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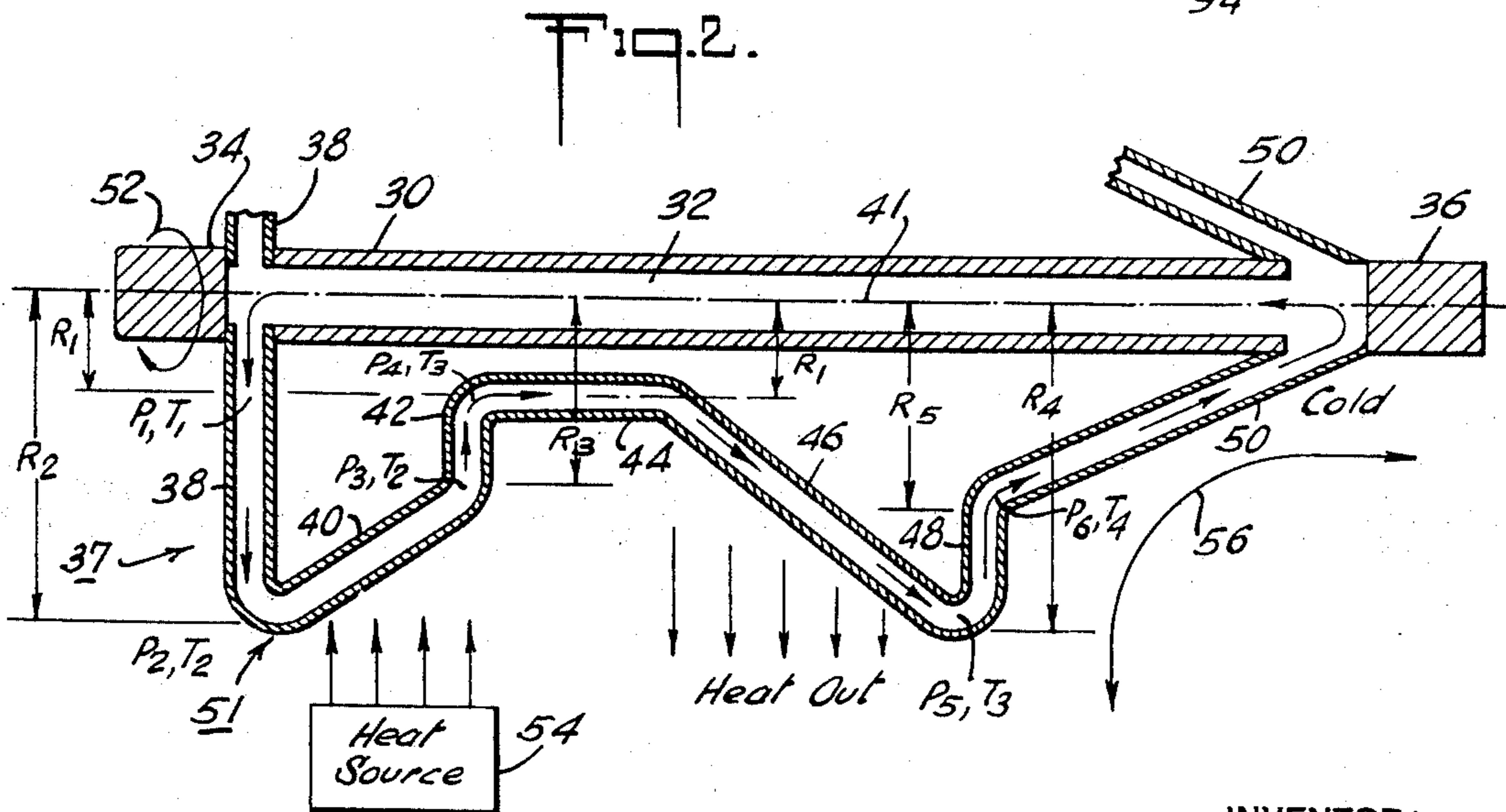
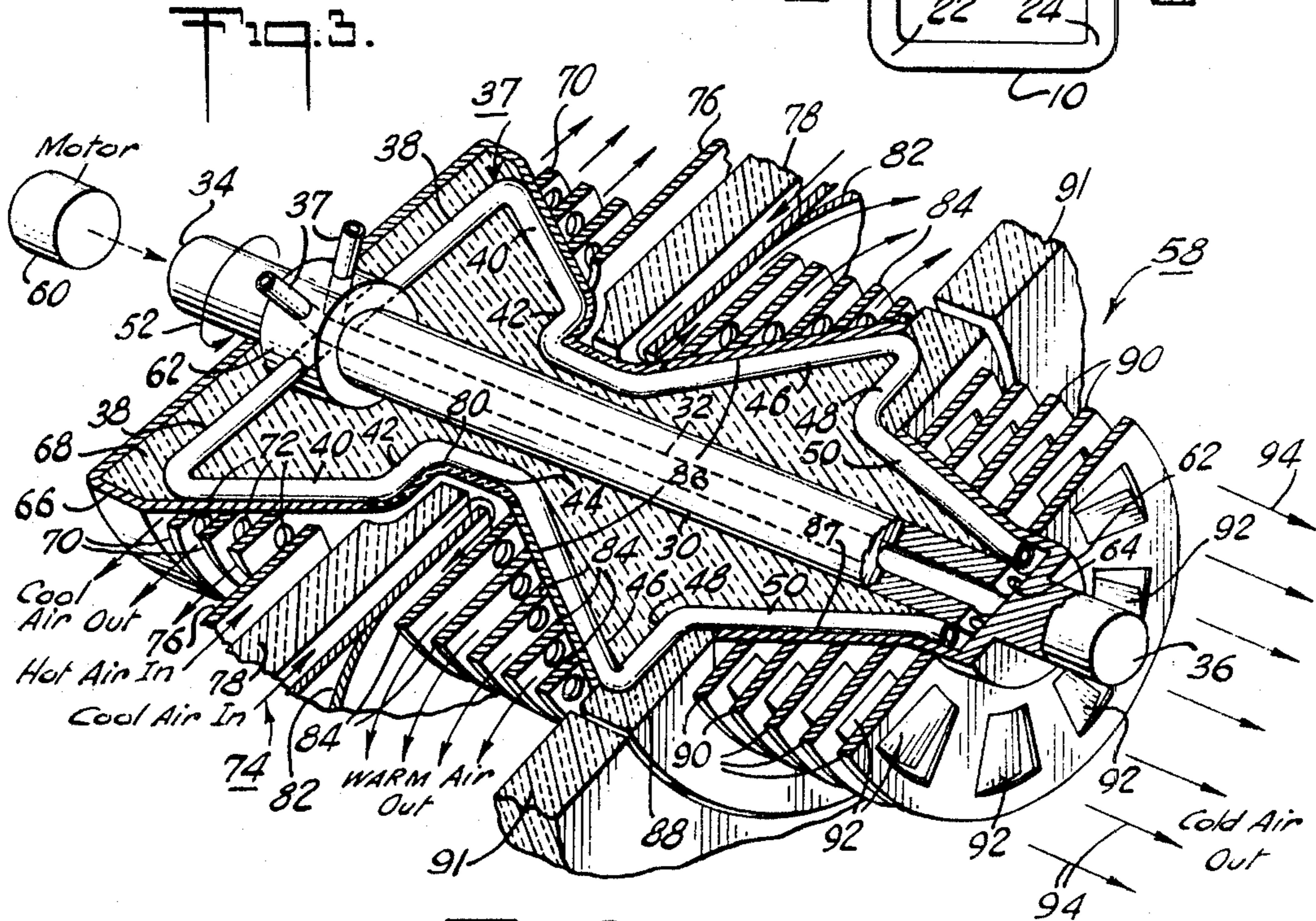
