METHOD AND SYSTEM FOR VAPORIZING AND SUPERHEATING CRYOGENIC FLUIDS

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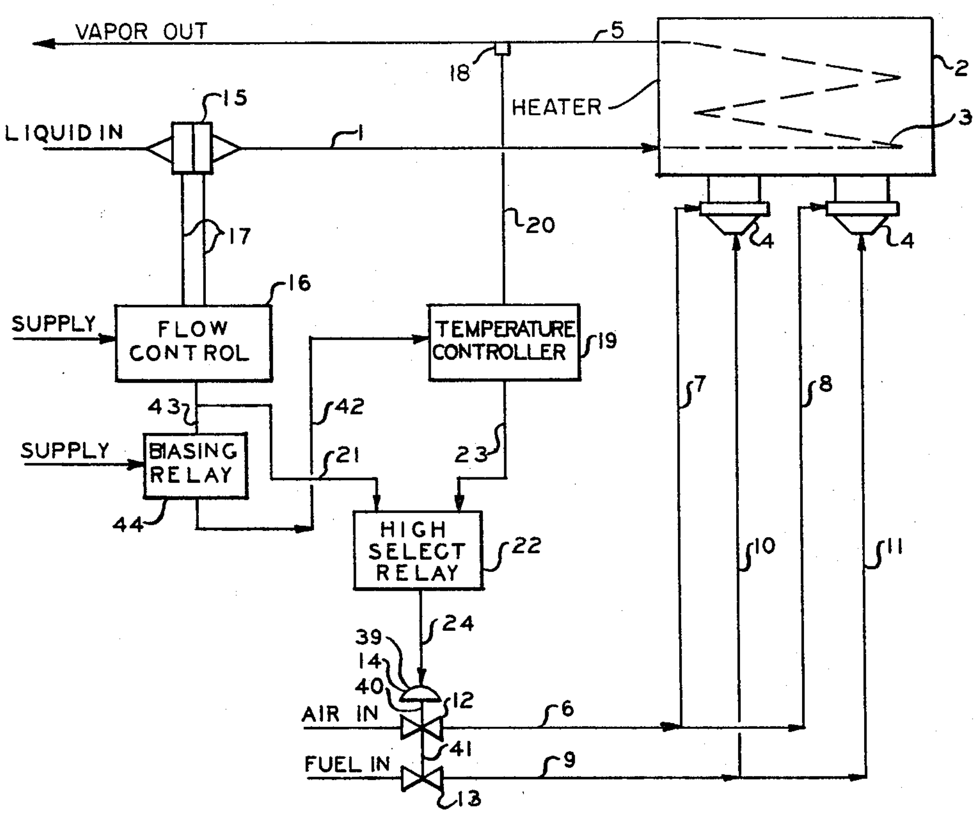

