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Martin et al.

[11] **3,802,212**

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[54] **REFRIGERATION APPARATUS**

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[52] **U.S. Cl.** **62/52,** 62/80, 62/81, 62/150, 62/151, 62/156, 62/275, 62/208, 62/514, 62/407, 165/2, 62/419, 62/159

[51] **Int. Cl.** **F17c 7/02**

[58] **Field of Search** 62/80, 81, 150, 151, 156, 62/52, 514, 275, 276

[56] **References Cited**

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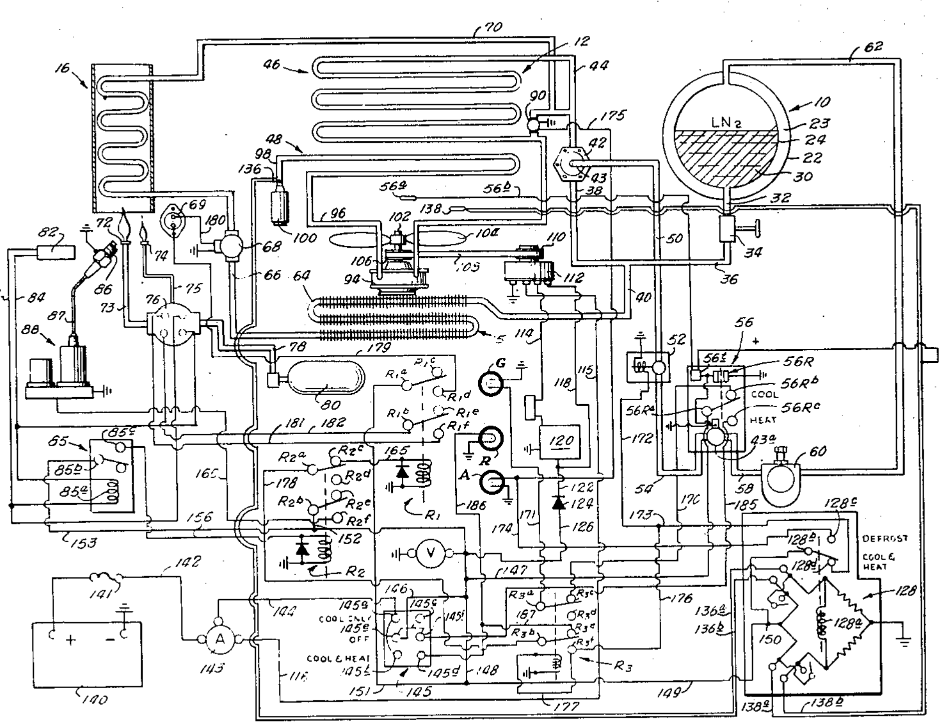
[57] **ABSTRACT**

Apparatus for refrigerating and heating comprising a source of liquid nitrogen arranged to deliver nitrogen selectively through coils of an evaporator or through heating apparatus and then through coils of the evaporator such that nitrogen can be employed for either cooling or heating a cargo compartment. Nitrogen gas exhausted from coils of the evaporator is released to ambient atmosphere outside of the compartment. Temperature sensors are positioned for sensing the temperature of nitrogen gas exhausted to atmosphere and to sense the temperature of air which has been drawn across the evaporator coils. Control apparatus initiates a defrost cycle to cause heated nitrogen vapor to be passed through evaporator coils for defrosting the coils when ice accumulates thereon in sufficient quantity to insulate the coils causing a predetermined temperature differential between the exhaust gas and air drawn across the evaporator coils.

