Oct. 7, 1969 F. W. KANTOR 3,470,704
THERMODYNAMIC APPARATUS AND METHOD
Filed Jan. 10, 1967 4 Sheets-Sheet 1

Fig.1.
(PRIOR ART)

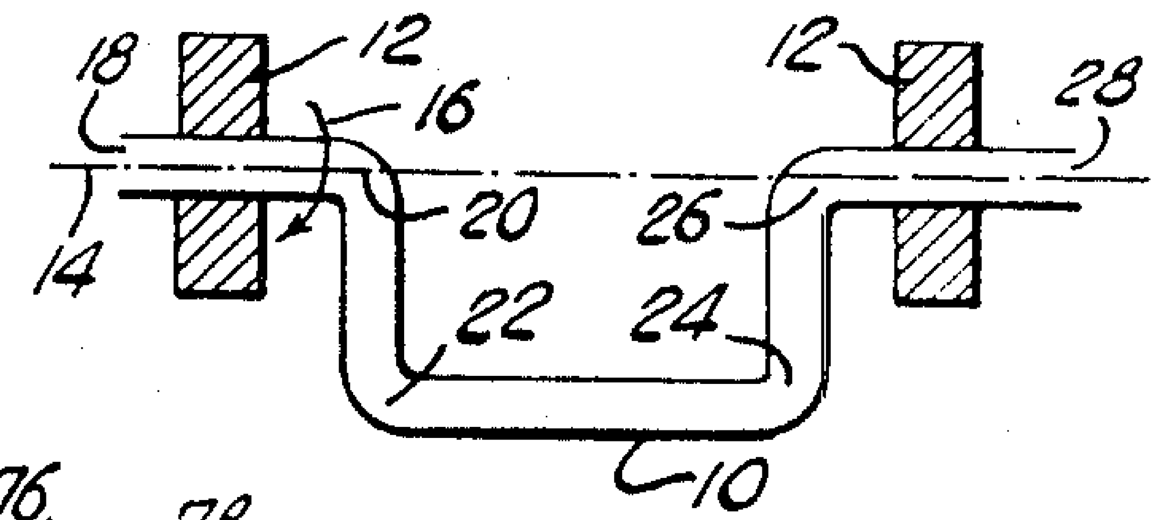

Fig.3.

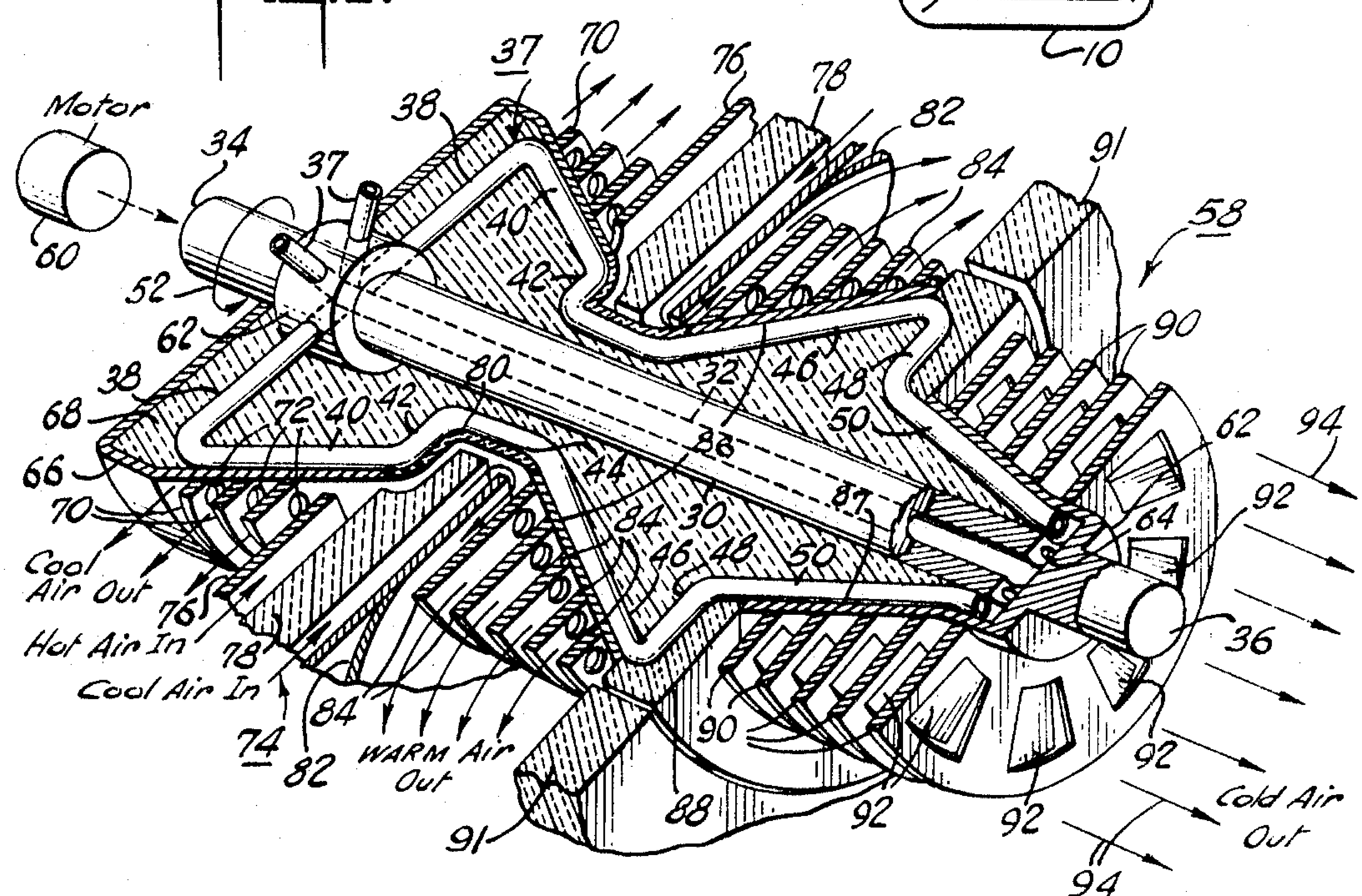

Fig.2.