FIG. 1

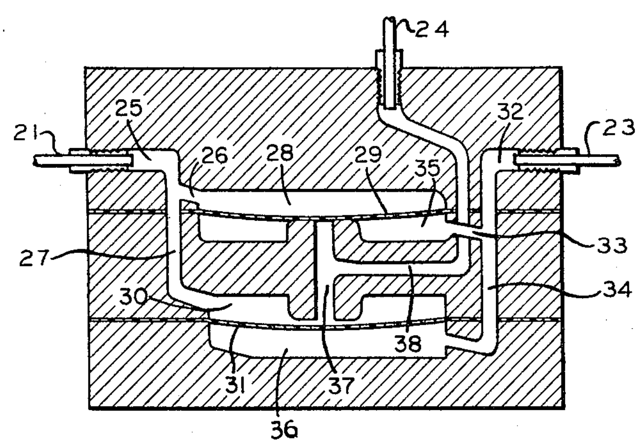

FIG. 2

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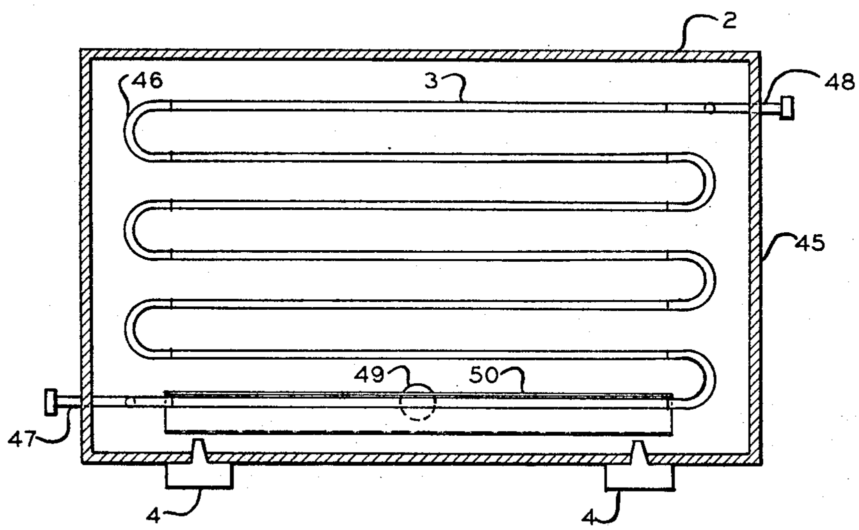

FIG. 3

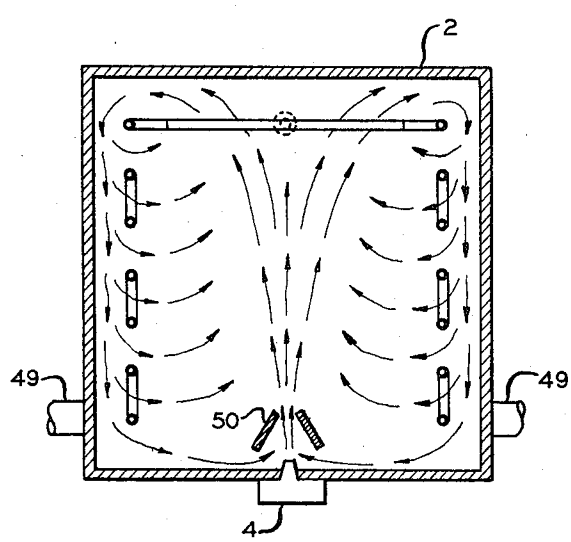

FIG. 4

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3,398,723
METHOD AND SYSTEM FOR VAPORIZING AND SUPERHEATING CRYOGENIC FLUIDS

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ABSTRACT OF THE DISCLOSURE

The present invention relates to an improved method and system for vaporizing and superheating cryogenic fluids, and more particularly, to an improved method and system for convectively heating cryogenic fluids wherein the fluids are vaporized and superheated to a desired temperature under constant or varying throughput conditions.

Background of the invention

The present invention relates to an improved method and system for vaporizing and superheating cryogenic fluids. Cryogenic fluids are those fluids which can exist in the liquid phase only at very low temperatures when at moderate pressures. Such fluids are commonly stored in the liquid phase, and are subsequently converted to the vapor phase for use. For example, liquified natural gas is commonly utilized in the natural gas industry for meeting peak natural gas demands. In areas where natural gas is not locally produced it must be transported by pipeline from remote producing fields. During periods of peak gas consumption, such as a prolonged cold spell, the demand for natural gas may exceed the capacity of the pipeline. When this condition exists, the stored liquified natural gas is vaporized, superheated to prevent subsequent condensation, and injected into the pipeline in order to meet the demand.

Prior to the present invention many attempts have been made with little success to vaporize and superheat cryogenic fluids by directly heating the fluids. These prior attempts have utilized fluid heaters in which the fluid to be heated is conveyed through tubes in a furnace and heat is transferred to the fluid by radiation and convection from combustion gases and flames in the furnace. Due to the very low temperature of cryogenic fluids (approximately −260° F. for liquified natural gas) water vapor condenses on the tubes in the furnace causing layers of ice to form on the outside of the tubes. These layers of ice then reflect radiant heat from the combustion flames in the furnace preventing proper vaporization and superheating of the cryogenic fluids conveyed through the tubes. Prior attempts have failed to overcome this problem. In addition, prior attempts to use direct fired heating of cryogenic fluids have failed due to the utilization of inadequate control systems.