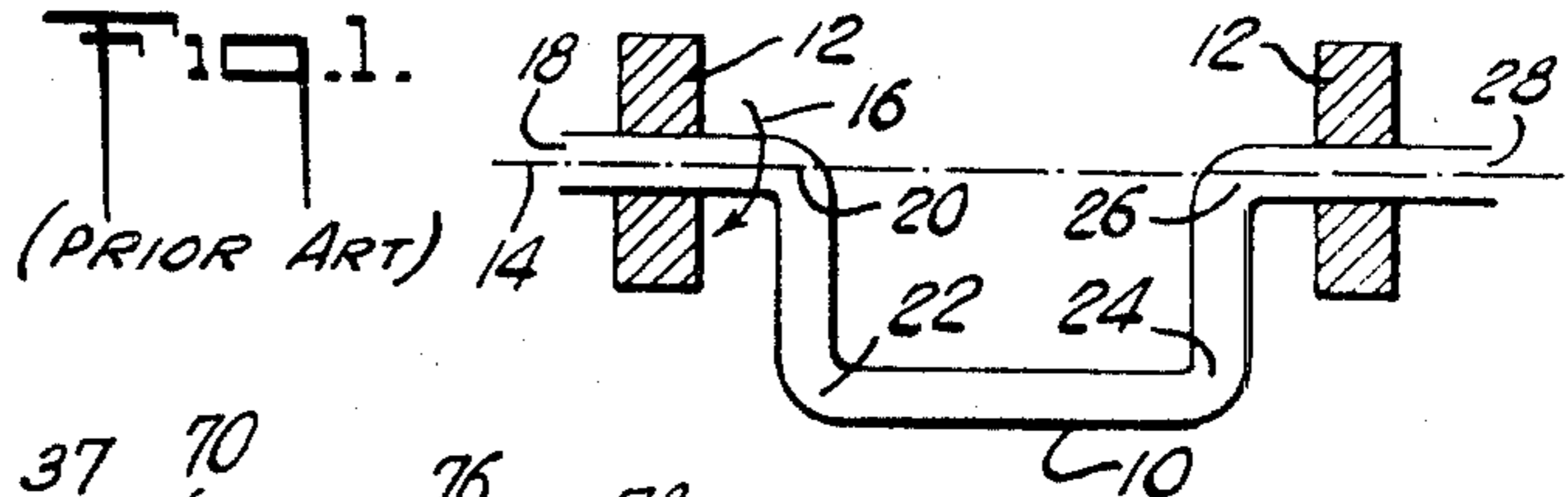
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3,470,704