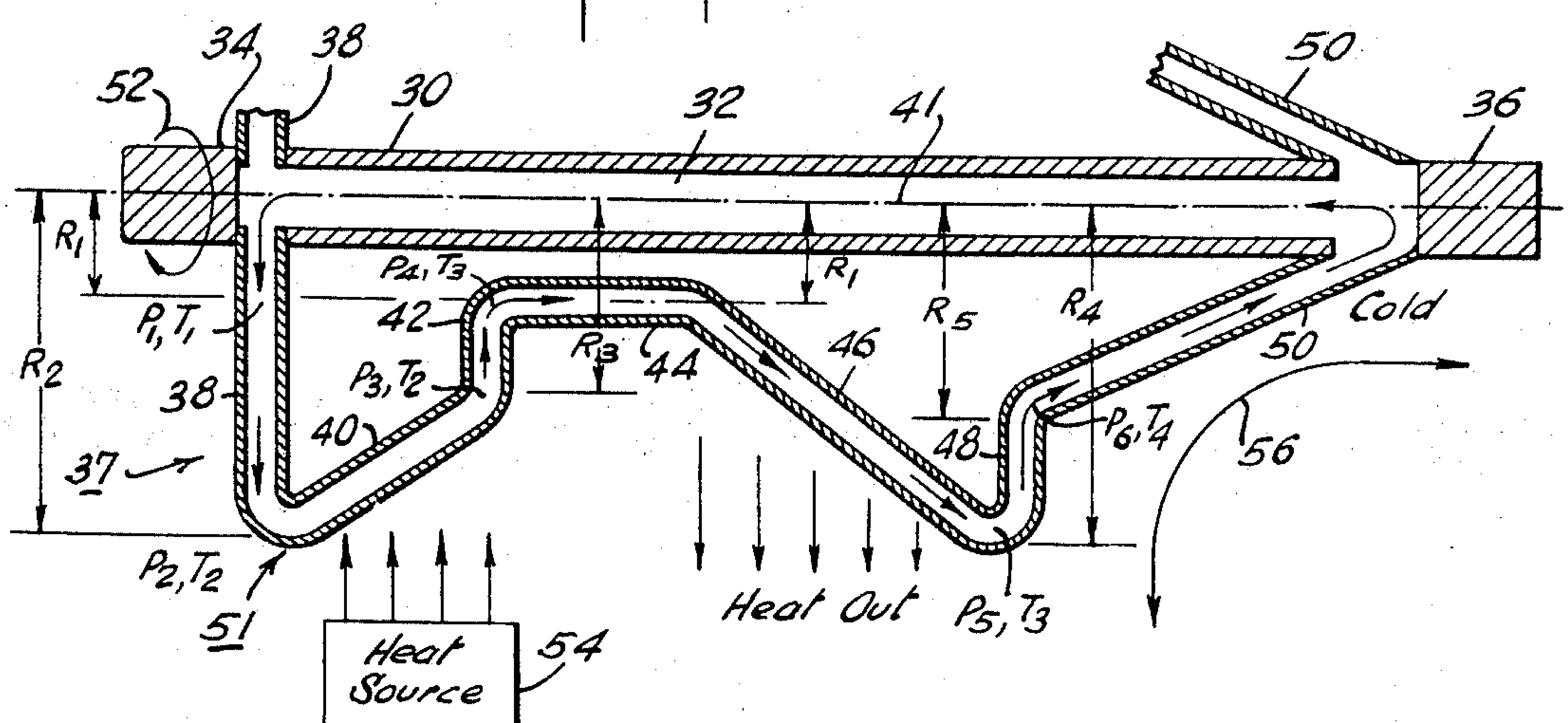

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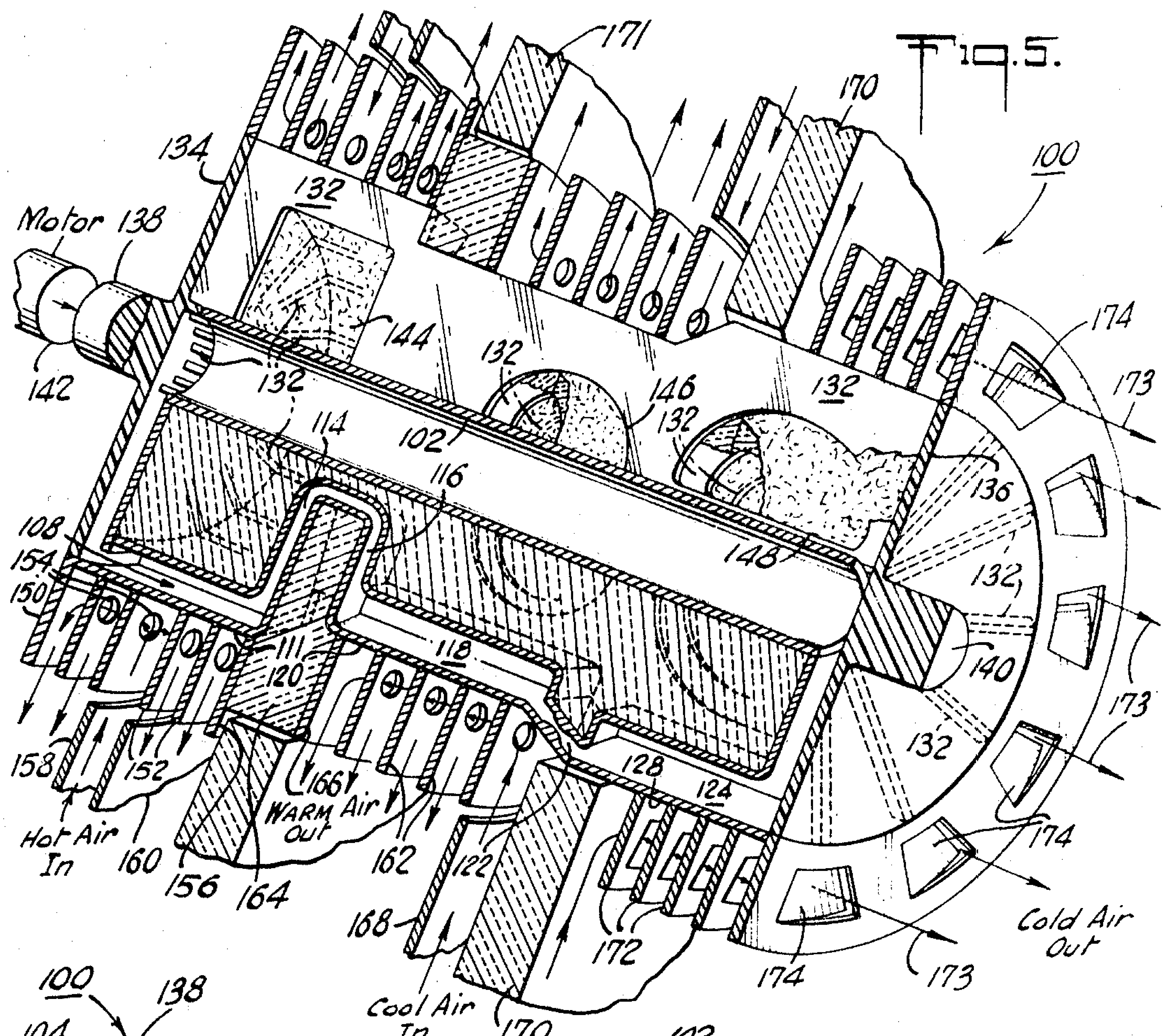
Fig. 5.



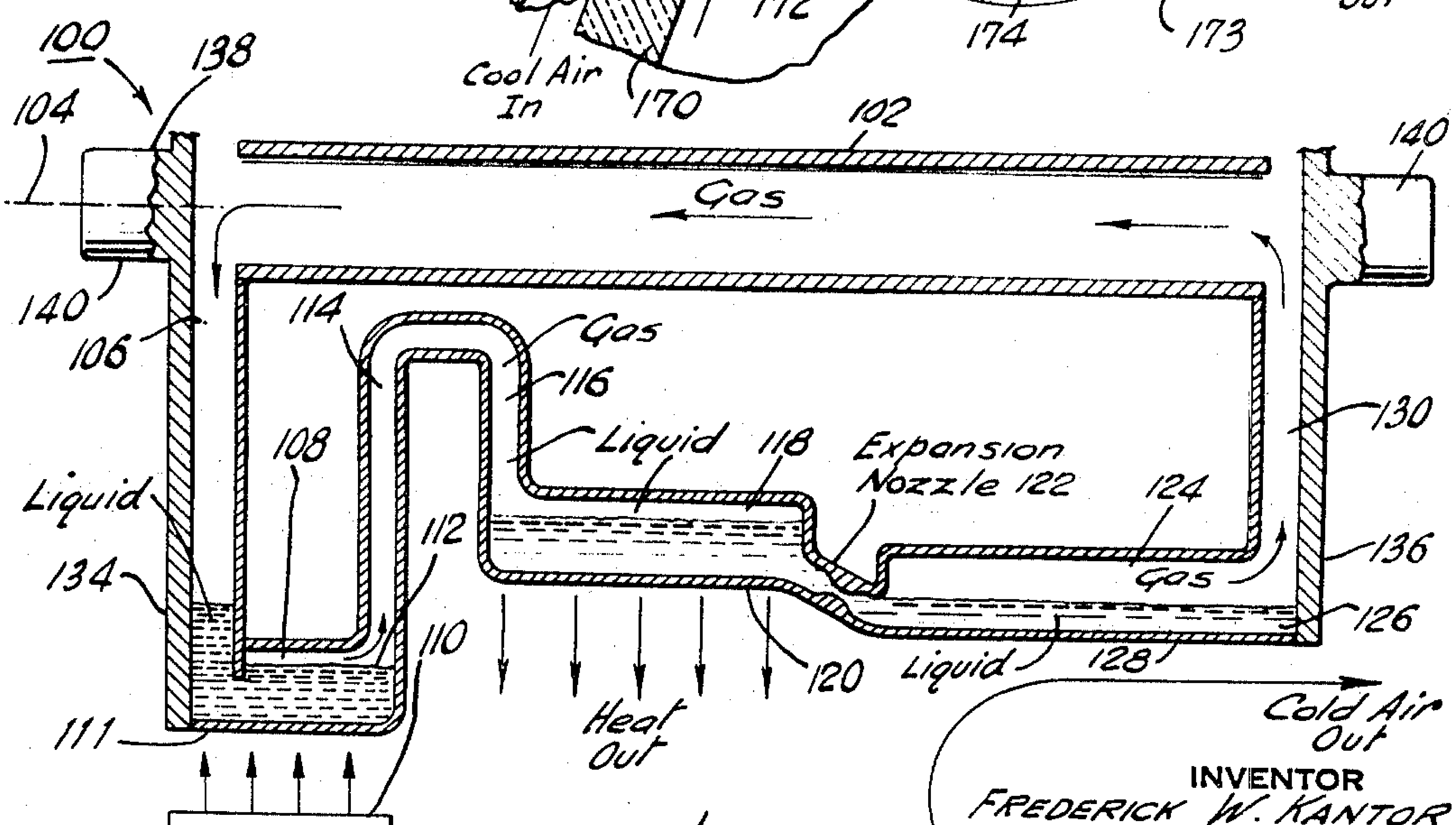


Fig. 4.