Because of the failure of methods including direct radiant heating hereinbefore described, methods for vaporizing and superheating cryogenic fluids indirectly have been proposed. These methods include directly heating a fluid such as isopentane or water in a furnace, conducting the hot isopentane or water to a heat exchanger, and exchanging heat with the fluid to be vaporized and superheated. These indirect heating methods require expensive and elaborate apparatus, and in addition, fail to achieve adequate heating control. It is essential in most applications that the method for vaporizing and superheating cryogenic fluids achieve close heating control. That is, when the flow rate of fluid to be vaporized and superheated changes, the heat transferred to the fluid must also immediately change so that all the fluid in the liquid phase is vaporized and superheated the desired amount. For example, in the application where liquified natural gas is being vaporized for distribution to domestic consumers, condensation of the gas after vaporization would be detrimental. Therefore, it is essential that a level of superheat be maintained at all times. Quite often sudden increases in the flow of the liquified natural gases required are encountered. These flow increases cause a drop in the quantity of superheat imparted to the gas, and unless the heat input is immediately increased inadequate superheating or even inadequate vaporization of a portion of the liquified natural gas results. The indirect methods utilizing isopentane or water inherently include slow response to sudden changes in flow since the heat input to the intermediate heat transfer fluid must be first increased before the heat input to the fluid being vaporized and superheated can be increased.

The present invention provides a method and system for vaporizing and superheating cryogenic fluids whereby direct heating of the fluid is accomplished and close control of the heat content of the fluid being heated is achieved.

Summary of the invention

The present invention is directed to a method and system for vaporizing and superheating cryogenic fluids wherein heat is transferred to the fluid totally through convective heat transfer with no heat being transferred by radiant heat transfer. The fluid is passed through a furnace within a plurality of tubes. Fuel and air are combusted in combustion chambers attached to the furnace, and hot products of combustion are discharged into the furnace at a high velocity. Because of the very low inlet temperature of the cryogenic fluid to be vaporized water condenses on the tubes containing the fluid from the hot products of combustion. This condensed water then freezes on the tubes forming layers of ice. However, the ice has little effect on the rate of heat transferred from the hot products of combustion to the fluid since all the heat is transferred by convection and the rate of convective heat transfer is relative to the area of surface being heated rather than the material of the surface. Thus, a heating step is provided wherein heat is transferred solely by convection, the rate of which is not affected by the presence of layers of ice on the tubes containing the fluid being heated.

The present invention further provides for closely controlling the level of superheat imparted to the fluid after it has been vaporized even though the fluid flow rate may vary. This is accomplished through the provision of controlling the volume of hot products of combustion released into the furnace in proportion to the temperature of the superheated vapors leaving the furnace and in proportion to the flow rate of fluid to the furnace.

It is, therefore, a general object of the present invention to provide an improved method and system for vaporizing and superheating cryogenic fluids wherein convective heat is transferred directly to the fluids from hot products of combustion.

A further object of the present invention is the provision of a method and system wherein cryogenic fluids are vaporized and superheated to a desired level by controlling the rate of convective heat transferred from hot products of combustion to said fluids.

It is still a further object of the present invention to provide a method and system for vaporizing and superheating cryogenic fluids by conducting the fluid to a heater and detecting the flow rate of the fluid, heating the fluid and detecting the temperature of the fluid after it is heated, controlling the heating of the fluid in a predetermined relation to the detected flow rate and the detected temperature so that said fluid is vaporized and superheated to a desired temperature.

Other and further objects, features, and advantages will be apparent from the following description of presently preferred embodiments of the invention, given for the purpose of disclosure, and taken in conjunction with the accompanying drawings.

Description of the drawings

In the drawings forming a part of the disclosure herein, like character references designate like parts throughout the several views wherein:

FIGURE 1 illustrates in diagrammatic form a system for carrying out the method of this invention,

FIGURE 2 is a sectional view of the high select relay shown in FIGURE 1,

FIGURE 3 is a front sectional elevation of a heater similar to that illustrated in FIGURE 1, and

FIGURE 4 is a side sectional elevation of a heater similar to that illustrated in FIGURE 1.