THERMODYNAMIC APPARATUS AND METHOD

Filed Jan. 10, 1967

4 Sheets-Sheet 1



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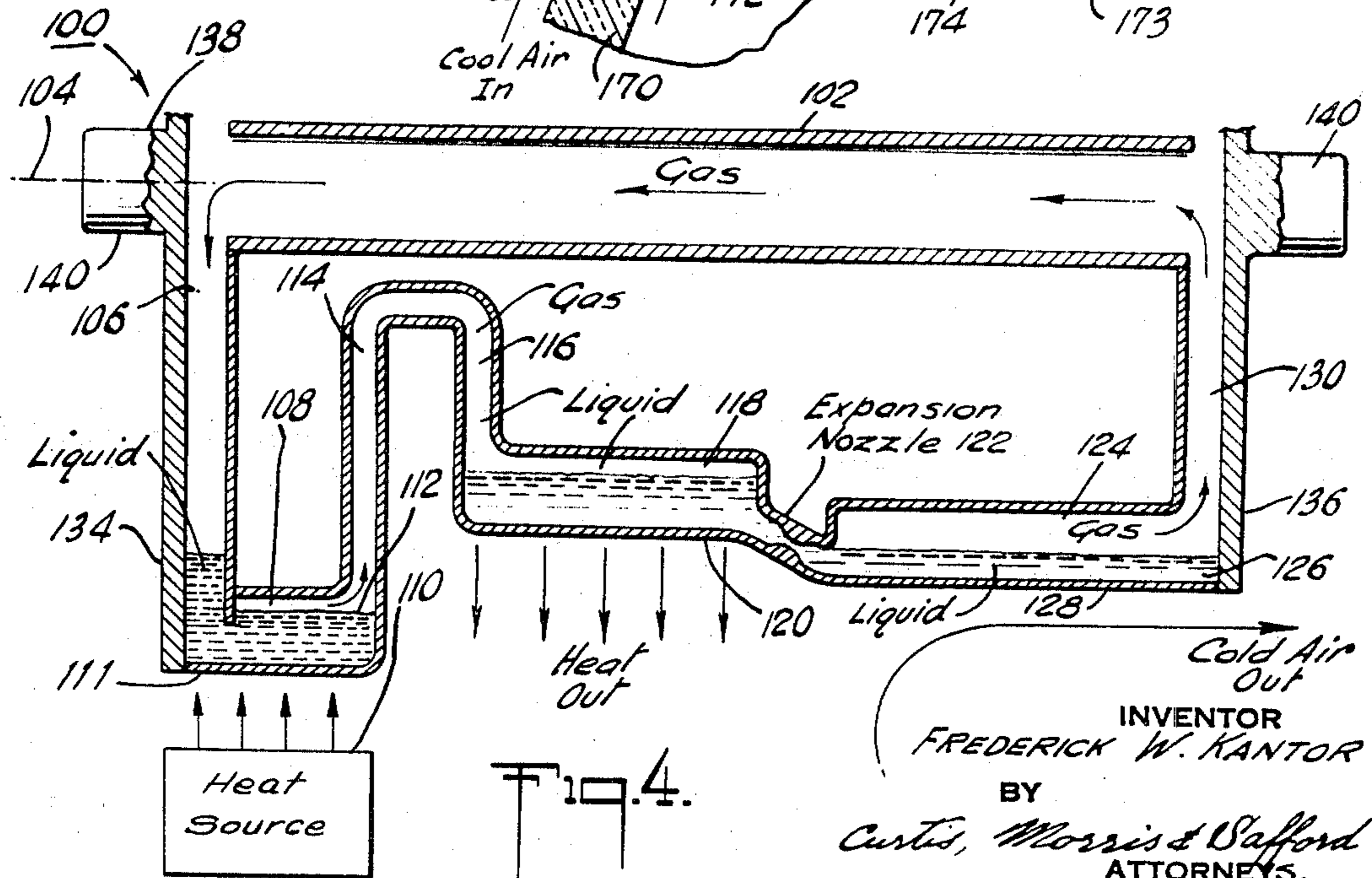
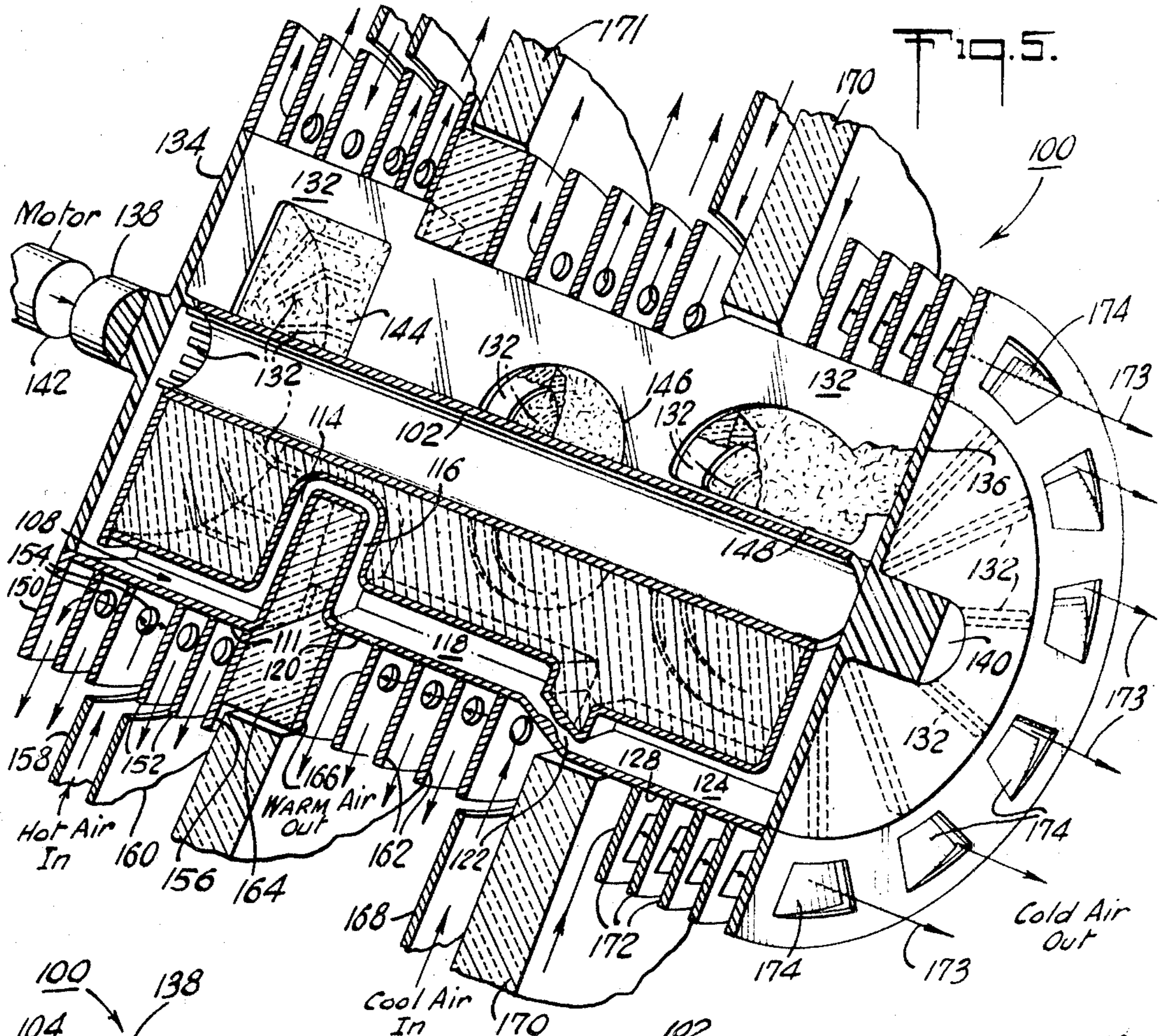