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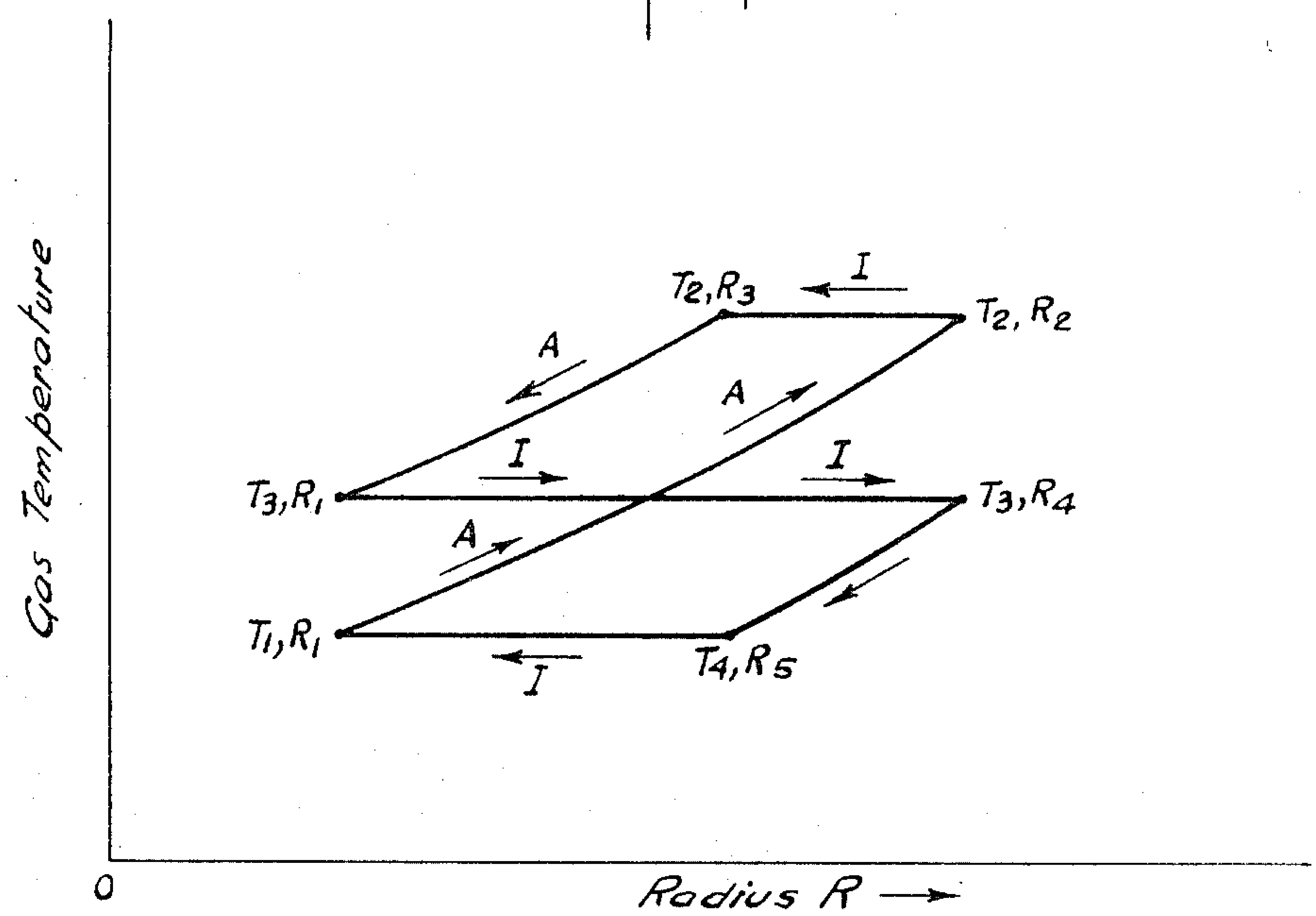
Fig. 6.



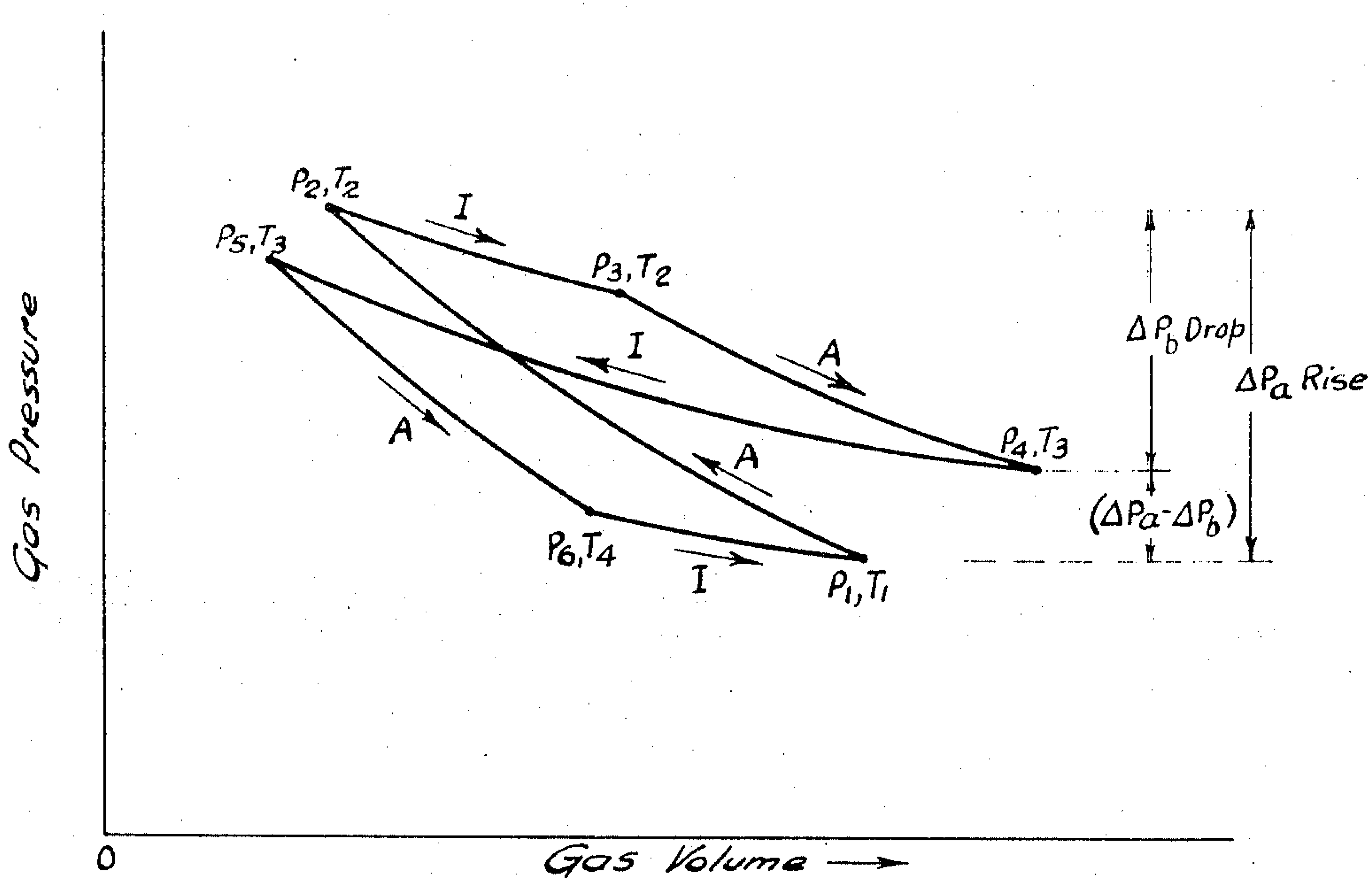


Fig. 7.

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Fig. 8.