19 Claims, 9 Drawing Figures



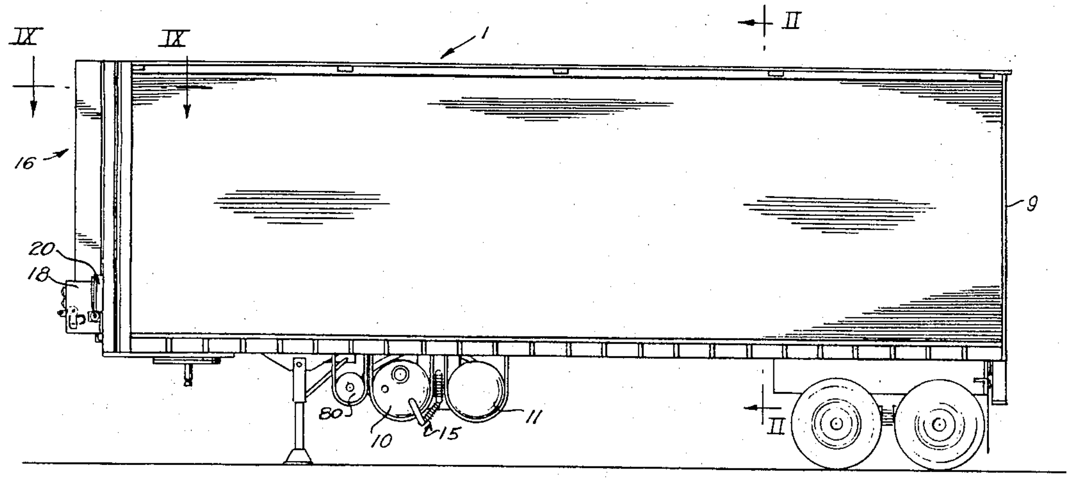


Fig. I

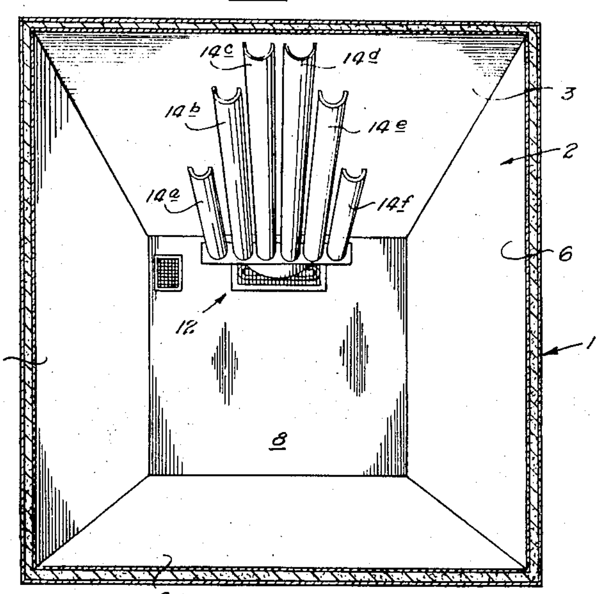


Fig. II

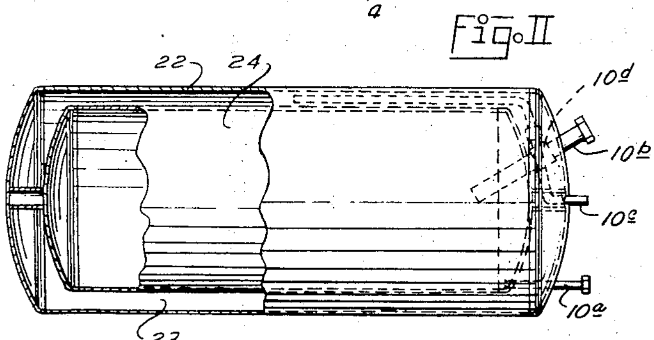


Fig. IV

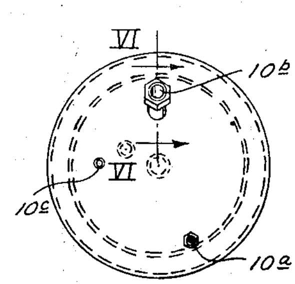


Fig. V

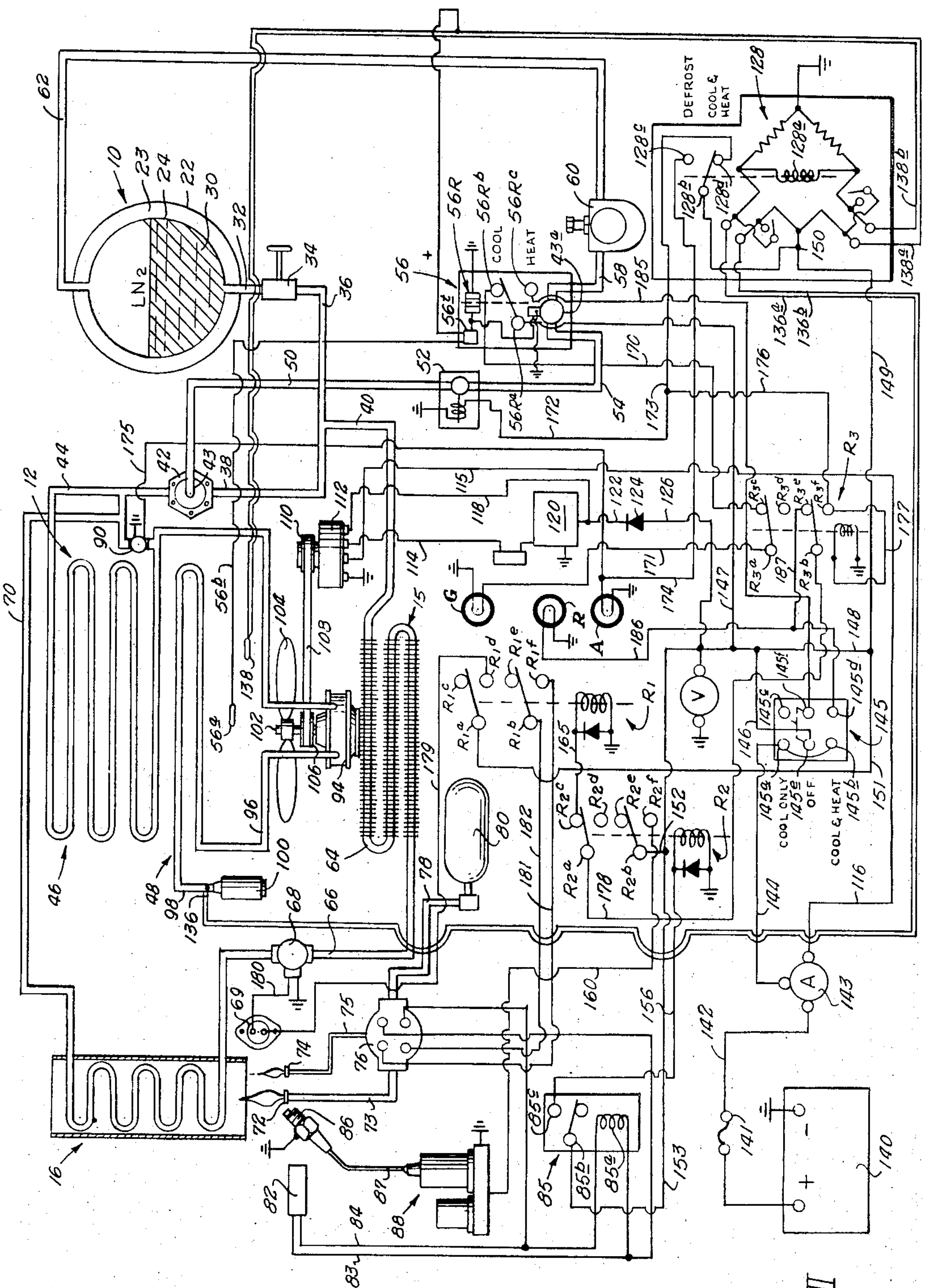


Fig. III

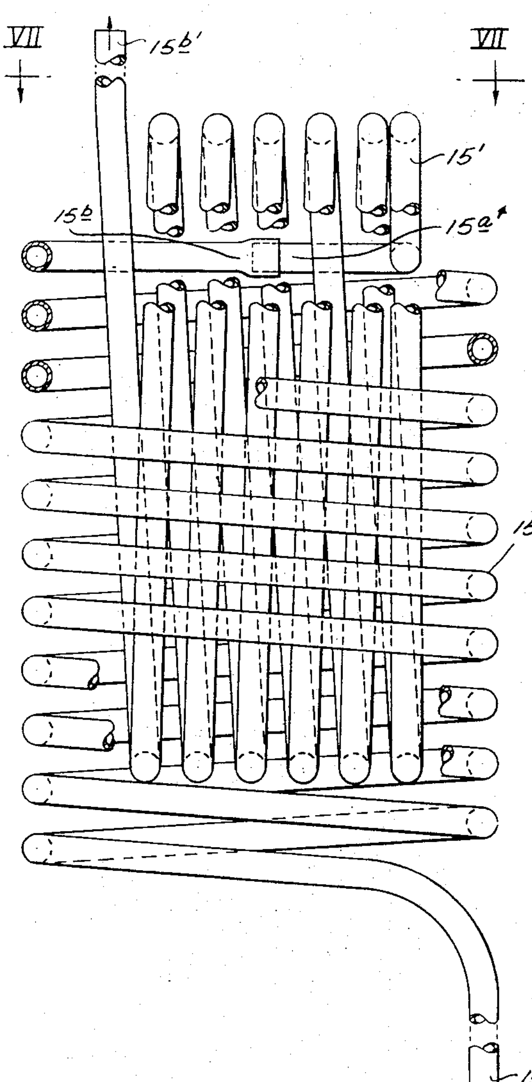


Fig. VIII

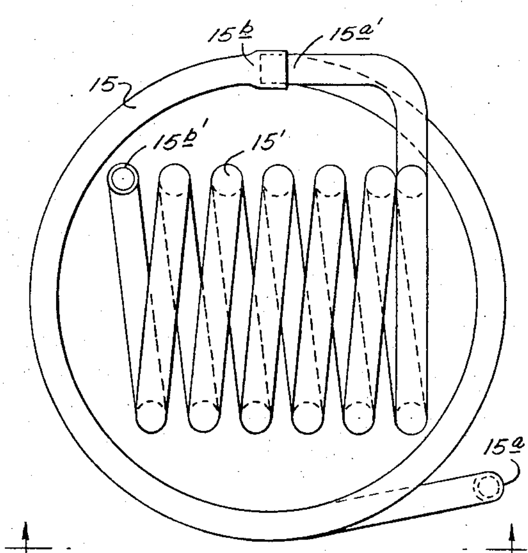


Fig. VII

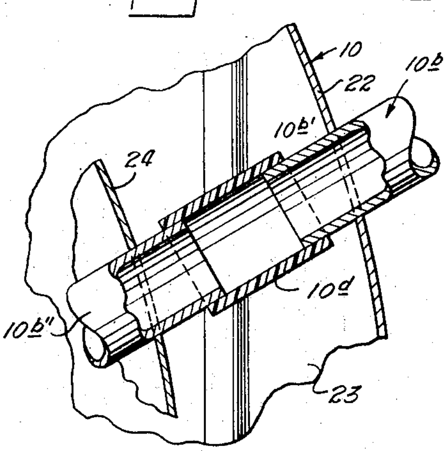


Fig. VI

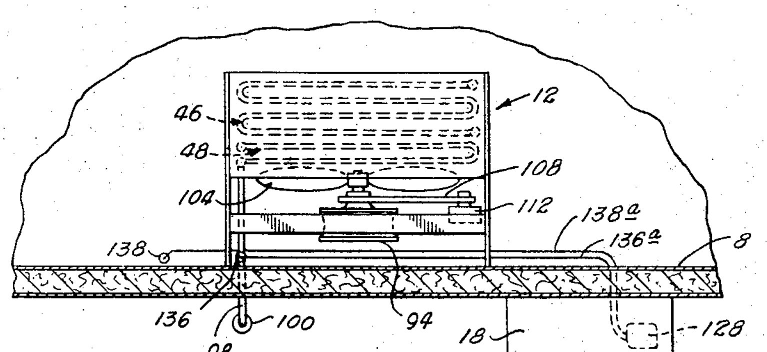


Fig. IX

REFRIGERATION APPARATUS

BACKGROUND OF INVENTION

Apparatus has been devised heretofore for spraying vapor of cryogenic liquid through nozzles into an insulated compartment in which food products are transported. One such spray system is described in U. S. Pat. No. 3,525,235 which points out undesirable characteristics of such systems including variations of several degrees Fahrenheit in temperatures at various locations throughout a compartment.

Spray type systems which discharge cryogenic gas, such as nitrogen, into a refrigeration compartment have numerous inherent characteristics which render the use thereof undesirable because of the presence of the nitrogen enriched atmosphere within the compartment. Meats exposed to the atmosphere often absorb the nitrogen resulting in discoloration of the meat. Vegetable products over a period of time wilt when deprived of oxygen.

The nitrogen gas deposited by a spray system must be removed from the compartment before products can be unloaded therefrom since workman cannot breathe the nitrogen enriched atmosphere. Such evacuation of the atmosphere within the cargo compartment has required excessive quantities of nitrogen to cool the fresh air after a door has been opened to unload a portion of the cargo. The fresh humid air also resulted in excessive frosting.

Refrigeration systems heretofore devised, wherein vapor from cryogenic gas was directed through coils of an evaporator through which air within a compartment was circulated by a fan, have been generally commercially unacceptable because excessive quantities of moisture collect on the evaporator coils forming ice, substantially reducing the heat transfer rate from the coolant to the air drawn across surfaces of the evaporator.

Refrigeration systems heretofore employed for cooling cargo compartments in which food products were transported did not have the capability of circulating heated air uniformly through the compartment when the ambient temperature outside the compartment was less than the minimum allowable temperature inside the compartment. Consequently transporting vegetables, such as lettuce and tomatoes, during winter months in northern portions of the United States and Canada required the use of space heaters positioned at various locations in the compartment to prevent freeze damage.

SUMMARY OF INVENTION

We have developed apparatus for controlling temperature within a mobile compartment wherein vapor delivered from a source of liquid nitrogen or other suitable cryogenic gas, is directed through the evaporator coils for cooling same and then directed through a pneumatically operated motor for driving a fan to circulate air in the compartment across surfaces of the evaporator coils. Nitrogen vapor after passing through the evaporator coils and motor is exhausted to atmosphere.

