gaseous gas from said conduit means at a second location therein spaced from said first location, a heating system comprising a source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the pressure of gaseous gas produced in said conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to vaporize liquified gas in said conduit means and inhibit formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products.

3. Apparatus for vaporizing a low temperature liquified gas by hot gaseous combustion products comprising: A gas-containing system including upwardly extending elongated conduit means comprising an upwardly extending heat-transfer wall adapted to have one side thereof exposed to liquified gas and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing substantially increased heat-transfer area, means for supplying liquified gas to said conduit means at a lower location, and means for removing gaseous gas from said conduit means at an upper location; a heating system comprising a source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source downwardly through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the pressure of gaseous gas produced in said conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to vaporize liquified gas in said conduit means and inhibit formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products.

4. Apparatus for vaporizing a low temperature liquified gas by hot gaseous combustion products comprising: A gas-containing system including upwardly extending elongated conduit means comprising an upwardly extending heat-transfer wall adapted to have one side thereof exposed to liquified gas and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing extended heat-transfer surfaces that per unit of length of said wall provide a heat-transfer area at least twice as great as that of a like wall having no projections, means for supplying liquified gas to said conduit means at a lower location, and means for removing gaseous gas from said conduit means at an upper location; a heating system comprising a source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source downwardly through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the pressure of gaseous gas produced in said conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to vaporize liquified gas in said conduit means and inhibit formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products.

5. Apparatus for heating a low temperature gas by hot gaseous combustion products containing water vapor, comprising: a gas-containing system containing upwardly extending elongated conduit means comprising an upwardly extending heat-transfer wall adapted to have one side thereof exposed to gas to be heated and the other side thereof exposed to said hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing extended heat-transfer surfaces that, per unit of length of said wall, provide a heat-transfer area at least twice as great as that of a like wall having no projections, means for supplying gas to be heated, at a temperature which tends to form on said tube runs ice from the water vapor in said gaseous combustion products, to said conduit means at a lower location and means for removing gaseous gas from said conduit means at an upper location; a heating system comprising a source of hot gaseous combustion products containing water vapor, a passage extending

along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source downwardly through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the temperature of gaseous gas produced in said conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to heat said gas to be heated in said conduit means and inhibit the formation on said projections on said heat-transfer wall of ice from the water vapor in said combustion products that could substantially impede flow of gaseous combustion products.

6. Apparatus for vaporizing and heating a low temperature liquified gas by hot gaseous combustion products comprising: a first gas-containing system including first upwardly extending elongated conduit means comprising an upwardly extending heat-transfer wall adapted to have one side thereof exposed to liquified gas and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing extended heat-transfer surfaces that, per unit of length of said wall, provide a heat-transfer area at least twice as great as that of a like wall having no projections, means for supplying liquified gas to said first conduit means at a lower location, and means for receiving gaseous gas from said first conduit means at an upper location; a first heating system comprising a source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall having said projections, means causing hot gaseous combustion products to flow from said source downward through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the pressure of gaseous gas produced in said first conduit means to control said source so that heat supplied by said hot gaseous combustion products to said heat-transfer wall and said projections thereon is sufficient to vaporize liquified gas in said first conduit means and inhihit formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products; and a second gas-containing system including second upwardly extending elongated conduit means comprising an upwardly extending heat-transfer wall adapted to have one side thereof exposed to gas to be heated and the other side thereof exposed to hot gaseous combustion products, projections on the side of said wall adapted to be exposed to said hot gaseous combustion products providing extended heat-transfer surfaces that, per unit of length of said wall, provide a heat-transfer area at least twice as great as that of a like wall having no projections, means connecting said receiving means of said first gas-containing system to a lower location in said conduit means of said second gas-containing system; and means for removing gaseous gas from said second conduit means at an upper location thereof; a heating system comprising a second source of hot gaseous combustion products, a passage extending along the side of said heat-transfer wall of said second gas-containing system having said projections, means causing hot gaseous combustion products to flow from said source downwardly through said passage, said passage being shaped to cause said hot gaseous combustion products flowing through said passage to pass in close proximity to said surface of said heat-transfer wall and said projections thereon; and means responsive to the temperature of gaseous gas produced in said second conduit means to control said source so the heat supplied by said hot gaseous combustion products to said heat-transfer wall and projections thereon is sufficient to heat said gas to be heated in said second conduit means and inhibit the formation on said heat-transfer wall of ice that could substantially impede flow of gaseous combustion products.