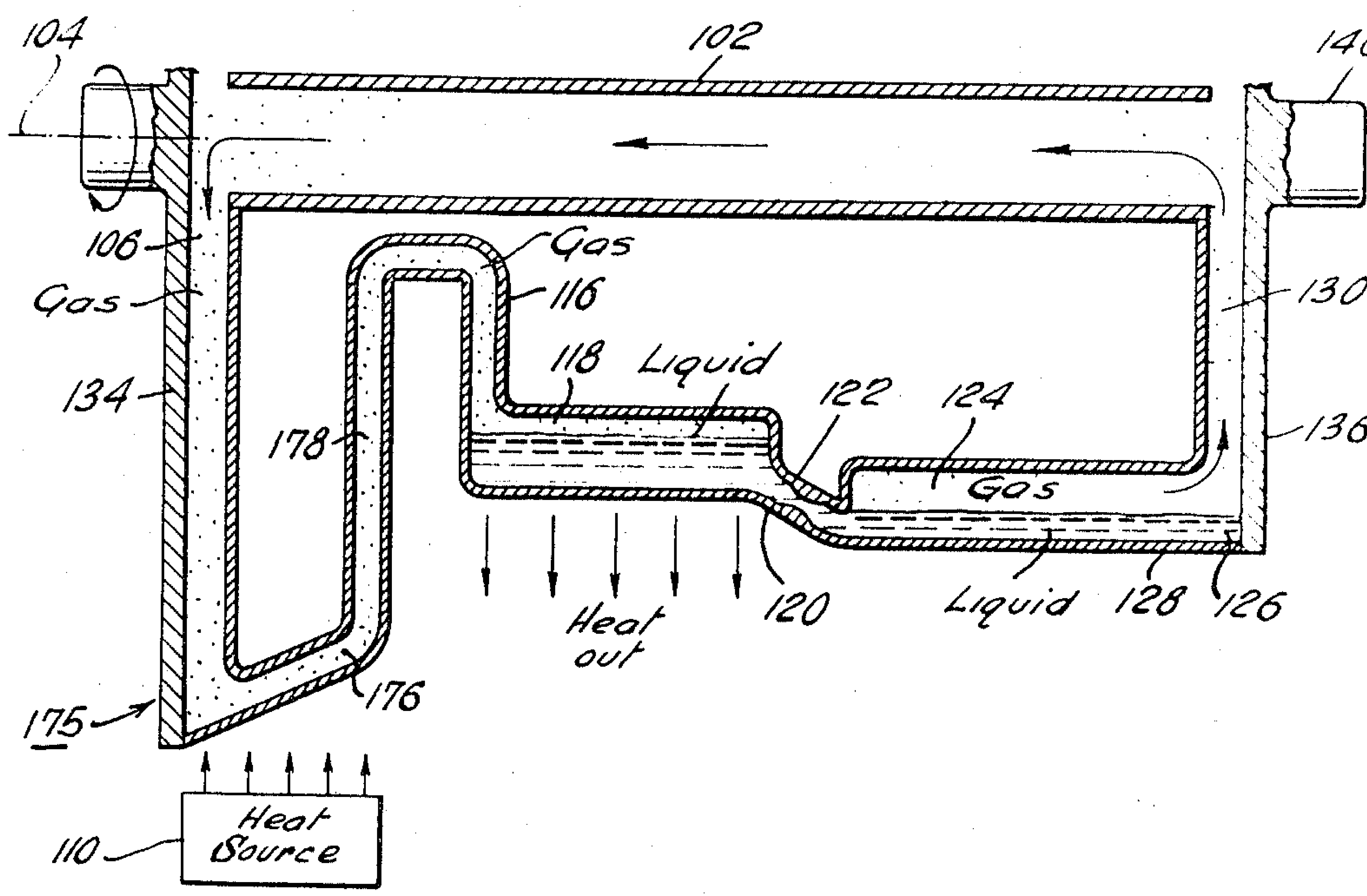
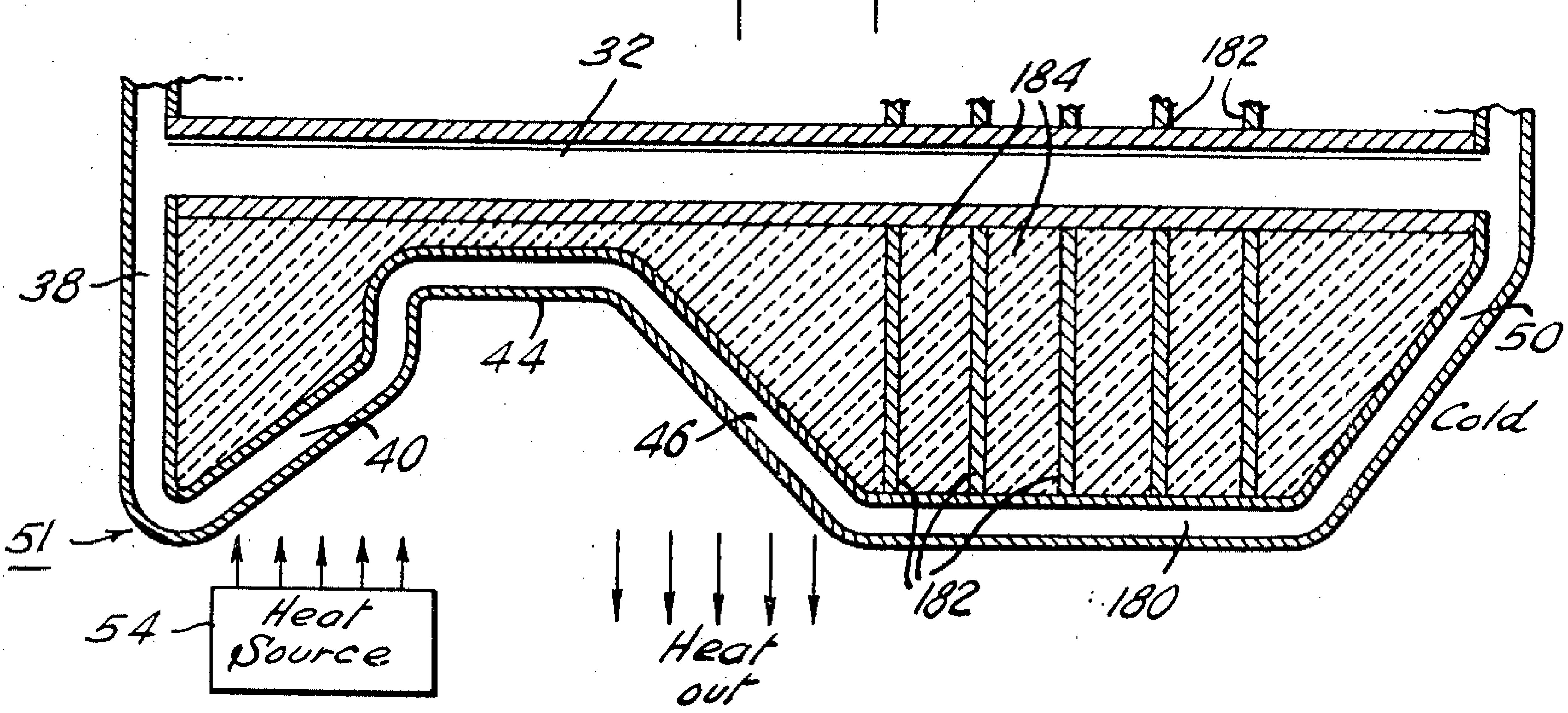


Fig. 9.



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THERMODYNAMIC APPARATUS AND METHOD

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Int. Cl. F25b *3/00*
U.S. Cl. 62—115 39 Claims

ABSTRACT OF THE DISCLOSURE

A working fluid is rotated in a rotary enclosure with the fluid moving first away from and then towards the axis of rotation in a closed loop within the enclosure. The fluid is moved in its closed-loop path by means of a thermodynamic pump which makes use of the differing densities and differential centrifugal forces on the working fluid to pump the fluid through the conduit. Troublesome rotary gas seals are not used, and a working fluid having a relatively high density can be used in order to minimize the rotational speeds required. Also, the working fluid can be given a relatively high initial pressure. In one embodiment of the invention the working fluid changes between the gaseous and liquid states, and in another embodiment heat is transferred between portions of the loop at different radii to provide very low refrigeration temperatures.

This invention relates to thermodynamic apparatus and methods; more particularly, the present invention relates to highly efficient apparatus for refrigeration and heating.

A theoretically highly efficient but impractical refrigerator device has been proposed in U.S. Patent 2,393,338 to J. R. Roebuck, and "A Novel Form of Refrigerator," 16 Journal of Applied Physics 285–295, May 1945, by J. R. Roebuck. The basic form of the device proposed by Roebuck is shown in FIGURE 1 of the drawings. The tube **10**, which is supported in bearings **12**, is rotated at a very high speed about a central axis **14**, as indicated by the arrow **16**.

Compressed air is introduced into the tube **10** at its inlet **18**. The gas moves radially outwardly from the axis **14** between points **20** and **22** in the tube. While doing so, the gas is compressed and heated by the centrifugal force created by the rotation. During its movement between points **20** and **22**, the gas is cooled by means of water flowing in cooling coils (not shown) so that temperature of the gas remains substantially constant.

While traveling between points **22** and **24**, the gas is unaffected by the rotational motion. However, while moving from point **24** to point **26** the gas expands and becomes substantially cooler. The cold gas then flows out of the outlet opening **28** for use in refrigeration.