Temperature sensitive control apparatus is employed for regulating the flow rate of nitrogen vapor through the evaporator coils. The control apparatus is adapted to divert nitrogen through a vaporizer, exposed to ambient temperature, and to direct vapor therefrom through a heating apparatus. The vapor is heated to a temperature of for example 1,000° F. and is delivered through the evaporator coils and the pneumatic motor to cause heated air to be circulated through the storage compartment.

Temperature sensing apparatus is disposed within the system for sensing the temperature differential between return air drawn from across the evaporator coils and nitrogen vapor exhausted from the evaporator coils and pneumatic motor to ambient atmosphere.

We have observed that the heat transfer rate through walls of the evaporator coils is high so long as the temperature differential between the exhaust coolant and air drawn across surfaces of the evaporator coils is less than approximately 35° F. However, as ice begins to form on surfaces of the evaporator coils, the coils become insulated reducing the heat transfer rate through the walls thereof which requires defrosting if efficient operation is to be maintained. Control apparatus is connected to the temperature sensors such that heated nitrogen vapor is routed through the evaporator coils and the pneumatic motor for defrosting same when the temperature differential between return air and exhaust gas exceeds a predetermined limit, for example 35° F.

The defrost cycle is terminated by the control apparatus when the temperature of the heated exhaust vapor and the temperature of the return air, which has passed over surfaces of the evaporator coils, are substantially equal.

A primary object of our invention is to provide refrigeration apparatus particularly adapted to control temperature of a compartment in any vehicle, such as a transport trailer, railroad car, airplane or ship, which is self-contained and which utilizes liquified gas to refrigerate, heat and defrost a compartment without connection to an external source of power.

Another object of our invention is to provide refrigeration apparatus utilizing liquified gas to provide high refrigeration capacity without altering the normal oxygen content in the compartment.

A further object of the invention is to provide refrigeration apparatus which employs the expanding force of cryogenic gas to drive a pneumatic motor to provide forced air circulation through a compartment for providing even temperature control therethrough.

A still further object of our invention is to provide a refrigeration apparatus, having a cryogenic evaporator coil, adapted to be triggered to a defrost cycle when the temperature differential between gas exhausted from the evaporator coil and return air drawn across surfaces of the evaporator exceeds a first predetermined limit and which is triggered back into a cooling cycle when the temperature differential reaches a second predetermined limit.

A further object of our invention is to provide refrigeration apparatus for transport vehicles having a minimum number of moving parts to provide a reliable system requiring minimum maintenance.

A still further object of the invention is to provide a refrigeration system for transport vehicles having high cooling capacity which occupies minimum space within the cargo compartment.

Other and further objects of our invention will become apparent by reference to the detailed description hereinafter following and to the drawings annexed hereto.

DESCRIPTION OF DRAWING

Drawings of a preferred embodiment of our invention are annexed hereto so that the invention will be better and more fully understood, in which:

FIG. I is a side elevational view of a transport vehicle having refrigeration apparatus installed thereon:

FIG. II is a cross-sectional view taken substantially along line II—II of FIG. I;

FIG. III is a schematic diagram of the refrigeration apparatus;

FIG. IV is a partially sectionalized elevational view of a storage vessel for cryogenic gas;

FIG. V is an end view of the tank illustrated in FIG. IV;

FIG. VI is a cross-sectional view taken substantially along line VI—VI in FIG. V;

FIG. VII is a plan view of heat exchanger coils;

FIG. VIII is a side elevational view of the heat exchanger coils; and

FIG. IX is a diagrammatic illustration of the sensor arrangement employed for triggering the defrost cycle.

Numeral references are employed to designate like parts throughout the various figures of the drawing.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIGS. I and II of the drawing, the numeral **1** generally designates a transport vehicle having a cargo compartment **2** disposed therein. The vehicle **1** may assume any desired configuration having top and bottom walls **3** and **4** connected across and upper and lower ends of side walls **5** and **6** and end walls **8** and **9** forming an insulated area on the inside thereof.

As will be hereinafter more fully described, one or more sources **10** and **11** of liquified cryogenic gas are provided for delivering coolant to an evaporator **12**. In the particular embodiment of the invention illustrated in FIG. II, the evaporator **12** is secured to an upper portion of front end wall **8** of the transport and is arranged to force cooled air through a plurality of air ducts **14*a*–14*f*** of varying lengths such that cooled air is distributed uniformly throughout the compartment **2.**

The source of cryogenic gas **10** and **11** is connected through a vaporizer **15,** preferably disposed outside the refrigerated cargo area **2,** to a heating device **16.** Heated vapor from heating device **16** is delivered through coils of evaporator **12** for defrosting same and for causing heating air to be delivered through the cargo compartment.

As will be hereinafter more fully explained, a container **18** houses apparatus employed for controlling the flow of both hot and cold vapor through coils of evaporator **12** and an indicator **20** is connected to suitable temperature sensing means inside cargo compartment **2** for providing a visual indication of the temperature therein.

Referring to FIG. III of the drawing, the source of cryogenic gas **10** preferably comprises an insulated container having an outer shell **22** and an inner shell **24** spaced by a vacuum chamber **23,** as will be hereafter more fully described in the description relating to FIGS. IV, V and VI of the drawing.

Container **10** contains liquid nitrogen **30** and the volume of container **10** above the liquid nitrogen is filled with nitrogen vapor. An insulated tube **32** is arranged to deliver liquid nitrogen through flow control valve **34** to a line **36** communicating with branch lines **38** and **40.**

Branch line **38** is connected through valve **42** and line **44** with primary coils **46** of evaporator **12.**

The flow passage through valve **42** is controlled by suitable actuating means **43** connected to a valve element in the body of the valve. Actuator **43** is preferably pneumatically operated having a movable element disposed therein such that a change in fluid pressure delivered thereto through line **50** causes the movable element to move thereby shifting the valve element for controlling flow through valve **42.** Line **50** is connected through a three-way solenoid actuated valve **52** and line **54** to pneumatic temperature controller **56.**

Temperature controller **56** is of conventional design comprising a capillary type temperature sensor **56*a*** connected through line **56*b*** to control apparatus of the controller **56.** Pressurized fluid is delivered from controller **56** through solenoid actuated valve **43*a*** to line **54** so long as sensor **56*a*** is maintained at a temperature higher than that set on a thermostat in the controller. Controller **56** preferably has a visual indicator associated therewith to indicate the temperature of air in the cargo compartment **2.** Controller **56** preferably has temperature recording apparatus associated therewith (not shown) for plotting temperature in relation to time. Such instruments are commercially available from the Partlow Corporation of New Hartford, N. Y..