7. A method of heating a low temperature fluid by heat transfer from hot gaseous combustion products containing water vapor, the temperature of the fluid being so low as to tend to cause the formation of ice from the water vapor in said combustion products, which method comprises maintaining the low temperature fluid in a column in contact with one side of a heat transfer wall, passing hot gaseous combustion products along the other side of said wall in contact with projections thereon providing substantially increased heat transfer area, and controlling the temperature and rate of flow of said hot gaseous combustion products along said wall so that at least the free end portions of said projections are maintained at elevated temperatures high enough to prevent ice formation on said free end portions of said projections that could harmfully impede flow of said hot gaseous combustion products.

8. A method of heating a low temperature fluid by heat transfer from hot gaseous combustion products containing water vapor, the temperature of the fluid being so low as to tend to cause the formation of ice from the water vapor in said combustion products, which method comprises maintaining the low temperature fluid in a column in contact with one side of a heat transfer wall the other side of which has projections thereon providing substantially increased heat transfer areas, collecting from said column said fluid in the gaseous state, passing said hot gaseous combustion products along said side of said heat transfer wall having said projections thereon in contact with said projections, and controlling in response to the pressure of the collected gaseous gas the temperature and the rate of flow of said gaseous combustion products along said wall so that heat transferred through said wall to said low temperature fluid in said column heats said low temperature fluid and so that at least the free end portions of said projections are maintained at elevated temperatures high enough to prevent ice formation on said free end portions of said projections that could harmfully impede flow of hot gaseous combustion products.

9. A method of heating a low temperature fluid by heat transfer from hot gaseous combustion products containing water vapor, the temperature of said fluid gas being so low as to tend to cause the formation of ice from the water vapor in said combustion products, which method comprises maintaining the low temperature fluid in a column in contact with one side of a heat transfer wall the other side of which has projections thereon providing substantially increased heat transfer area, collecting from said column said fluid in a gaseous state, passing said hot gaseous combustion products along said side of said heat transfer wall having said projections thereon in contact with said projections, and controlling in response to the temperatures of the collected gaseous gas the temperature and rate of flow of said hot gaseous combustion products so that heat transferred through said wall to said low temperature fluid in said column heats said low temperature fluid and so that at least the free end portions of said projections are maintained at elevated temperatures high enough to prevent ice formation on the free end portions of said projections that could harmfully impede flow of said hot gaseous combustion products.

10. Apparatus for heating a low temperature gas by hot gaseous combustion products containing water vapor, comprising: a gas-containing system comprising a sinuous tube comprising a bundle of closely-spaced, parallel tube runs having heat transfer projections on the exteriors of said tube runs, means defining an insulated

opening in which said bundle of tube runs is disposed, said opening being shaped to cause gas passing through said opening to be in close proximity to said tubes and the projections thereon, means for supplying to one end of said sinuous tube gas to be heated at a temperature which tends to form on said tube runs ice from water vapor in said gaseous combustion products, and means for removing from the other end of said sinuous tube gas that has been heated; a heating system comprising a source of hot gaseous combustion products containing water vapor, means causing said hot gaseous combustion products to flow from said source to said passage and to flow through said passage in close proximity to the exteriors of said tube runs and said projections thereon; and means responsive to the temperature of the gas that is heated in said tube to control said source so that the heat supplied by said hot gaseous combustion products to said tube runs and the projections thereon is sufficient to heat gas to be heated in said tube and inhibit formation on said projections on said tube runs of ice from said water vapor in said combustion products that could substantially impede flow of gaseous combustion products.

11. A method of vaporizing and heating a low temperature liquified gas comprising: maintaining the liquified gas in a first upwardly-extending column in which the liquified gas is in contact with one side of a first heat transfer wall, collecting gaseous gas at the top of said first column, passing hot gaseous products of combustion downwardly along the other side of said first heat transfer wall, and controlling in response to the pressure of the collected gaseous gas the rate of flow of said gaseous combustion products and the heat content thereof to transfer through said first heat transfer wall to said liquified gas in said first column heat at a rate that causes the formation in said first column of bubbles of gas substantially completely surrounded by liquid and that inhibits formation on said first heat transfer wall of ice that could harmfully affect heat transfer through said wall; and passing the gaseous gas collected at the top of said first column to the lower portion of a second upwardly-extending column in which the gas is maintained in contact with one side of a second heat transfer wall, collecting heated gaseous gas at the top of said second column, passing hot gaseous products of combustion downwardly along the other side of said second heat transfer wall, and controlling in response to the temperature of collected gaseous gas the rate of flow of said gaseous combustion products and the heat content thereof to transfer through said second heat transfer wall to said gas in said second column heat at a rate that causes the gas in said second column to be substantially heated and that inhibits formation on said second heat transfer wall of ice that could harmfully affect heat transfer through said wall.

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