One aspect of the above-described prior art thermodynamic system is highly attractive. In theory, its thermodynamic cycle approaches a true Carnot cycle and thus is highly efficient. However, the equipment actually proposed for this system is highly impractical since it requires the provision of a separate mechanical gas compressor, and requires expensive and troublesome gas seals at the inlet to and the outlet from the rotating member **10**. Furthermore, extraordinarily high rotating speeds of the order of 100,000 to 200,000 r.p.m. are required in order to provide effective operation. These deficiencies have been so severe that, it is believed, the device has not been commercially adopted to any substantial extent.

In accordance with the foregoing, it is an object of the present invention to provide thermodynamic apparatus and methods utilizing centrifugal force, which apparatus and methods do not require auxiliary mechanical compressors or gas seals, and do not require excessively high rotational speeds to develop sufficient centrifugal forces. It is a further object of the present invention to provide such apparatus and methods which are highly efficient, and to provide apparatus which is compact and relatively simple and inexpensive to build and maintain.

In accordance with the present invention, the gas seals and mechanical compressor are eliminated by moving the working fluid in a closed loop path within a rotor by means of a thermodynamic pump. The requirement for high rotational speeds is eliminated by using a working fluid of relatively high density and, in one embodiment of the invention, changing a gas into a liquid and then back into a gas again. The working fluid can be sealed in the closed loop at relatively high initial pressures, if desired. Other features of the invention are described in detail in the following description.

The drawings and description that follow describe the invention and indicate some of the ways in which it can be used. In addition, some of the advantages provided by the invention will be pointed out.

In the drawings:

FIGURE 1 is a schematic diagram of a prior art device;

FIGURE 2 is a schematic diagram of a device and method in accordance with the present invention;

FIGURE 3 is a perspective, partially broken-away and partially schematic view of the thermodynamic device shown schematically in FIGURE 2;

FIGURE 4 is a schematic diagram of another embodiment of the present invention;

FIGURE 5 is a perspective, partially broken-away and partially schematic view of the device shown schematically in FIGURE 4;

FIGURES 6 and 7 are graphs showing the qualitative variations of various operational parameters of the device shown in FIGURES 2 and 3; and

FIGURES 8 and 9 are schematic diagrams of two other embodiments of the present invention.

FIGURE 2 is a schematic diagram of a portion of the complete thermodynamic device shown in FIGURE 3, and is used to facilitate explanation of the principles of operation of the invention.

The structure defining the working fluid flow conduit in FIGURE 2 includes a shaft **30** with a hollow flow passage **32** for the working fluid, and solid end portions **34** and **36**. Several tubes, indicated generally at **37**, are connected between the opposite ends of the central conduit **32** of the shaft **30**. However, only one such tube is shown in FIGURE 2 in order to simplify the drawing.

The tube **37**, which is made of a suitably thermally conductive material, includes a first section **38** which extends radially outwardly from the left end of conduit **32**, a second section **40** which extends back towards the rotational axis **41** of the shaft **30** at an acute angle to the axis. Another section **42** extends radially towards the axis **41**, a further section **44** extends parallel to the axis **41**, and another section **46** extends outwardly at an acute angle from the axis **41**. A section **48** then proceeds radially inwardly towards axis **41**, and a final section **50** extends towards axis **41** at an acute angle and communicates with the right end of conduit **32**.

The conduit **32** and the tube **37** connecting its ends together comprise a closed loop conduit for carrying the working medium. The tube sections **38**, **40** and **42** comprise a thermodynamic pump, indicated at **51**, for pumping the fluid through the conduit in the direction indicated by the arrows, and the tube sections **46**, **48** and **50** comprise a refrigerator section, indicated at **53**, which operates on the same principles as the prior art device shown in FIGURE 1.

In accordance with one aspect of the present invention, the working fluid preferably is a gas of a density which is high relative to the density of air. Suitable high-density gases are well known in the art. For example, each of the refrigerants comprising flurochloromethane and flurochloroethane and sold under the trademark "Freon" by Du Pont has a density several times greater than that of air under standard conditions and is quite suitable for use as a working fluid in the present invention. As will be explained in greater detail below, the use of high-density fluids significantly reduces the speed at which the loop must be rotated.

The thermodynamic system shown in FIGURE 2 operates as follows: the shaft **30** is rotated about its axis **41** as indicated by the arrow **52**. Centrifugal force created by the rotation compresses the fluid in section **38**. Section **38** is insulated so that the gas is compressed in it substantially adiabatically; that is, without the gain or loss of heat through the walls.

The changes in gas pressure and volume are shown qualitatively in FIGURE 7. The starting point in the diagram of FIGURE 7 is located at the same distance R_1 from the axis **41** as the center of tube portion **44**. At that point in tube **38** the gas pressure and temperature are P_1 and T_1. At a greater radius R_2, the gas has been compressed to a pressure P_2, and its pressure thus has been increased by an amount ΔP_a. As is shown by FIGURE 6, which qualitatively illustrates the variation of gas temperature with conduit radius R, the temperature T_2 at the radius R_2 also is substantially increased over the temperature T_1 due to compression of the gas.

When the gas flows back towards axis **41** in section **40**, the gas pressure decreases as the radial distance decreases. Simultaneously, the temperature of the gas tends to decrease due to expansion of the gas, and this would reduce the expansion compared to the isothermal case. However, heat is added to the gas from a heat source **54** so that the gas expands isothermally and has a lower density than it otherwise would have had. The angle at which the tube section **40** is inclined with respect to axis **41** is set at a value such that the amount of heat added by heat souce **54** will maintain the temperature in the gas constant along the entire length of tube **40**, thus providing isothermal expansion of the gas along section **40**. Although the tube **40** is shown as a straight section in FIGURE 2, it should be understood that it may have a complex curved shape in order to ensure that the expansion of the gas is isothermal at all points along section **40**. Adiabatic changes in the state of the gas are indicated by "A" symbols in FIGURES 6 and 7, and isothermal changes are indicated by "I" symbols.

The tube section **42** extends toward axis **41** from a radius R_3 to radius R_1. Tube sections **42** and **44** are insulated so that expansion of the gas therein is adiabatic. Referring again to FIGURES 6 and 7, the gas at the innermost end of section **42** has a pressure P_4 and a temperature T_3. The different densities of the gas in the sections **38** and **40–42** creates a pressure difference which is greatly augmented by the action of centrifugal force on the columns of gas. The pressure P_4 is less than the pressure P_2 at the outermost end of tube **38** by an amount ΔP_a minus ΔP_b (see FIGURE 7). This pressure difference is the pumping pressure provided by the pumping unit **51**.

The temperature T_3 of the gas in tube section **44** preferably is approximately equal to that of the ambient medium. In tube section **46**, the gas is again compressed, but is cooled by heat transfer to the ambient medium so that its temperature is maintained substantially constant; for example, to within five or ten percent of the temperature T_3. Thus, as is indicated in FIGURES 6 and 7, the gas is compressed isothermally to a higher pressure P_5 at a radius R_4. Water or other liquids can be used as coolants instead of air, as is well-known in the prior art.

The gas then is expanded adiabatically in section **48** to a lower pressure P_6 and a lower temperature T_4. In section **50**, the gas further expands isothermally, and eventually flows through the axial conduit **32** and eventually returns to the initial pressure and temperature P_1 and T_1. Sections **32** and **48** are insulated to provide adiabatic conditions. The expansion in section **50** is made substantially isothermal by extracting heat from the ambient medium by heat transfer to the gas. The arrow **56** indicates the flow of ambient air either toward or away from the axis **104** along and in contact with section **50**, thus providing the heat transfer desired. The cold air then is used for air cooling or refrigeration, as desired.

It is to be noted that a positive pressure is created in the gas in section **46**, and a negative or back pressure is created in sections **48** and **50** due to the differing densities of the gases as acted on by centrifugal force. The negative or back pressure is greater than the positive or forward pressure. This excess of back pressure tends to oppose the forward pressure produced by the pumping section **51** and thus tends to oppose the flow of fluid in the conduit. However, the forward pumping pressure always is greater than the back pressure and the gas flows around the closed loop in the direction indicated by the arrows in FIGURE 2. The process is thermodynamically reversible, thus indicating its high efficiency.

The device and method described above can be used in heating as well as refrigeration. For example, in a home heating system, the heat source could be the home furnace, the cold end of the device would communicate with the air outside the house, and the heat dissipated in isothermally compressing the working fluid in conduit section **46** would be used to heat the air in the house. Such a system would have the high thermodynamic efficiency lacking in present systems but would not have excessive complexity. Other arrangements using the invention in heating may be provided in accordance with the prior art.