Description of the preferred embodiment

Referring now to the drawings, and particularly to FIGURE 1, conduit **1** leads a supply of cryogenic fluid in liquid form to a heater generally indicated by the reference numeral **2**. The fluid passes through a plurality of heating tubes **3** connected in series and disposed within heater **2**. The number and arrangement of heating tubes **3** is determined by standard engineering design practices taking into account such factors as the volume of fluid to be vaporized and superheated, the composition of the fluid, etc. Hot products of combustion are discharged into heater **2** from combustion chambers **4** causing convective heat to be transferred to the fluid within heating tubes **3** as will be discussed in greater detail below. The cryogenic fluid within heating tubes **3** is vaporized and superheated a desired amount. Conduit **5** leads the superheated vapor from the system to a point of use or further distribution.

Combustion chambers **4** are each capable of producing a high velocity jet of hot products of combustion and are of the type described and shown in U.S. Patent No. 3,265,113. Fuel and air are intimately mixed in the combustion chambers, combusted, and hot products of combustion only are discharged from the chambers. Conduit **6** leads air from a source to conduits **7** and **8**. Conduit **7** leads air to one of combustion chambers **4**, and conduit **8** leads air to the other of combustion chambers **4**. Valve **12** in conduit **6** regulates the flow of air traveling from its source to combustion chambers **4**. Conduit **9** leads fuel from a source to conduits **10** and **11**. Conduit **10** leads fuel to one of combustion chambers **4**, and conduit **11** leads fuel to the other of combustion chambers **4**. Valve **13** in conduit **9** regulates the flow of fuel traveling from its source to combustion chambers **4**. If it is desired to regulate the flow of air and fuel to combustion chambers **4** manually, valves **12** and **13** may be manually operable. The system shown illustrates apparatus for automatically controlling the flow of fuel and air to combustion chambers **4** which is the preferred embodiment of the present invention. Valves **12** and **13** are shown as a pneumatically operable assembly generally designated by reference numeral **14**.

A pair of orifice flanges and an orifice, generally designated by reference numeral **15**, are installed in conduit **1**. A pneumatic flow controller **16** senses the differential pressure drop of the fluid across orifice assembly **15** through conduits **17**. Flow controller **16** is of the pneumatic type wherein air or other gas is supplied to the instrument at a pressure level of 20 p.s.i.g. the instrument responds to the differential pressure across orifice assembly **15** with a proportional output pneumatic signal of from 0 to 15 p.s.i.g. No further detailed description of the orifice assembly **15** or the flow controller **16** is given since any conventional pneumatic differential pressure type of flow controller assembly may be used.

A temperature sensing element **18** is installed in conduit **5** and is connected to temperature controller **19** by conduit **20**. Temperature controller **19** is also of the pneumatic type wherein air or other gas is supplied to it at a pressure level of 20 p.s.i.g., and it responds to the temperature sensed by element **18** with a proportional output pneumatic signal of from 0 to 15 p.s.i.g. No further detailed description of element **18**, conduit **20**, or temperature controller **19** is given since any conventional pneumatic temperature controller assembly may be used.

A first portion of the output signal from flow controller **16** is led by conduit **43** to biasing relay **44**. Biasing relay **44** is a relay of the type wherein an output signal adjustably proportional to the input signal is generated. Air or other gas at a pressure level of 30 p.s.i.g. is supplied biasing relay **44** so that an output signal of from 0 to 25 p.s.i.g. may be generated in proportion to the signal generated by flow controller **16**. No further description is given as any biasing relay of the type described may be used.

The output signal from biasing relay **44** is led by conduit **42** to temperature controller **19** and is used as the supply for temperature controller **19**.

A second portion of the output signal from flow controller **16** is led by conduit **21** to one input connection of high select relay **22**, and the output signal from temperature controller **19** is led by conduit **23** to a second input connection of high select relay **22**. High select relay **22** is of the type which responds to two input pneumatic signals with one output pneumatic signal of a pressure level equal to the highest of the two input signals.