Pneumatic temperature controller **56** is connected through line **58,** pressure regulator **60** and line **62** to an upper portion of nitrogen tank **10** such that nitrogen vapor is delivered therethrough.

During a cooling cycle liquid nitrogen passes through branch line **38,** valve **42,** and line **44** to the coils of evaporator **12.**

For defrosting coils of evaporator **12,** liquid nitrogen passes through branch line **40** to vaporizer **64** which is exposed to ambient atmosphere outside of the cargo compartment **2** to provide sufficient heating to cause the nitrogen to vaporize. Vapor from vaporizer **64** passes through line **66** and solenoid actuated valve **68** to the heating device generally designated by numeral **16.** Heated vapor passing from heating device **16** passes through line **70** to vaporizer **12** as will be hereinafter more fully described.

The heating device **16** comprises a burner **72** and a pilot light **74** connected through lines **73** and **75,** respectively, to valve **76.** A suitable fuel, such as propane, is delivered through line **78** from tank **80.**

A conventional pilot generator **82** is connected through conductors **83** and **84** to the coil **85*a*** of thermostatically controlled pilot single pole double throw relay **85** having a pole **85*b*** and contacts **85*c*** and **85*d*.** Pilot generator **82** and pilot relay **85** are safety devices adapted to prevent opening of valve **76** for releasing fuel from burner **72** unless pilot light **72** has been previously ignited. If pilot generator **82** is heated by pilot **74** current is generated maintaining coil **85*a*** of relay **85** in an energized condition causing a circuit to be broken through pole **85*b*** and contact **85*c*.**

An electrical ignition system is provided comprising an igniter plug **86** connected through plug wire **87** to an igniter system **88**.

The igniter system **88** comprises an induction coil and a vibrator which is arranged to periodically make and break the primary circuit. The igniter system is connected through line **160** to a source of low voltage electricity as will be hereinafter more fully explained.

Line **160** is connected to the primary of the induction coil through an automatic switch which is actuated by the vibrator. When the vibrator opens the circuit, the induction coil generates a high voltage, delivered through plug wire **87**, which is sufficient to cause a spark momentarily to jump the static spark points of igniter plug **86** for igniting fuel delivered through burner **72**.

A heat sensitive switch **69**, adapted to close when temperature is more than, for example, 200° F and to open when temperature is less than 190° F, is positioned adjacent burner **72**. Switch **69** is disposed in the energizing circuit connected with solenoid actuated valve **68** through which vapor is delivered to the heating device **16**. It should be readily apparent that switch **69** prevents actuation of valve **68** to an open position unless burner **74** has been ignited for heating vapor passing through heating device **16**.

Heated vapor delivered from heating device **16** passes through line **70** to line **44** communicating with the entrance end of primary coils **46** of evaporator **12**. Line **70** also communicates through solenoid actuated valve **90** with line **92** which is connected to the intake passage of a pneumatic motor **94**. The outlet passage of motor **94** is connected through a line **96** to secondary coils **48** of evaporator **12**, said secondary coils being connected through line **98** to muffler **100** through which nitrogen vapor is exhausted to atmosphere outside the cargo compartment **2** of the vehicle.

Heating device **16** has coils **15** and **15'** as illustrated in FIGS. VII and VIII which are preferably arranged such that the axes thereof are disposed perpendicularly. The outer coil **15** has an inlet end **15*a***, connected through valve **68** to pipe **66** and vaporizer **64**, and an outlet end **15*b*** adapted to connect with the inlet end **15*a*'** of the inner coil **15'**. Inner coil **15'** has a discharge end **15*b*'** connected to pipe **70** which delivers heated vapor to evaporator **12**.

Heat from burner **72** is transferred through walls of coils **15** and **15'** for heating nitrogen vapor flowing therethrough. Vapor discharged from coil **15'** is preferably heated to a temperature of approximately b1,000° F. providing a high heating capacity while expending a relatively small volume of liquid nitrogen. The volume of the heated vapor is approximately 600 times the volume of liquid nitrogen delivered to vaporizer **64** from tank **10**.

As best illustrated in FIGS. IV, V and VI, tank **10**, comprising inner and outer shells **22** and **24** separated by evacuated space **23**, has pipes extending through the walls thereof. Liquid nitrogen flows into and out of tank **10** through tube **10*a*** connected to line **32** communicating with evaporator **12** and vaporizer **64**. Vapor passes through tube **10*b*** to temperature controller **56**. A vacuum line **10*c*** is sealed after space **23** has been evacuated.

Lines **10*a***, **10*b*** and **10*c*** are preferably constructed of stainless steel or other suitable material. To prevent heat transfer from the tubes, some of which are exposed to ambient temperature, each of said tubes is segmented (FIG. VI) and a coupling **10*d*** joins segments **10*b*'** and **10*b*''**. Coupling **10d** is constructed of polyvinyl chloride or other suitable heat insulator material and is positioned in vacuum chamber **23** between inner and outer shells **22** and **24**. Thus, coupling **10d** interrupts the heat conductive path along walls of segments **10*b*'** and **10*b*''** of tube **10*b***.

Pneumatic motor **94** has a shaft **102** on which a fan blade **104** is mounted such that the flow of nitrogen vapor through pneumatic motor **94** causes fan blade **104** to rotate causing air within the cargo compartment **2** of vehicle **1** to pass across the primary coils **46** and the secondary coils **48** of evaporator **12**.

Shaft **102** has a pulley **106** secured thereto about which a belt **108**, in driving engagement with a pulley **110** on an alternator, extends. Alternator **112** is a standard AC generator of the type normally used in present day modern automobiles such as the Delco "DELCOTRON," the Ford "Autolite" and alternators manufactured by Motorola and Leech-Neville. The alternator **112** is connected to be driven by the pneumatic motor **94** and has a field terminal, an output terminal and a neutral terminal.

