

[54] NITROGEN VAPOR ENGINE

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[22] Filed: **Sept. 23, 1971**

[21] Appl. No.: **182,994**

[52] U.S. Cl. **60/26, 60/36**

[51] Int. Cl. **F01k 25/10, F03g 7/04**

[58] Field of Search **60/36, 26**

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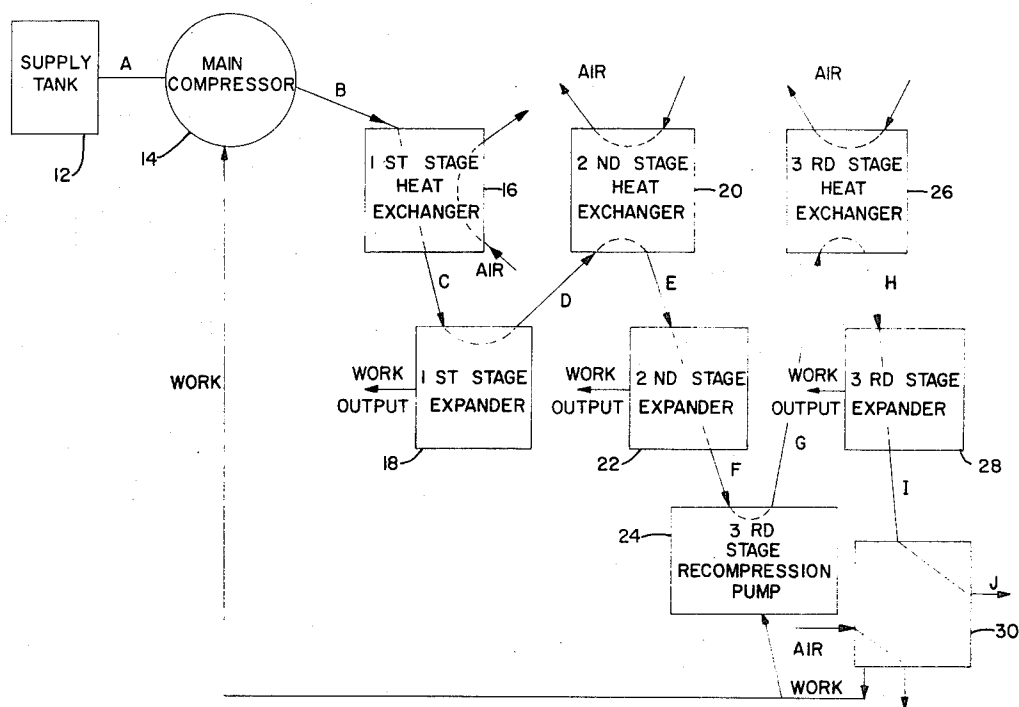