FIGURE 2 illustrates one form of such a relay. Input pneumatic signals are led into the relay by conduits **21** and **23**. The pneumatic signal from conduit **21** is led by passage **25** to passages **26** and **27**. Passage **26** leads a portion of the signal into chamber **28** wherein its pressure is exerted on the top surface of diaphragm **29**. Passage **27** leads a portion of the signal into chamber **30** wherein its pressure is exerted on the top surface of diaphragm **31**. Diaphragms **29** and **31** are flexible rubber, or other similar material, which will respond to pneumatic pressure by expanding or bulging. The input pneumatic signal from conduit **23** is led by passage **32** to passages **33** and **34**. Passage **33** leads a portion of the signal into chamber **35** wherein its pressure is exerted on the bottom side of diaphragm **29**, and passage **34** leads a portion of the signal into chamber **36** wherein its pressure is exerted on the bottom side of diaphragm **31**. Passage **37** is located between diaphragms **29** and **31** so that its openings are adjacent to diaphragms **29** and **31**. When the pressure level of the pneumatic signal on the top sides of diaphragms **29** and **31** is equal to the pressure level of the pneumatic signal exerting pressure on the bottom sides of diaphragms **29** and **31** pressure is communicated from both of chambers **30** and **35** to passage **38** through passage **37**. When the pressure of the signal in chambers **28** and **30** becomes greater than the pressure of the signal in chambers **35** and **36**, diaphragms **29** and **31** will bulge towards chambers **35** and **36**. Diaphragm **29** will bulge against the top opening of passage **37** sealing it off. Diaphragm **31** will bulge away from the bottom opening of passage **37** allowing communication of the signal in chamber **30** with passage **38** through passage **37** as shown in FIGURE 2. The signal will be led by passage **38** to output conduit **24**. When the pressure in chambers **35** and **36** becomes greater than the pressure in **28** and **30**, diaphragms **29** and **31** will bulge in the direction of least pressure, sealing the bottom opening of passage **37**, and allowing the signal in chamber **35** to communicate with passage **38** through passage **37**. Thus, the highest of the two input pneumatic signals entering the relay through passages **25** and **32** will be communicated with passage **38** allowing it to exit through conduit **24**.

Referring again to FIGURE 1, high select relay **22** transmits an output pneumatic signal of a pressure level equal to the highest of either the signal from biasing relay **44**, or the signal from temperature controller **19**. This signal is led by conduit **24** to pneumatically operable valve assembly **14**. Assembly **14** is comprised of a pneumatic operator **39** which is adjustably attached to both valve **12** and valve **13**. Pneumatic operator **39** can be any standard transducer of pneumatic pressure to mechanical motion. Operator **39** is mechanically and adjustably linked to valve **12** by link **40** so that movement of operator **39** opens or closes valve **12**. Link **41** is adjustably attached to valves **12** and **13** so that movement of valve **12** moves valve **13** in a predetermined ratio. No further detailed description of valve assembly **14** is given since any pneumatically operated ratio valve assembly may be used.

In operation, the flow of cryogenic fluid in liquid form passing through conduit **1** is sensed by flow controller **16**. A proportional output signal is generated by flow controller **16** and a portion of it is routed to high select relay **22**. A second portion of the output signal from flow controller **16** is routed to biasing relay **44** and the output from biasing relay **44** is used as the supply for temperature controller **19**. The cryogenic fluid is vaporized and superheated in heater **2**. Temperature controller **19** senses the temperature of the superheated vapors passing through conduit **5** and generates a proportional signal which is routed to high select relay **22**. Flow controller **16** is adjusted to generate an output signal of approximately 9 p.s.i.g. when the flow of cryogenic fluid passing through conduit **1** is normal. Biasing relay **44** is adjusted to generate an output signal of 20 p.s.i.g. when the input signal from flow controller **16** is 9 p.s.i.g. Temperature controller **19** is adjusted with a 20 p.s.i.g. supply signal from biasing relay **44** to generate a 12 p.s.i.g. output signal when the temperature of the vapors in conduit **5** is normal. Valve assembly **14** is adjusted to maintain fuel and air flow rates to combustion chambers **4** in the proper volume of fuel to volume of air ratio so that the desired vapor temperature in conduit **5** is maintained. As the temperature of the superheated vapors in conduit **5** varies, valve assembly **14** will receive a proportional signal up to the maximum range of temperature controller **19** (15 p.s.i.g.), and down to the output signal of flow controller **16** (9 p.s.i.g.). As long as the flow of cryogenic fluid through conduit **1** remains constant this 5 p.s.i.g. range is adequate to maintain a constant temperature of vapors in conduit **5**. If the flow of fluid in conduit **1** drops unexpectedly, the output signal from flow controller **16** will drop proportionally. The output signal from biasing relay **44** will also drop proportionally causing the output signal from temperature controller **19** to drop in a corresponding manner. Thus, valve assembly **14** will immediately receive a lower signal when the flow to heater **2** drops, even though the temperature of the vapors in conduit **5** has not yet changed. In the event the flow of fluid in conduit **1** unexpectedly increases the reverse of the steps outlined above will result causing valve assembly **14** to receive an immediate higher signal. Changes in the signal to valve assembly **14** will in turn raise or lower the volume of air and fuel being combusted in combustion chambers **4** which in turn causes more or less heat to be transferred to the fluid being vaporized and superheated. Thus, a system is provided which will cause the heat input to the cryogenic fluid to change immediately upon either flow or temperature changes, and which will maintain a desired temperature thereafter.