Alternator **112** is connected with a voltage regulator **120** which serves to regulate the voltage and current. Regulator **120** has a field terminal connected to line **114**, and an output terminal connected through line **122**, rectifier **124** and line **126** to line **153**, as will be hereinafter described for maintaining battery **140** in a charged condition.

The control system illustrated in FIG. III generally comprises double pole-double throw relays **R1**, **R2**, and **R3** actuated by signals delivered from temperature controller **56** and defrost controller **128**.

When thermostat **56t** of temperature controller **56** calls for cooling, indicator light G is illuminated and valve **52** is held open.

When defrost controller **128** calls for defrosting, indicator light A is illuminated and the coils of relays **R1** and **R2** are energized to turn on the burner **72**, to permit opening of valve **68**, and to open valve **43**.

During heat and defrost cycles valve **43** is closed because line **50** is vented through valve **52**.

Defrost controller **128** comprises a resistance bridge network arranged for energizing or de-energizing a relay which controls apparatus for triggering and terminating a defrost cycle.

The resistance bridge network of defrost controller **128** includes a first thermistor **136** mounted in vapor exhaust line **98** through which nitrogen vapor is exhausted to atmosphere. Thermistor **136** is a temperature-sensitive resistance, the resistance of which varies with temperature.

A second thermistor **138** is disposed inside cargo compartment **2** and is positioned such that air drawn across coils **46** and **48** of evaporator **12** flows across thermistor **138** when returning to the cargo compartment **2**.

Thermistor **136** is connected through lines **136*a*** and **136*b*** to defrost controller **128** and thermistor **138** is connected thereto through lines **138*a*** and **138*b***.

Thermistors **136** and **138** are connected in a resistance bridge network such that when the resistance of thermistor **136** increases more than the resistance of thermistor **138**, because ice has formed on coils **46** and **48** of evaporator **12**, the resistance bridge will become unbalanced. Current then energizes the coil **128***a* of the relay connected across the bridge network, causing the flow of liquid nitrogen to evaporator **12** to be stopped and causing heated nitrogen vapor to flow therethrough melting ice from the surface thereof.

It should be apparent that temperature sensor devices such as silicon diodes and thermocouples may be employed in lieu of thermistors **136** and **138** for sensing temperature and that changes in voltage or current may be employed to trigger defrost controller **128**. It should be further apparent to persons skilled in the art that defrost controller **128** may include other and further devices for detecting an unbalanced condition in the bridge network. For example, we contemplate employment of a differential integrated circuit amplifier to detect the unbalance and to feed an output voltage to a phase-controlled pulse generator which delivers trigger pulses to a triac and, thus, controls current through lines **173** and **174** to initiate and terminate defrost cycles.

Current for actuating the control apparatus and the heating apparatus is delivered from battery **140** having a negative terminal connected to ground and a positive terminal connected through a fuse **141** and conductor **142** to an ammeter **143**. The ammeter **143** is connected through line **116** to alternator **112** and through a line **144** to terminals **145***a* and **145***b* of a double pole-double throw main power switch **145**.

The main power switch **145** has an off position wherein pole **145***e* is disconnected from contacts **145***a* and **145***b*, a "cool only" position wherein pole **145***e* engages contact **145***a*, and a "cool and heat" position wherein pole **145***e* engages contact **145***b*. In the "cool and heat" position pole **145***f* of main switch **145** engages contact **145***d* allowing a circuit to be completed through contact **56** R*c* of relay **56***r* of temperature controller **56** to the coil of relay R1 as will be hereinafter more fully explained. When the switch **145** is in the "cool only" position the contact **56** R*c* of temperature controller **56** is isolated from the control system.

Pole **145***e* of the main switch **145** is connected through line **146** and line **147** to the pole **56**R*a* of the relay in temperature controller **56**.

Pole **145***e* of main switch **145** is connected through line **146**, line **148** and line **149** to terminal **150** of defrost controller **128**. Terminal **150** of defrost controller **128** is connected to pole **128***b* of the relay in the defrost controller and is connected to lines **136***b* and **138***b* connected to the thermistors **136** and **138**, respectively, in a bridge network.

Pole **145***e* of main switch **145** is connected through conductors **146, 148** and **151** to the pole R1*a* of relay R1.

The pole **145***e* of main switch **145** is connected through conductors **146** and **152** to the pole R2*b* of relay R2, and through conductors **146** and **153** to the pole **85***b* of pilot relay **85**.

From the foregoing it should be readily apparent that when pole **145***e* of main switch **145** engages the contact **145***a* or **145***b* the positive terminal of battery **140** is connected to pole **85***b* of pilot relay **85**, to pole R2*b* of relay R2, to pole R1*a* of relay R1, to pole **128***b* of defrost controller **128**, and to pole **56**R*a* of temperature controller **56**.

Remaining parts of the electrical control system will be hereinafter described in conjunction with the operation thereof.

OPERATION

The operation and function of the apparatus hereinbefore described is as follows:

Poles **145***e* and **145***f* of main power switch **145** are moved to the "cool and heat" position for energizing the control circuit.

If the thermostat **56***t* of temperature controller **56** is calling for a cooling cycle, electrical current is directed from the positive terminal of battery **140** to pole **56**R*a* of temperature controller **56**, as hereinbefore described, and through contact **56**Rb of the relay of temperature controller **56**, conductor **170**, contact R3*c* and pole R3*a* of relay R3, and conductor **173** to lamp G to provide visual indication that cooling is required.

Unless a defrost cycle has been initiated, the positive terminal of battery **140** is connected through pole **128***b* of the relay in defrost controller **128** to contact **128***d*, and through line **172** to the coil of solenoid actuated valve **52**, holding valve **52** open permitting flow of nitrogen vapor therethrough. Vapor from container **10** passes through line **62**, regulator **60**, line **58**, valve **43***a*, line **54**, valve **52** and line **50** to pressurize actuator **43** for maintaining valve **42** in an open position.