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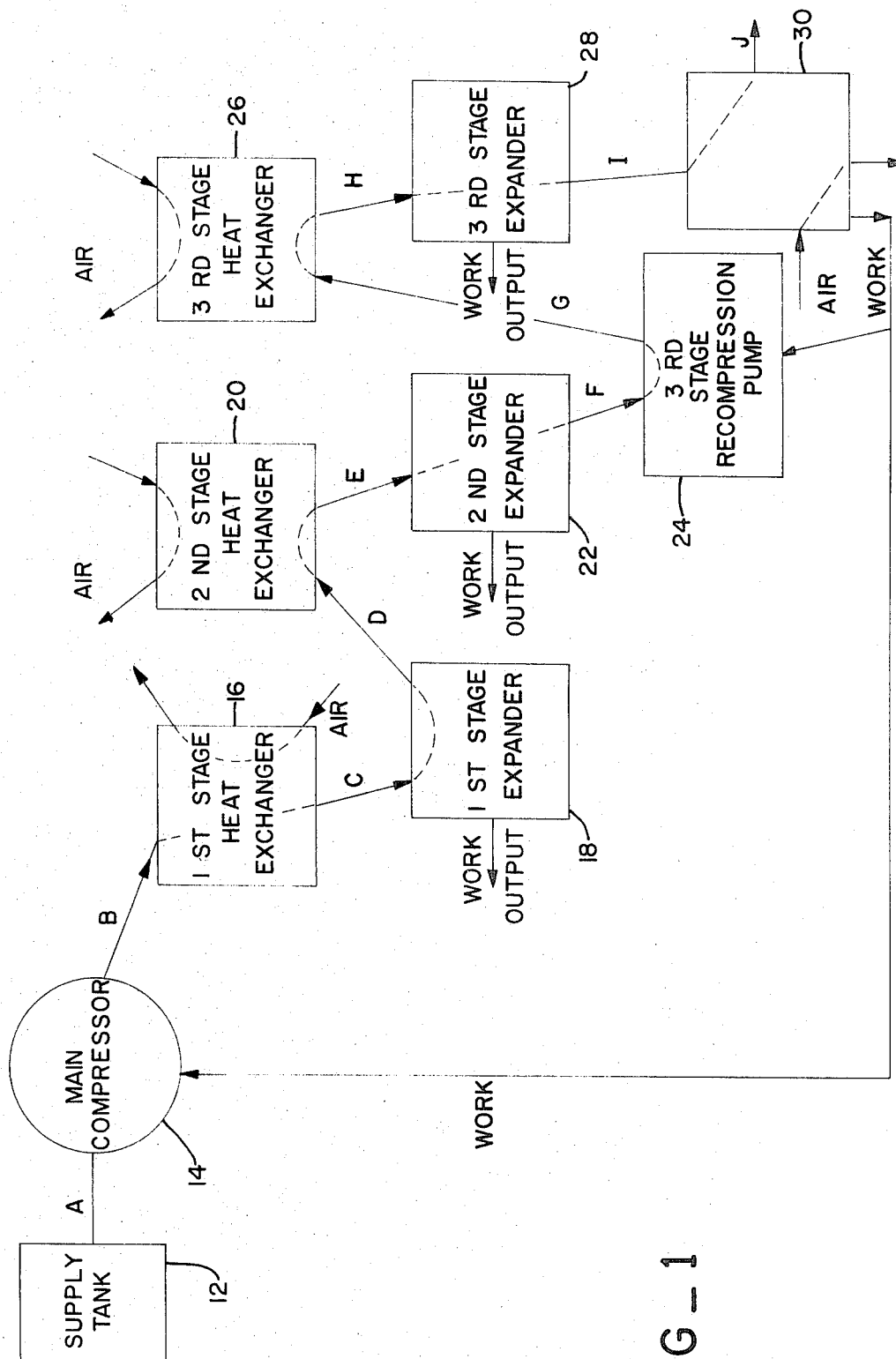
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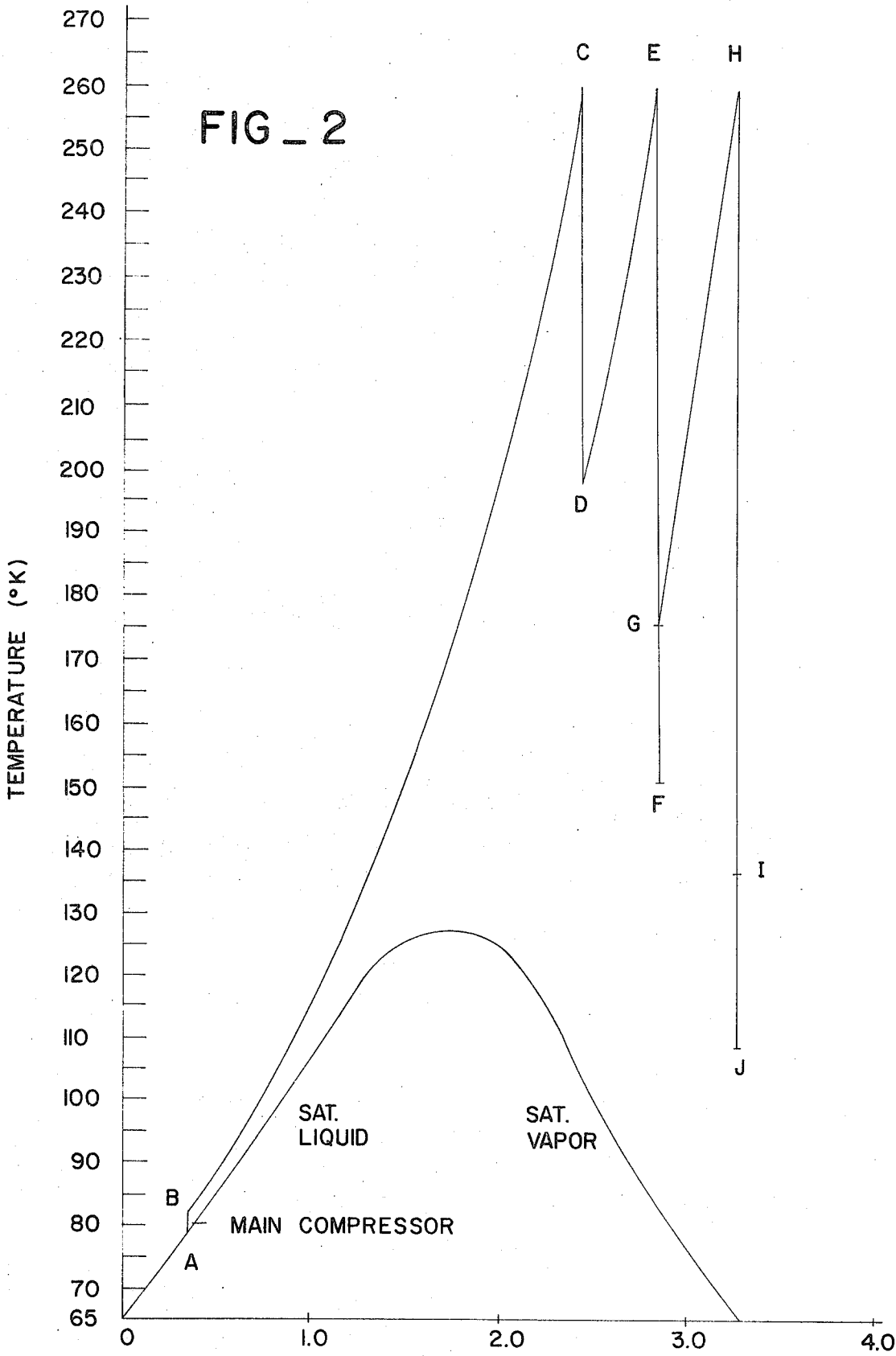
[57] ABSTRACT