Referring now to FIGURES 3 and 4, a heater of the type necessary for carrying out the present invention is illustrated. A plurality of heating tubes **3** are connected in two parallel banks as shown. Return bends **46** are used to connect the tubes in each bank in series. An inlet connection **47** passes through furnace structure **45** in the lower portion of one vertical wall, and an exit connection **48** passes through furnace structure **45** in the upper portion of the opposite vertical wall. High velocity hot products of combustion are discharged from combustion chambers **4**, said chambers having been previously described. Because of the high velocity of the hot products of combustion, efficient circulation of the hot products of combustion occurs within furnace structure **45** as shown by the arrows in FIGURE 4. Baffles **50** are disposed within furnace structure **45** in the position illustrated to facilitate circulation of the hot products of combustion. After the hot products of combustion have circulated through the heater they exit through openings **49** in the lower portion of opposite walls of furnace structure **2**. Since combustion of fuel and air supplied to combustion chambers **4** takes place entirely within chambers **4**, and only hot products of combustion enter the furnace structure, heat is transferred to the fluid within heating tubes **3** by a convective heat transfer process only. The rate of convective heat transferred depends on the surface heated, and not on the material of the surface. Thus, layers of ice which may form on the heating tubes **3** due to the very low temperature level of the fluid being heated have little or no effect on the heat transfer rate from the hot products of combustion to the fluid within the heating tubes.

The present invention, therefore, is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those inherent therein. While presently preferred embodiments of the invention are given for the purpose of disclosure, numerous changes in the details of construction and arrangement of parts can be made which will readily suggest themselves to those skilled in the art and which are encompassed within the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. A method for vaporizing and superheating cryogenic fluids which comprises:
   - conducting the fluid to a heater;
   - detecting the flow rate of said fluid before it enters said heater;
   - heating said fluid;
   - detecting the temperature of said fluid after it is heated;
   - controlling the heating of said fluid in predetermined relation to said detected flow rate and said detected temperature so that said fluid is vaporized and superheated to a constant temperature; and
   - conducting said fluid to a point of distribution.

2. A method for vaporizing and superheating cryogenic fluids which comprises:
   - conducting the fluid to a heater;
   - detecting the flow rate of said fluid before it enters said heater;
   - passing said fluid through a heater within a plurality of tubes;
   - discharging high velocity hot products of combustion within said heater;
   - contacting said tubes containing said fluid with said hot products of combustion whereby heat is transferred from said hot products of combustion to said fluid as it passes through said heater;
   - detecting the temperature of said fluid after it is heated;
   - controlling the heat transferred to said fluid in predetermined relation to said detected flow rate and said detected temperature so that said fluid is vaporized and superheated to a constant temperature; and
   - conducting said fluid to a point of distribution.

3. A method for vaporizing and superheating cryogenic fluids which comprises:
   - conducting the fluid to a heater;
   - detecting the flow rate of said fluid before it enters said heater;
   - heating said fluid whereby it is vaporized and superheated;
   - detecting the temperature of said fluid after it is heated;
   - regulating the heating of said fluid in a predetermined relationship with said detected temperature when said detected flow rate is constant;

regulating the heating of said fluid in predetermined relationship with said detected flow rate when said detected flow rate is not constant; and

conducting said fluid to a point of distribution.