It is an advantage of the present invention that the maximum radius of the rotor can be made relatively small (e.g. 2 to 4 inches) even though the rotational speed of the device is low (e.g. 1,000 to 3,000 r.p.m.). The amount of compression provided by the device is a function of the maximum radius of the flow conduit and the density of the working fluid. By the use of a high-density working fluid such as the "Freon" gases disclosed above, the required rotational speed and the maximum conduit radius are minimized. In fact, the rotational speed is brought within the realm of practicality by the present by reducing the required speed from the 100,000 to 200,000 r.p.m. speed previously required to the vicinity of 1,000 to 3,000 r.p.m. An important advantage of this reduction in rotational speed is that heat can be conducted into and out of the rotating system by simple fins instead of the elaborate liquid conduit system required in the prior art devices. These fins move with a velocity compatible with their utilization as impeller blades for moving gases through the cold and warm air ducts external to the rotating assembly. What is more, by providing a closed loop conduit contained entirely within the rotating device, troublesome seals are not required for passing the working fluid into and out of the rotating system. This greatly saves in complexity, maintenance, and cost of the device, and makes it possible to use high-density working fluids and seal them in the closed loop at relatively high pressures.

The entire thermodynamic device shown in FIGURE 3 comprises a rotor structure generally indicated at **58** and a motor **60** (illustrated schematically) which drives the rotor structure **58**. Suitable bearings (not shown) are provided at ends **34** and **36** of the central shaft **30**. It is another advantage of the present invention that the motor **60** need not be very powerful, since its only function, after driving the rotor **58** up to its operating speed, is to maintain it at the speed attained and to drive the fan blades secured to the rotor. Maintaining the speed of the rotor requires very little energy from the motor since the source of energy for the thermodynamic system is the heat source **54**, not the motor.

As is shown in FIGURE 3, the gas flow tubes **37** are arranged symmetrically about the axis of rotation **41**. It is indicated schematically in FIGURE 3 that three pairs of opposed tubes **37** (six separate tubes) are provided in the device shown. However, the number of separate tubes provided is optional.

Each tube **37** is secured at each end in a manifold structure **62** secured to the outside of shaft **30**. Each tube communicates with the conduit **32** by means of a separate port **64** extending through the side-wall of the shaft **30**. The thickness of the side-wall of the shaft **30** is made relatively great so as to give it sufficient structural strength despite the weakening effects of the ports **64**.

The rotor **58** includes a first housing section **66**, preferably of metal, which extends around the pump portion **51** of the structure and is insulated from the gas flow conduits by means of insulation **68** at all places except along the tube section **40**. The metal of the housing makes intimate contact with the metal of the tube section **40**. A plurality of radial heat-transfer fins **70** extends from the outer surface of housing section **66**.

A stationary gas guidance arrangement **74** is mounted on a suitable external support structure (not shown). The structure **74** has a first annular guide member **76** which extends around the housing **66** and is spaced at a relatively great distance from the housing. Positioned to the right of plate **76** is an insulating member **78**, also of annular shape, which closely fits the contours of an external section **80** of insulation which covers tube sections **42** and **44**. Hot air (or other gas) is introduced between the insulating member **78** and the plate **76** and flows towards the fins **70**. The fins **70** have holes **72** spaced around their periphery which catch the heated air and pass it from one fin to the next and throw the air radially outwardly after its heat has been transferred to the tube sections **40** in the rotor. The structure **74** includes another annular plate **82** spaced to the right of insulating member **78** which guides cool air towards a plurality of fins **84** with holes in them which are secured to the outside of another metal housing **86** which makes intimate contact with the portion **46** of the gas flow conduit. The cool air is transferred through the holes in the fins from one fin to the next and is thrown outwardly after heat has been transferred to the air.

Another metal housing **87** makes intimate contact with the sections **50** of the gas flow tubes, while the tube section **48** is insulated by means of insulation **88**. A plurality of fins **89** extend from the housing **86**. Another annular insulating ring **91** extends around and in close proximity to the insulation **88**. The ring **91** separates the fins **84** from the fins **90** in order to insulate the gas flows to and from those sets of fins from one another. Each fin has a plurality of inwardly-bent blade portions **92** which act as fan blades to push the cold air forward as indicated by the arrows **94**. Warm air is drawn in towards the fins **90** from the atmosphere, is cooled due to contact with the cold tube portions **50** and fins **92**, and then is pushed outwardly by the fan blades **92**. As is well known in the art, many other forms of heat exchanging fins can be used here, and gas flows can be directed as desired.

The device shown in FIGURE 3 is ideally suited for air conditioning or refrigeration, and is especially valuable in applications in which a heat source already is available, such as in automobiles and similar equipment. Heat can be obtained from the engine of the automobile, and the warm air given off by the device can be expelled from the car. The air to be cooled is taken from the interior or exterior of the car, is cooled, and then is circulated in the car. Thus, a simple, compact, self-contained and relatively inexepnsive automobile air cooler is provided.

The radii, rotational speed, initial pressure at which the fluid is sealed in the device, and selection of working fluid advantageously can be varied quite readily in order to adjust the operation of the device to adapt it to specific uses. The working fluid desirably should be selected so

that it will not liquify at the speeds and radii selected. However, in the embodiments shown in FIGURES 4, 5 and 8, the gas, radii and rotational speed are selected so as to deliberately produce liquefaction of the working gas.

In the device **100** shown in FIGURES 4 and 5, the refrigerant gas, preferably "Freon," is selected to liquify at a chosen pressure and temperature, and the maximum radius of the flow conduit and the rotational speed of the rotor are selected so as to liquify the gas at a given radius, while maintaining it in a gaseous state at the axis.

Referring first to the schematic diagram of FIGURE 4, the device **100** includes an axial tube **102** which communicates at its open ends with a plurality of radial conduits extending outwardly from the axis of rotation **104** of the tube **102** and communicating with reservoirs near the outermost surface of the device. Only one set of conduits and reservoirs is shown in FIGURE 4 for the sake of simplicity.

The gas in the axial tube **102** flows into a first radial conduit or passageway **106**, and, because of the high density of the gas, the radius and rotational speed of the device, and the type of gas used, the gas liquifies at some point along the conduit. The liquid then flows into a reservoir or chamber **108** in which it collects. Chamber **108** has an outer surface **111** which extends in a direction generally parallel to the rotational axis **104**. A heat source **110** delivers heat to surface **111** in order to heat the liquid and cause it to boil and return to the gaseous state. The chamber **108** provides a relatively broad external heat transfer surface **111** and a relatively large liquid surface area from which to boil gas.

The gas boiling out of chamber **108** flows inwardly towards axis **104** through a conduit **114**, and cools due to expansion resulting from the reduction of centrifugal force on the gas. The gas then passes into another conduit **116** extending radially outwardly and again is compressed by centrifugal force and again liquifies. The liquid flows from conduit **116** into a second chamber **118** which has an outside surface **120** extending in the direction of the axis **104**. Heat is extracted from the condensing fluid at surface **120** and the liquid flows through an expansion nozzle **122** into a third chamber **124**. Due to the heat loss of the liquid in chamber **118** and its flow through the expansion nozzle **122**, part of the liquid evaporates into a gas in chamber **124**, and part of it flows through the nozzle **122** in liquid form and collects at **126** on the inside of the outer wall **128** of chamber **124**. Heat is extracted at surface **128** from the fluid or object being cooled, and the liquid **126** evaporates and passes through the inwardly-directed radial passageway **130** back to the conduit **102** to complete a closed loop flow path. The evaporation of the liquid in chamber **124** cools the liquid **126** and the surface **128** and provides excellent refrigeration.

The liquid and gas are driven around the closed loop by a pump related to that used in the embodiment shown in FIGURES 2 and 3. The passages **106**, **108** and **114** constitute a pump section. The liquid and gas in passage **106** has a far greater density than the gas in passage **114**. Thus, the pressures created by centrifugal force on the fluids in passage **106** far exceed the pressures from the gas in passage **114** and the resulting pressure difference pumps the fluids around the closed loop.

This embodiment of the invention has an advantage in that the outer surfaces **111**, **120** and **128** of the liquid chambers **108**, **118** and **124** form rather broad surface areas for maximizing the rate of heat transfer. The heat transfer is further improved by the fact that each surface is in contact with a liquid which is thrown against it with great force. The liquid conducts heat much better than a gas. Insulation of the passages and chambers is provided in all places where heat transfer is not specifically desired so as to maximize the efficiency of the device.

The chambers **108** and **124** are shown in FIGURE 4 as being located at greater radii than the chamber **118**. This is done merely to illustrate that the radial position of each of the chambers **108**, **118** and **124** can be adjusted as required for the particular thermodynamic use to which the equipment is to be put.