Fig. 4.

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Fig. 6.

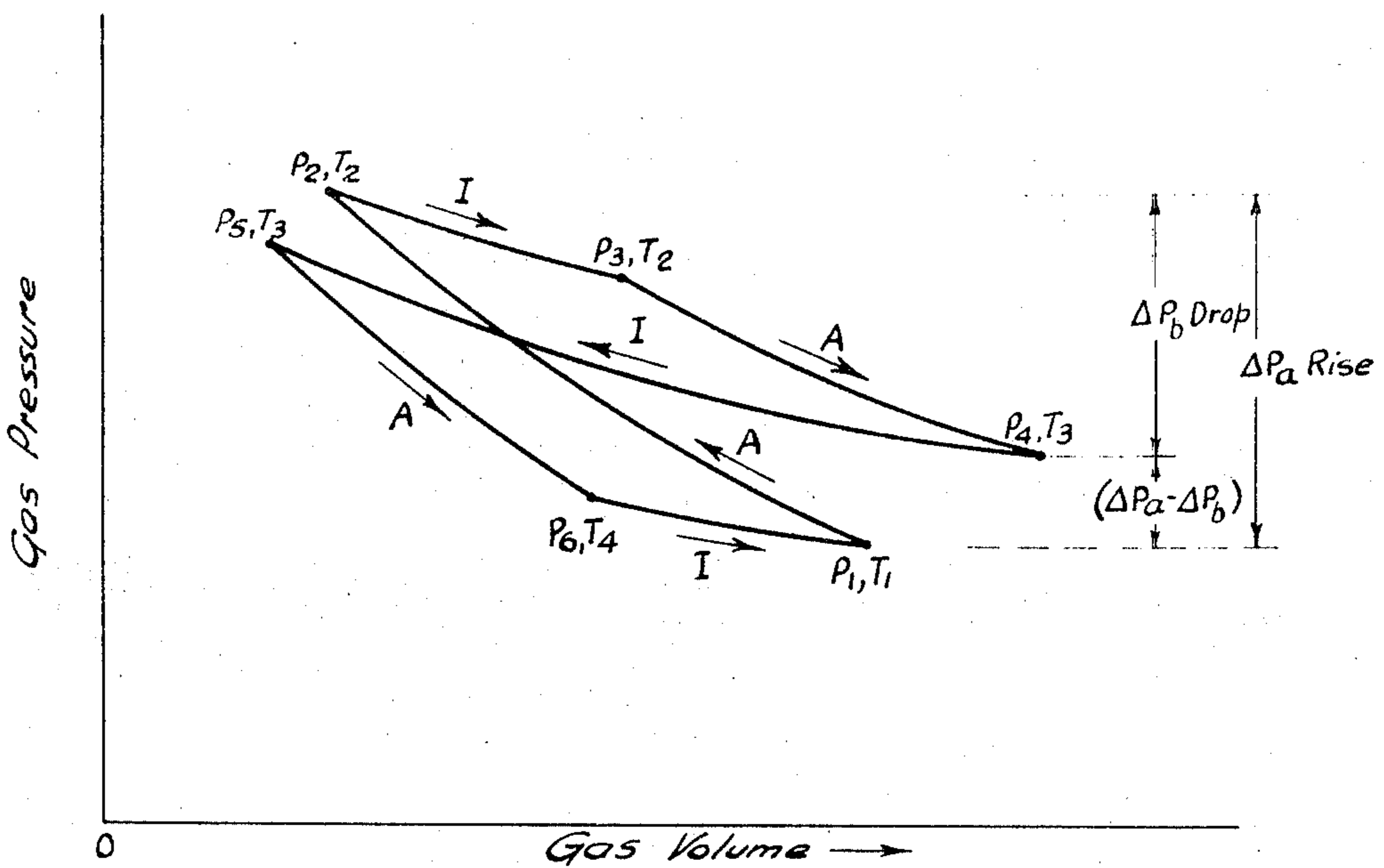
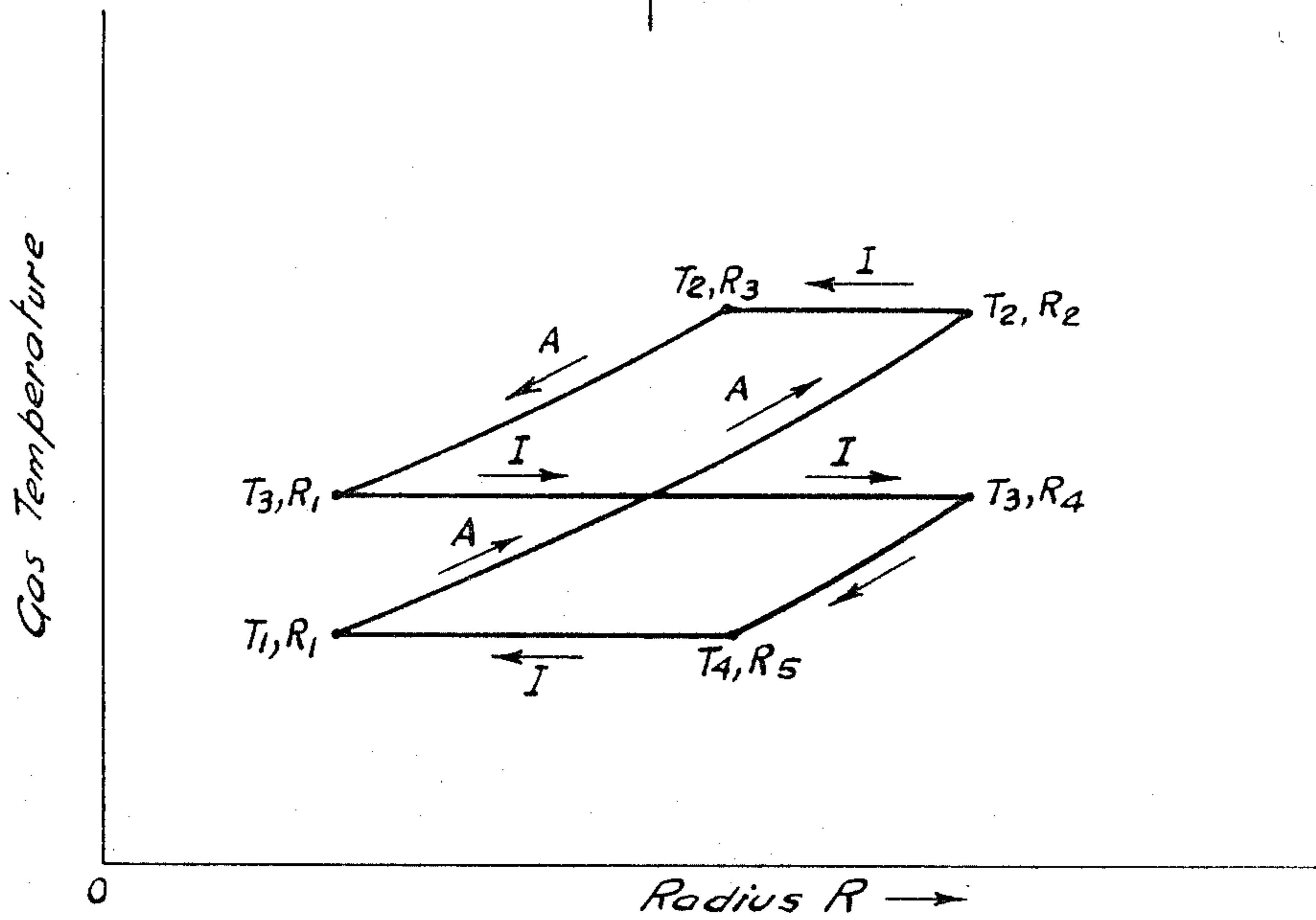


Fig. 7.