4. A method for vaporizing and superheating cryogenic fluids which comprises:

conducting the fluid to a heater;

detecting the flow rate of said fluid;

passing said fluid through said heater within a plurality of tubes;

mixing combustion air and fuel gas intimately within a gas burner;

burning said mixture of air and gas within said burner thereby creating hot products of combustion within said burner;

releasing said hot products of combustion into said heater;

contacting said tubes containing said fluid with said hot products of combination to said fluid as it passes through said heater thereby vaporizing and superheating said fluid;

detecting the temperature of said fluid after it has passed through said heater;

changing the rate of flow of combustion air and fuel gas to said gas burner in direct proportion to changes in said detected temperature when said detected flow rate is constant;

changing the rate of flow of combustion air and fuel gas to said gas burner in direct proportion to changes in said detected flow rate when said detected flow rate is not constant; and

conducting said fluid to a point of distribution.

5. A system for vaporizing and superheating cryogenic fluids which comprises:

a furnace structure;

a plurality of heating tubes disposed within said furnace structure defining a continuous flow path and having an inlet and an outlet passing through said furnace structure;

means for combusting fuel and air attached to said furnace structure whereby hot products of combustion are discharged into said furnace structure;

a first conduit connected to the inlet of said heating tubes and connected to source of cryogenic fluid supply;

a second conduit connected to the outlet of said heating tubes and connected to a vapor distribution system;

a third conduit connected to the air inlet of said means for combusting fuel and air;

a first valve connected to said third conduit and connected to a source of air;

a fourth conduit connected to the fuel inlet of said means for combusting fuel and air;

a secnod valve connected to said fourth conduit and connected to a source of fuel;

means for controlling the ratio of the volume of air which passes through said first valve to the volume of fuel which passes through said second valve wherbey said ratio is constant over a range of fuel and air volumes; and

means for detecting fluid flow in said first conduit and for controlling the volume of air and fuel passing through said first and second valves whereby the volume of fuel and air changes in predetermined relationship with said detected fluid flow.

6. A system for vaporizing and superheating cryogenic fluids which comprises:

a furnace structure;

a plurality of heating tubes disposed within said furnace structure defining a continuous flow path and having an inlet and an outlet passing through said furnace structure;

means for combusting fuel and air attached to said furnace structure whereby hot products of combustion are discharged into said furnace structure;

a first conduit connected to the inlet of said heating tubes and connected to a source of cryogenic fluid supply;

a second conduit connected to the outlet of said heating tubes and connected to a vapor distribution system;

a third conduit connected to the air inlet of said means for combusting fuel and air;

a first valve connected to said third conduit and connected to a source of air;

a fourth conduit connected to the fuel inlet of said means for combusting fuel and air;

a second valve connected to said fourth conduit and connected to a source of fuel;

means for controlling the ratio of the volume of air which passes through said first valve to the volume of fuel which passes through said second valve whereby said ratio is constant over a range of fuel and air volumes; and

means for detecting fluid temperature in said second conduit and for controlling the volume of fuel and air passing through said first and second valves whereby the volume of fuel and air changes in predetermined relationship with the detected fluid temperature in said second conduit.

7. A system for vaporizing and superheating cryogenic fluids which comprises:

a furnace structure;

a plurality of heating tubes disposed within said furnace structure defining a continuous flow path and having an inlet and an outlet passing through said furnace structure;

means for combusting fuel and air attached to said furnace structure whereby hot products of combustion are discharged into said furnace structure;

a first conduit connected to the inlet of said heating tubes and connected to a source of cryogenic fluid supply;

fluid flow responsive means in said first conduit;

a second conduit connected to the outlet of said heating tubes and connected to a vapor distribution system;

fluid temperature responsive means in said second conduit;

a third conduit connected to the air inlet of said means for combusting fuel and air;

a first valve connected to said third conduit and connected to a source of air;

a fourth conduit connected to the fuel inlet of said means for combusting fuel and air;

a second valve connected to said fourth conduit and connected to a source of fuel;

means for controlling the ratio of the volume of air which passes through said first valve to the volume of fuel which passes through said second valve whereby said ratio is constant over a range of fuel and air volumes; and

means for controlling the volume of fuel and air passing through said first and second valves regulated by said flow responsive means and said temperature responsive means whereby the volume of fuel and air is changed in predetermined relationship with said flow and temperature.

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