The construction of the complete thermodynamic device 100 is shown in FIGURE 5, and includes a plurality of radial spacers 132, preferably of thermal insulating material, each of which abuts the tube 102 at one edge and extends outwardly to the outer surfaces 111, 120 and 128 of the liquid chambers 108, 118, and 124. The spacers are longer than the tube 102 and abut at their ends against insulating end plates 134 and 136, each of which has a centrally-located shaft member 138 or 140. This construction effectively separates the rotor into a plurality of radial compartments (16 compartments in the specific device shown in FIGURE 5) each of whose cross-section is shaped like the sector of a circle. The separators 132 are provided so that the liquid and gases flowing in the passageways in a radial direction will not swirl in the rotor due to Coriolis forces. A motor 142 rotates the rotor 100 at the desired speed.

Each of the spacers 132 preferably has a plurality of large holes as indicated at 144, 146 and 148 in order to minimize its weight and provide access for filling the spaces around the flow passages with insulation material.

A fin 150 without holes, and a plurality of other fins 152 extend outwardly from the surface 111 of liquid chamber 108. Each fin 152 has a series of peripherally-spaced holes 154. Another fin 156 without holes is provided at the far right edge of the surface 111. A stationary air duct is formed by a pair of parallel annular plates 158 and 160 which extend around the unit 100 in close proximity to the center fins on the surface 111. Hot air is introduced into the passageway formed between the plates 158 and 160 and flows between the fins by means of holes in the fins, and then is thrown outwardly after it has transferred its heat to the fins.

A plurality of other radial fins 162 with holes in them extend from the outer surface 120 of chamber 118. A solid fin 166 is positioned at the left edge of surface 120 and is joined with the fin 156 on surface 111 by means of insulation material 164. Another annular plate 168 and an annular insulation member 170 guide cool air towards the fins 162. The air passes through the holes in the fins and outwardly after absorbing heat from the fins and the surface 120. Another stationary annular insulator 171 extends around and near the insulator 164. Insulators 170 and 171 serve to insulate adjacent fins and the related air flows from one another.

Fins 172 protrude from the surface 128 of chamber 124. Air is drawn from the ambient medium into the fins 172 and is blown outwardly in the direction of the arrows 173 by means of fan blades 174 formed in the fins 172 in the same manner as the blades 92 are formed in the fins of the FIGURE 3 device. The fins 172 conduct heat from the ambient air into the liquid 126 in the chamber 124, thus cooling the air and evaporating the liquid. The cold air then is used for refrigeration. Of course, the device 100 also can be used for heating, in substantially the same way as the device shown in FIGURES 2 and 3.

A further advantage of the structure shown in FIGURES 4 and 5 is that it has considerably greater total area for heat transfer in the same volume occupied by the structure shown in FIGURES 2 and 3. Also, the radial separators 132 improve the strength of the structure.

The embodiment shown in FIGURE 8 is identical to that shown in FIGURES 4 and 5 except that a gas pumping unit 175 like the unit 51 shown in FIGURE 2 replaces the liquid pumping unit shown in FIGURE 4. More specifically, an angular passage 176 and a straight passage 178 replace the chamber 108 and the passage 114, respectively. The distances of chambers 118 and 124 from the axis 104 can be adjusted to suit the desired thermodynamic operating conditions. The radial dimensions of pumping unit 175 are made greater than those of the chambers 118 and 124 in order to maximize the pumping pressure provided by the pumping unit. However, the working fluid, initial pressure and other variables are selected so that the working fluid in passages 106, 176 and 178 remains in a gaseous state at all times despite the fact that the fluid liquefies in chamber 118 which may be at a smaller radius. The difference is that heat is extracted in chamber 118, but not in the pump section. The gas pumping section provides pressure for forcing the liquid and gas around the closed loop in the same manner as described in connection with FIGURE 2.

FIGURE 9 illustrates another embodiment of the invention which is identical to that shown in FIGURES 2 and 3 except that an elongated conduit section 180 parallel to axial section 32 is provided together with a plurality of thermally conductive washers 182 separated from one another by insulation 184. Also, only the section 50 returns the section 180 to the axis, and the radial section 48 is not provided. Thus, the movement of the gas through section 50 is substantially isothermal so as to maintain reversibility of the processes of cooling and of regenerative heat exchange. The gas in section 180 conducts its heat to opposite, relatively short portions of the tube 32 through the mutually-insulated washers 182 and thus is pre-cooled by the cooling of the system in a thermal "feed-back" or "regeneration" arrangement. This enables the provision of very low cold temperatures in section 50, and makes the thermodynamic device quite valuable for use in the liquefaction of gases and other uses in which very low temperatures are required.

Alternatively, the washers 182 may be made of insulating material and the spaces between them filled with either a liquid or gas instead of solid insulation 184. Radial spacers (not shown) such as the spacers 132 shown in FIGURE 5 can be used to prevent Coriolis swirling of the fluids in the spaces. The fluids provide the heat transfer between sections 180 and 32 instead of the washers. The fluids preferably are different from those flowing in the closed loop, and/or are stored at different pressures to maximize heat transfer.

One of the important advantages of the invention is that there is a sufficient number of adjustable parameters to permit the thermodynamic operation to closely approximate a Carnot cycle operating between three arbitrarily chosen temperatures. By the addition of a multiplicity of thermally conductive sections in the closed conduit system, heat can be exchanged isothermally with a multiplicity of external reservoirs at various temperatures.

Many different and well known heat sources and means of heat transfer can be used: for example, a system for use in space could have a reflector for gathering solar energy, and fins for radiating heat from the intermediate temperature section. Once the rotor had been set into rotation, very little energy would be required to maintain its rotation. As an alternative, a radio-isotope source could be used as a heat source.

The above description of the invention is intended to be illustrative and not limiting. Various changes or modifications in the embodiments described may occur to those skilled in the art and these can be made without departing from the spirit or scope of the invention as set forth in the claims. Thus, it should be apparent that the invention is not limited to the specific structures illustrated in the drawings. For example, each of the various embodiments can be constructed in accordance with the structural concepts shown in the other embodiments, and these concepts may be used in combination with one another, all without departing from the invention.

I claim:

1. Thermodynamic apparatus comprising, in combination, a rotor, means for rotating said rotor, conduit means in said rotor for defining a closed loop fluid flow conduit within said rotor, said conduit having a first section extending away from the axis of rotation of said rotor, a second section extending toward said axis, and a third section joining said first and second sections, means

for removing heat from a fluid in said third section, and pump means for urging the flow of said fluid through said closed loop, said pump means comprising means for creating a continuous difference between the average density of a first volume element of fluid in said first section and a second volume element of fluid in said second section, said first and second volume elements being equal and being located at equal average radial distances from said axis.

2. Apparatus as in claim **1** in which said pump means includes means for heating said fluid at a location spaced outwardly from said axis.

3. Apparatus as in claim **2** in which said third section includes fourth and fifth sections of said conduit, said fourth section being connected to said second section and extending outwardly from said axis of rotation of said rotor, said fifth section being connected between said fourth and first sections and extending inwardly toward said axis, said heating means being positioned to conduct heat to said second section to heat the fluid therein.

4. Apparatus as in claim **3** in which said second section extends towards said axis at an acute angle whose magnitude is such that the temperature of the fluid in said second section remains substantially constant throughout said second section for a given rate of heat input to said second section.

5. Apparatus as in claim **4** including a sixth section of said conduit, said sixth section extending radially toward said axis at the end of said second section.

6. Apparatus as in claim **5** including thermal insulation material around said first and sixth sections.

7. Apparatus as in claim **1** including an expansion nozzle in said third section.

8. Apparatus as in claim **3** including an expansion nozzle in said third section.

9. Apparatus as in claim **8** including first, second and third liquid reservoirs, each located in one of said fourth, second and fifth conduit sections and having a thermally conductive outer surface extending in the direction of said axis of rotation.

10. Apparatus as in claim **3** in which said third section includes a sixth section which extends along the rotational axis of said rotor, and including a seventh section radially spaced from said axis and joining said fourth and fifth sections, said seventh section extending in a direction substantially parallel to said axis, and a plurality of longitudinally spaced and mutually insulated heat conducting means each of which is coupled between said sixth and seventh sections.

11. Apparatus as in claim **10** in which each of said heat conducting means comprises a radial fin, and including insulation between adjacent fins.

12. Apparatus as in claim **3** including first and second axially-extending chambers with thermally-conductive outer surfaces, an expansion nozzle joining said chambers, the first of said chambers comprising said fourth conduit section, the inlet end of said first chamber being connected to the outlet of said second section, and the outlet of said second chamber being connected to the inlet of said fifth section, a gas sealed in said closed loop, the system parameters, including the type of said gas, the radii of said sections and said chambers, and the rate of heat transfer to said second section and from said fourth section being such that said gas is a liquid in said chambers but is a gas in said closed loop along said axis, and in said fifth section.