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Fig. 8.

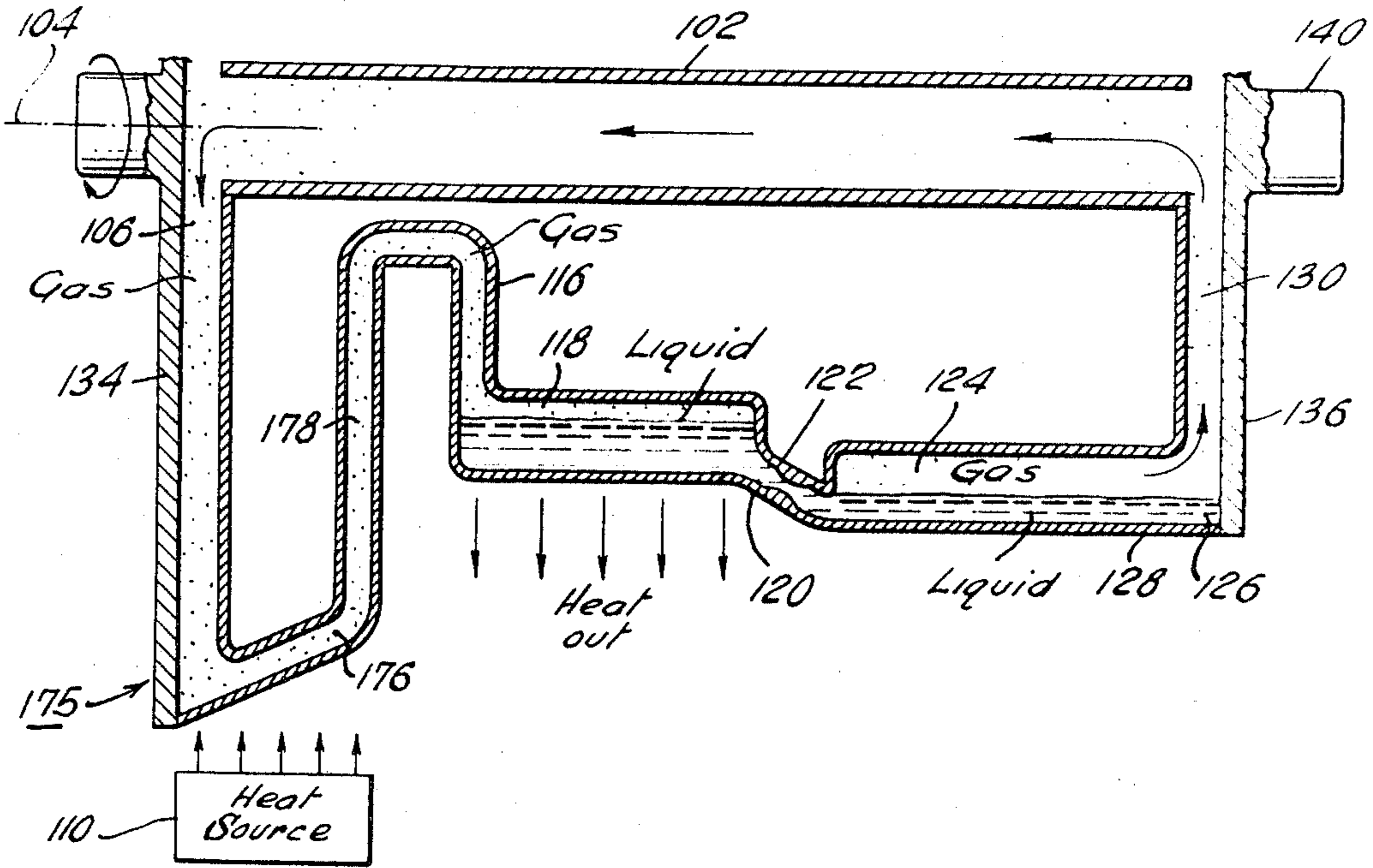
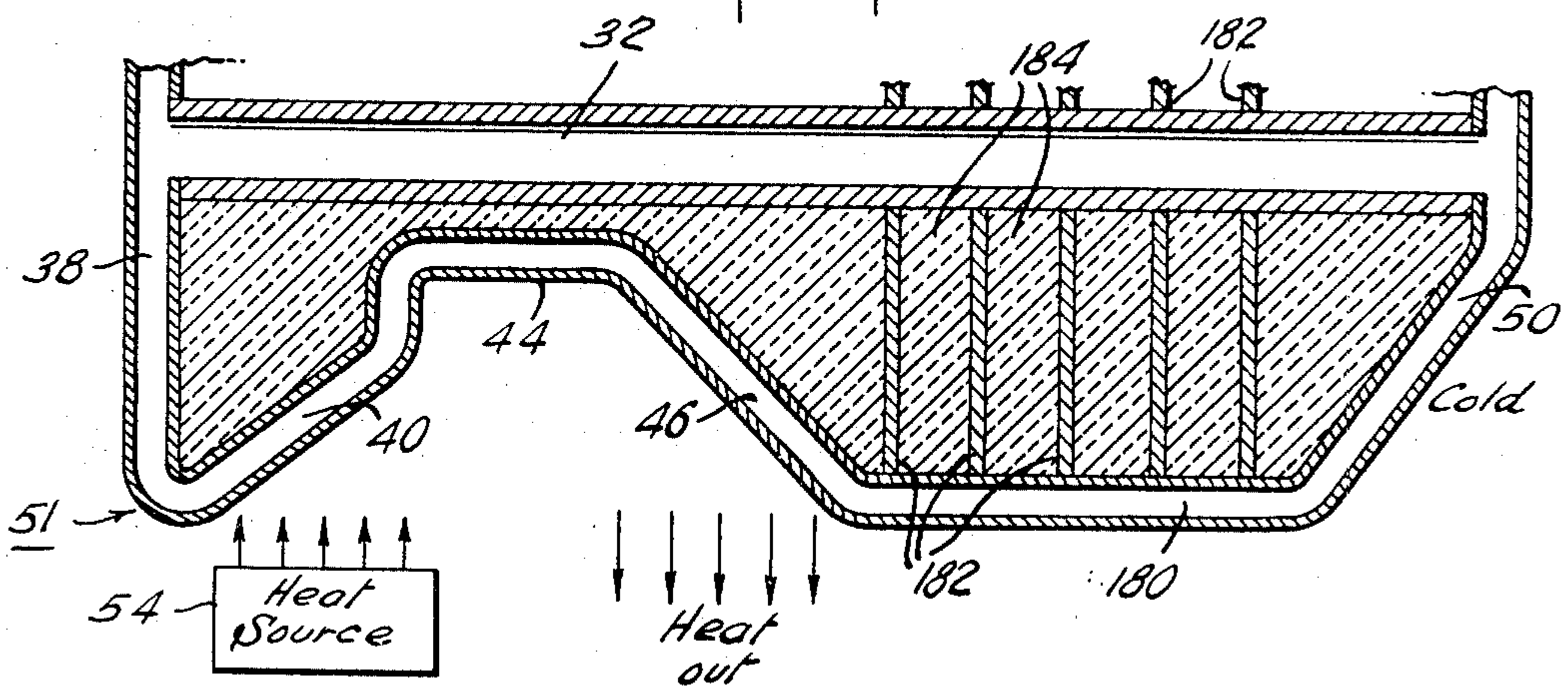


Fig. 9.



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**THERMODYNAMIC APPARATUS AND METHOD**  
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Filed Jan. 10, 1967, Ser. No. 608,323  
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

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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 fluorchloromethane and fluorchloroethane 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  $\Delta P_a$ . 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 source 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  $\Delta P_a$  minus  $\Delta P_b$  (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 even-

tually 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 inexpensive 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 pre-compressing 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 cor-

responding 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 conduit, 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.

#### References Cited

##### UNITED STATES PATENTS

2,724,953	11/1955	Justice	62—499
2,924,081	2/1960	Justice	62—499 X
3,013,407	12/1961	Justice	62—499
3,332,253	7/1967	Alexander	62—499

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U.S. Cl. X.R.

62—499

UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,470,704

October 7, 1969

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