Liquid nitrogen then flows through line **32**, valve **34**, line **36**, branch line **38**, valve **42** and line **44** into the primary coils **46** of evaporator **12**. The liquid nitrogen is at a temperature of approximately -320° F, and as heat is absorbed through the walls of primary coils **46** air adjacent thereto is cooled. Nitrogen from primary coils **46** passes through line **92** for driving pneumatic motor **94** causing fan **104** to circulate air across the primary and secondary coils. Nitrogen exhausted from motor **94** passes through line **96** to secondary coils **48** to absorb as much heat as possible before being exhausted through line **98** across thermistor **136** to ambient atmosphere through muffler **100**.

It should be readily apparent that no nitrogen passes into the cargo compartment of the vehicle.

As ice forms on coils **46** and **48** of the evaporator **12**, the rate of heat transfer through walls of the coils is reduced. When the temperature of air moving across the coils of the evaporator **12** reaches a predetermined temperature, for example, 28° F, above the temperature of nitrogen discharged across thermistor **136**, the resistance bridge network in defrost controller **128** becomes unbalanced energizing the coil **128***a*, causing pole **128***b* to move out of engagement with contact **128***d* and into engagement with contact **128***c*.

When the circuit through contact **128***d* is broken, the flow of current through conductor **172** and the coil of solenoid actuated valve **52** is stopped causing valve **52** to shift to a position stopping the flow of liquid nitrogen therethrough and causing line **50** connected to actuator **43** to be vented to atmosphere. This closes valve **42** stopping the flow of liquid nitrogen to coils of evaporator **12**.

When an electrical circuit is completed through contact **128***c* of defrost controller **128**, current flows through conductor **173** and conductor **174** to illuminate lamp A indicating that a defrost cycle has been initiated. Current flows from conductor **174** through conductor **175** to energize the coil of solenoid actuated valve **90** for opening valve **90.**

Current is also directed through contact **128***c*, conductor **173,** conductor **176,** and conductor **177** for energizing the coil of relay R3. Current then flows from conductor **176** through contact R3*f*, pole R3*b* of relay R3, and conductor **178** to pole R2*a*. If pilot light **74** is burning, pilot generator **82** will maintain the coil **85***a* of pilot relay **85** in an energized condition which maintains the coil of relay R2 in a non-energized condition.

Current from the pole R2*a* of relay R2 thus passes through contact R2*c* and conductor **165** to energize the coil of relay R1. When the coil of relay R1 is energized current from pole R1*a*, connected to the positive terminal of battery **140** as hereinbefore described, passes through contact R1d and conductor **179** to heat sensitive switch **69.** When the heat sensitive switch **69** is heated to a temperature, for example 200° F. the circuit is completed therethrough connecting current through conductor **180** to the coil of solenoid actuated valve **68** causing valve **68** to open.

When the coil of relay R1 is energized, the circuit is completed from pole R1*b* through contact R1*f* and through conductors **181** and **182** opening valve **76** causing fuel to flow from container **80** through line **78,** valve **76,** and line **73** to burner **72** for heating the coils **15** and **15'** of heating device **16.**

Heated vapor flow through conduit **70,** valve **90,** and line **92** to motor **94** for melting any ice on the surface thereof. Heated gas also flows from conduit **70** through conduit **44** to primary coils **46** of evaporator **12.** Vapor discharged from motor **94** passes through the secondary coils **48** and is exhausted to atmosphere.

When the temprature differential between sensors **136** and **138** reaches a predetermined limit, for example when the temperatures are substantially equal the defrost controller **128** causes current to flow through **128***a* switching the pole **128***b* out of engagement with contact **128***c*, de-energizing the coils of relays R1 and R3 and de-energizing the coil of solenoid actuated valve **52.** When such occurs the burner is turned off, valve **68** is closed stopping the flow of nitrogen vapor to heating device **16,** solenoid actuated valve **90** is closed blocking the bypass directly to motor **94.**

As pole **128***b* of defrost controller **128** moves into engagement with contact **128***d* the coil of solenoid actuated valve **52** becomes energized opening said valve which causes valve **42** to be opened permitting flow of liquid nitrogen to the primary primary coils **46** of the evaporator **12.**

It should be appreciated that the intense heat of vapor delivered from the heating device **16** results in very rapid melting of ice on surfaces of the coils **46** and **48** of evaporator **12** and on the surfaces of motor **94.** Although motor **94** is running during the defrost cycle, the defrost cycle is so short that the cargo compartment is not heated appreciably.

When the thermostat **56***t* in temperature controller **56** calls for a heating cycle, a switch in the thermostat **56***t* is closed energizing the coil of relay **56**R causing pole **56**R*a* to move out of engagement with contact **56**R*b* into engagement with contact **56**R*c*, and energizing the coil of solenoid actuated valve **43***a* causing valve **43***a* to close.

When pole **56**R*a* of temperature controller **56** engages contact **56**R*c*, current is directed through a conductor **185** through pole **145***f* of main power switch **145** through contact **145***b*, and through conductor **186** to illuminate lamp R. Current is also directed from contact **145***d* to main power switch **145** through conductor **187,** contact R3*e* and pole R3*b* of relay R3, and through conductor **178** to pole R2*a* of relay R2 for energizing the coil of relay R1 to light the burner **72,** and to direct nitrogen vapor through valve **68,** as hereinbefore described in the discussion related to the defrost cycle.

From the foregoing it should be readily apparent that we have developed apparatus employing liquid nitrogen, or other suitable cryogenic material, for cooling, heating and defrosting. The control system is self-sustained, being energized by a battery **140** which is maintained in a charged condition by alternator **112** driven by motor **94** which is driven by the flow of nitrogen therethrough.

The system is completely automatic employing thermostat control means to initiate cooling and heating cycles and employing means for sensing a temperature differential between air in the cargo compartment and nitrogen vapor discharged from the evaporator coils for initiating and terminating defrost cycles.

It should be appreciated that other and further embodiments of our invention may be devised without departing from the basic concept of the invention.