13. Apparatus as in claim **12** in which the maximum radius of said first section is substantially greater than that of either of said chambers, said parameters being such that said gas also is in a gaseous state in said first and second sections.

14. Thermodynamic apparatus comprising, in combination, a rotor, means for rotating said rotor, conduit means in said rotor having a first section for guiding the flow of fluid radially outwardly from the axis of rotation of said rotor, and a second section connected to said first section at a location spaced radially outwardly from said axis for guiding the flow of fluid back towards said axis, further conduit means joining said first and second conduit sections to conduct a fluid therebetween at a second location which is spaced inwardly towards said axis from said first location, means for creating a continuous difference between the average density of a first volume element of fluid in said first section and a second volume element of fluid in said second section, said first and second volume elements being equal and being located at equal average radial distances from said axis, and means connected to said conduit means for pressurizing and then expanding the fluid.

15. Apparatus as in claim **14** in which the fluid in at least one of said conduit sections is a liquid.

16. Apparatus as in claim **14** including gas liquefaction means for liquefying a gas in said conduit.

17. Apparatus as in claim **14** in which said difference-creating means includes an energy-developing flux source located externally of said rotor, and means for supplying energy to said fluid from said flux source by directing said flux through the walls of said rotor.

18. Apparatus as in claim **17** in which said energy-developing flux source is a heat source, and said flux is heat flux.

19. Apparatus as in claim **14** including means for conducting heat from the ambient medium into the fluid in said second section.

20. Apparatus as in claim **19** in which said heat-conducting means comprises a plurality of fins with angularly canted portions to serve as fan blades to move the cooled ambient gas.

21. Apparatus as in claim **14** including a gas hermetically sealed in said conduit.

22. Apparatus as in claim **31** in which said gas has a density substantially greater than that of air.

23. Apparatus as in claim **22** in which said gas is selected from the group consisting of fluorochloromethane and fluorochloroethane refrigerants.

24. A thermodynamic process comprising the steps of subjecting a fluid to centrifugal force at a first station in a rotary conduit to compress said fluid, simultaneously cooling said fluid to maintain said fluid at a substantially constant temperature while being compressed, reducing the centrifugal force on said fluid at a second station in said conduit to expand and cool said fluid, and heating said fluid at a third station in said rotary conduit to create a continuous difference between the average densities of first and second volume elements of said fluid in different radial portions of said conduit and to cause said fluid to flow from said first station to said second station.

25. A process as in claim **24** including the steps of precompressing said fluid at a fourth station by the application of centrifugal force thereto prior to said heating step, and then reducing said centrifugal force at said third station simultaneously with said heating of said fluid.

26. A process as in claim **25** in which said simultaneous heating and centrifugal force-reducing steps are controlled so that the temperature of said fluid remains substantially constant during said steps.

27. A process as in claim **26** including the step of substantially adiabatically expanding said fluid between said third and first stations, and in which the expansion of said fluid at said second station is at least partially substantially adiabatic and partially substantially isothermal.

28. A process as in claim **24** in which heat is exchanged between each of a plurality of thermally insulated positions on two portions of the fluid located at different radii in said rotary conduit.

29. A process as in claim **24** in which said fluid is cooled by heat transfer to another fluid desired to be heated.

30. A thermodynamic process comprising the steps of rotating a closed loop fluid conduit with a fluid therein, creating a difference between the average density of said fluid along a first segment of fluid flowing outwardly from the axis of rotation of said conduit and the average density of said fluid along a second segment of fluid flowing inwardly toward said axis, said segments being of equal radial length and being spaced from said axis at equal distances, using the centrifugal force applied to said fluid to compress it in one section, removing heat from said fluid simultaneously with said compression step, and allowing said fluid to expand and cool by reducing the centrifugal force on said fluid at another section.

31. A process as in claim 30 in which the average density of the fluid in said first segment exceeds that of the fluid in said second segment.

32. A process as in claim 31 in which the fluid in said first segment is a liquid and the fluid in said second segment is a gas.

33. Thermodynamic apparatus comprising, in combination, a rotor, a hollow member on the rotational axis of said rotor and extending beyond the ends of said rotor to serve as a drive shaft therefor, a manifold structure encircling each end of said hollow member and having a plurality of symmetrically-spaced peripheral holes each of which communicates with the hollow interior of said member through a hole in the wall of said hollow member, a plurality of tubes each of which is connected between correspondingly-positioned holes in said manifold structures so as to communicate with said hollow interior of said member and thus form a plurality of closed loop fluid flow conduits symmetrically positioned with respect to said axis and each having an axial branch in common with the other conduits each of said tubes having a first section extending radially outwardly from one of said manifolds, a second section extending back towards said axis at an acute angle, a third section extending radially towards said axis, a fourth section extending substantially parallel to said axis, a fifth section extending outwardly from said axis at an acute angle, a sixth section extending radially towards said axis, and a seventh section extending towards said axis at an acute angle and terminating in the other of said manifolds, first and second sets of annularly-shaped radial fins, the first in thermal contact with each of said second sections of said tubes, and the second in thermal contact with each of said fifth sections of said tubes, each of said fins having a plurality of peripherally spaced holes, a third set of radial fins in thermal contact with said seventh section of each of said tubes and being shaped like fan blades, a casing for said apparatus, thermal insulating material filling said casing and surrounding said member and said tubes at all places other than those at which fins make thermal contact, and stationary gas conduit means adjacent said rotor for guiding warm and cool gases into and out of contact with said sets of fins and isolating from one another the flows of gases past adjacent sets of fins.

34. Thermodynamic apparatus comprising, in combination, a rotor, a hollow member on the rotational axis of said rotor, a plurality of radial spacers extending radially outwardly from said axial hollow member and axially beyond each end of said member, a pair of end plates secured to the ends of said spacers and having axial projections to serve as drive and rotational support members, circumferentially-extending wall members extending between adjacent spacers to form generally sector-shaped fluid flow conduits and chambers, said wall members forming between each pair of spacers, a first conduit extending radially outwardly from and communicating with one end of said axial hollow member, a first chamber with an axially-extending heat-conductive outer wall, a second conduit extending radially toward and then away from said axis, second and third chambers with corresponding axially-extending heat-conductive outer walls, a fluid flow-restricting expansion nozzle connecting said second and third chambers, and a third conduit extending radially toward and communicating with the other end of said hollow member.

35. Apparatus as in claim 34 including two sets of annular radial fins connected to said first and second outer walls, said fins having peripheral holes, a third set of fins connected to said third outer wall and being shaped to form fan blades, means for guiding heated and cooled gases into and out of contact with said fins and isolating from one another the flows of gases past adjacent sets of fins, said spacers having holes in them where there are no conduits or chambers and being made of insulating material, further insulating material filling the interior of said rotor outside of said hollow member and said conduits and chambers.

36. A thermodynamic process comprising the steps of rotating a closed loop fluid conduit with a fluid therein, and creating a difference between the average density of said fluid along a first segment of fluid flowing outwardly from the axis of rotation of said conduit and the average density of said fluid along a second segment of fluid flowing inwardly toward said axis, said segments being of equal volume and being spaced from said axis at equal distances, said density difference-creating step including heating said fluid at a first position located at a first radial distance from said axis, and cooling said fluid at a second radial distance, and pressurizing and then expanding said fluid to perform heat pumping.

37. A method as in claim 36 in which said difference-creating step includes making the fluid in one of said segments a liquid and the fluid in the other of said segments a gas.

38. A method as in claim 36 in which said second radial distance is smaller than said first radial distance.

39. Thermodynamic apparatus comprising, in combination, a rotor, means for rotating said rotor, conduit means in said rotor having a first section for guiding the flow of fluid radially outwardly from the axis of rotation of said rotor, and a second section connected to said first section at a location spaced radially outwardly from said axis, for guiding the flow of fluid back towards said axis, further conduit means joining said first and second conduit sections to conduct a fluid therebetween at a second location which is spaced inwardly towards said axis from said first location, means for creating a continuous difference between the average density of a first volume element of fluid in said first section and a second volume element of fluid in said second section, said first and second volume elements being equal and being located at equal average radial distances from said axis, said difference-creating means comprising means for adding heat to said fluid at a first location in said conduit, and means for extracting heat from said fluid at a second location in said condiut, the radial distance of said first location from said axis being greater than the radial distance of said second location from said axis, and means connected to said conduit for pressurizing and then expanding the fluid.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,470,704 October 7, 196ſ

Frederick W. Kantor

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, line 36, claim reference numeral "31" should read -- 21 --.

Signed and sealed this 17th day of March 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, J
Commissioner of Patent