Having described our invention, we claim:

1. A method of controlling the heat transfer rate through a wall of a tube comprising the steps of: delivering coolant through the tube; moving fluid in heat exchange relation with the tube; sensing temperature of coolant exhausted from the tube; sensing temperature of fluid which is passed in heat exchange relation to the tube; and heating surfaces of the tube when a predetermined differential between temperature of coolant exhausted and temperature of fluid which has moved across the tube exists.

2. The method of claim **1** wherein the steps of sensing temperature of coolant exhausted and sensing temperature of fluid are accomplished by positioning a first temperature sensor in heat exchange relation with coolant exhausted from the tube; positioning a second temperature sensor in heat exchange relation with fluid which is passed in heat exchange relation with the tube, said first and second temperature sensors being connected in a resistance bridge network adapted to initiate the steps of heating surfaces of the tube and delivering coolant through the tube.

3. The method of claim **1** wherein the step of heating surfaces of the tube comprises, heating a volume of coolant; and delivering the heated coolant through the tube.

4. The method of claim **1** wherein the step of delivering coolant through the tube comprises, delivering liquified cryogenic gas through the tube.

5. The method of claim **4** wherein the cryogenic gas is nitrogen.

6. The method of claim **4** wherein the step of moving fluid in heat exchange relation with the tube comprises, delivering liquified cryogenic gas, which is circulated through the tube, through a means for driving a fan disposed in driving relation with the fluid.

7. A method of controlling apparatus to maintain temperature in a compartment within limits comprising the steps of: moving coolant through heat exchanger apparatus; moving fluid in heat exchange relation with the heat exchanger apparatus; generating a first signal representative of temperature of fluid in the compartment; generating a second signal representative of temperature of coolant exhausted from the heat exchanger apparatus; combining the first and second signals to produce a control signal; delivering coolant through the heat exchanger apparatus responsive to said control signal when the magnitude thereof is less than a predetermined value; and delivering heated fluid through the heat exchanger apparatus responsive to a control signal exceeding a predetermined value.

8. A method of controlling temperature in a compartment comprising the steps of: circulating liquid nitrogen through a primary coil; circulating nitrogen from the primary coil through a pneumatic motor arranged to drive a fan; circulating nitrogen from the motor through a secondary coil, said primary and secondary coils being positioned such that the motor moves air thereacross; and exhausting nitrogen from the secondary coil outside the compartment.

9. The method of claim **8** with the addition of the step of, stopping flow of liquid nitrogen to the primary coil when a predetermined quantity of ice has formed on surfaces thereof; delivering liquid nitrogen to a heating apparatus; directing heated nitrogen vapor through the primary coils, through the motor, and through the secondary coil for melting ice on surfaces thereof.

10. Temperature control apparatus comprising, a coil; means to deliver fluid through said coil; means to move air across the coil; first sensor means to sense temperature of air moving across the coil; second sensor means to sense the temperature of fluid exhausted from the coil; means to generate a signal when the temperature of air drawn from across the coil exceeds the temperature of fluid exhausted from said coil by a predetermined temperature; and means energized by said signal to heat surfaces of the coil to melt ice thereon.

11. The combination called for in claim **10** wherein the first and second sensor means each comprises temperature-sensitive resistance means positioned in heat exchange relation with the air and the coolant, respectively; and wherein the means to generate a signal comprises a resistance bridge network having the first and second sensor means disposed therein such that the bridge becomes unbalanced to generate a signal when the difference in temperature of air drawn across the coil exceeds the temperature of fluid exhausted from the coil by a predetermined amount.

12. The combination called for in claim **10** wherein the means energized by said signal to heat surface of the coil comprises, heater means; signal responsive valve means arranged to deliver coolant to the heating device; and means to deliver heated coolant from the heating device to the coil.

13. The combination called for in claim **10** wherein the means to move air across the coil comprises, a fluid driven motor connected in driving relation with impellar means; and means to direct fluid from said coil through the motor.

14. The combination called for in claim **10** wherein the means to deliver fluid through the coil comprises, a container; conduit means connected between said container and the coil; and means in said conduit means for controlling the flow of coolant therethrough.

15. The combination called for in claim **14** wherein the container comprises an outer shell; an inner shell disposed inside said outer shell; said shells being spaced apart to form a vacuum chamber between adjacent surfaces thereof; a first pipe segment extending through the wall of the inner shell; a second pipe segment extending through the wall of the outer shell, said first and second pipe segments having ends terminating in spaced apart relation in said vacuum chamber; and an insulated coupling arranged to join ends of said first and second pipe segments, said coupling being disposed in the vacuum chamber.

16. Apparatus to control temperature in a cargo compartment of a trailer comprising, a source of liquefied cryogenic gas carried by the trailer; an evaporator in the compartment; first conduit means connecting the evaporator and the source of liquefied gas; a heat exchanger; second conduit means connecting the heat exchanger with the source of liquefied gas; a pneumatically operated motor driven fan arranged to cause air in the compartment to circulate over surfaces of the evaporator; flow control means having a first position wherein the source of liquefied gas is connected with the motor, and having a second position wherein the heat exchanger is connected with the motor and the evaporator; a burner arranged to heat said heat exchanger; a source of fuel; and supply conduit means between said burner and said source of fuel.

17. The combination called for in claim **16** wherein the heat exchanger comprises an outer coil of conduit and an inner coil of conduit, said outer coil being positioned about said inner coil, said inner coil having a central axis disposed transversely of a central axis of said outer coil.

18. The combination called for in claim **16** with the addition of a current responsive valve in said supply conduit means; a pilot burner adjacent said burner; a fuel supply line between said source of fuel and said pilot burner; heat sensitive switch means adjacent said pilot burner; and electrical conductors between said switch means and said current responsive valve to prevent opening of said valve unless temperature adjacent said pilot burner exceeds a predetermined temperature.

19. Apparatus to control temperature in a compartment comprising, a source of liquefied cryogenic gas; a primary evaporator in the compartment; first conduit means connecting the primary evaporator and the source of liquefied gas; a pneumatically driven motor in the compartment; second conduit means between said primary evaporator and said motor; a secondary evaporator in said compartment; third conduit means connecting said motor and said secondary evaporator; a fan driven by said motor; and means supporting said primary and secondary evaporators such that the fan moves air across each of the evaporators.

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