An open-cycle thermodynamic engine using a working fluid which is a gas at ambient conditions and which is liquefiable at temperatures below ambient. The engine operates by compressing the working fluid, such as liquid nitrogen, with a pump, convectively heating the nitrogen in a heat exchanger, and isentropically expanding the nitrogen within an expandable chamber to produce shaft work. The cycle is repeated both with-out compression and with compression of the working fluid. To salvage the remaining energy in the nitrogen or other fluid, an exhaust engine is used. In one embodiment the exhaust engine uses an expandable chamber and piston driven by a plurality of long, small diameter heat responsive wires coupled under tension between the chamber wall and piston. When gases of different temperatures are directed across the chamber, the wires expand and contract thereby reciprocally moving the piston. In another embodiment of the heat engine a manifold is connected to numerous closed tubes in which nitrogen is heated by natural convection. When the pressures within the tubes reach a maximum, the tubes are selectively exhausted against a double acting piston to produce work.

4 Claims, 8 Drawing Figures







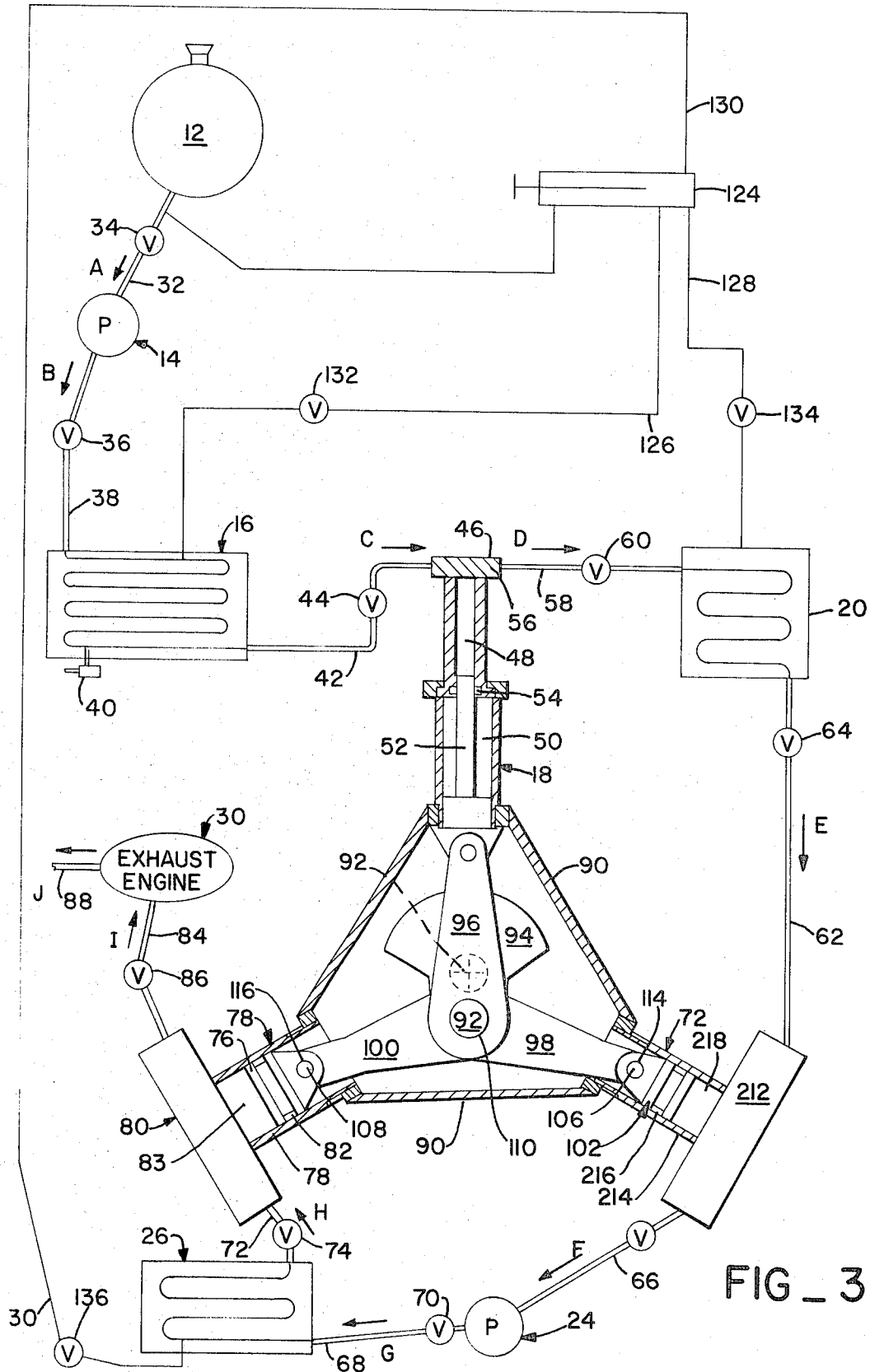
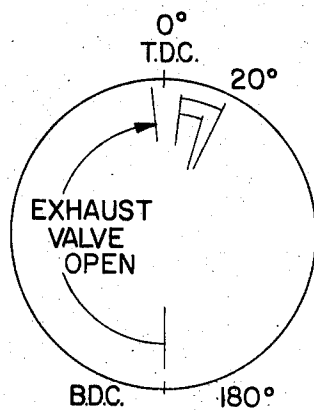
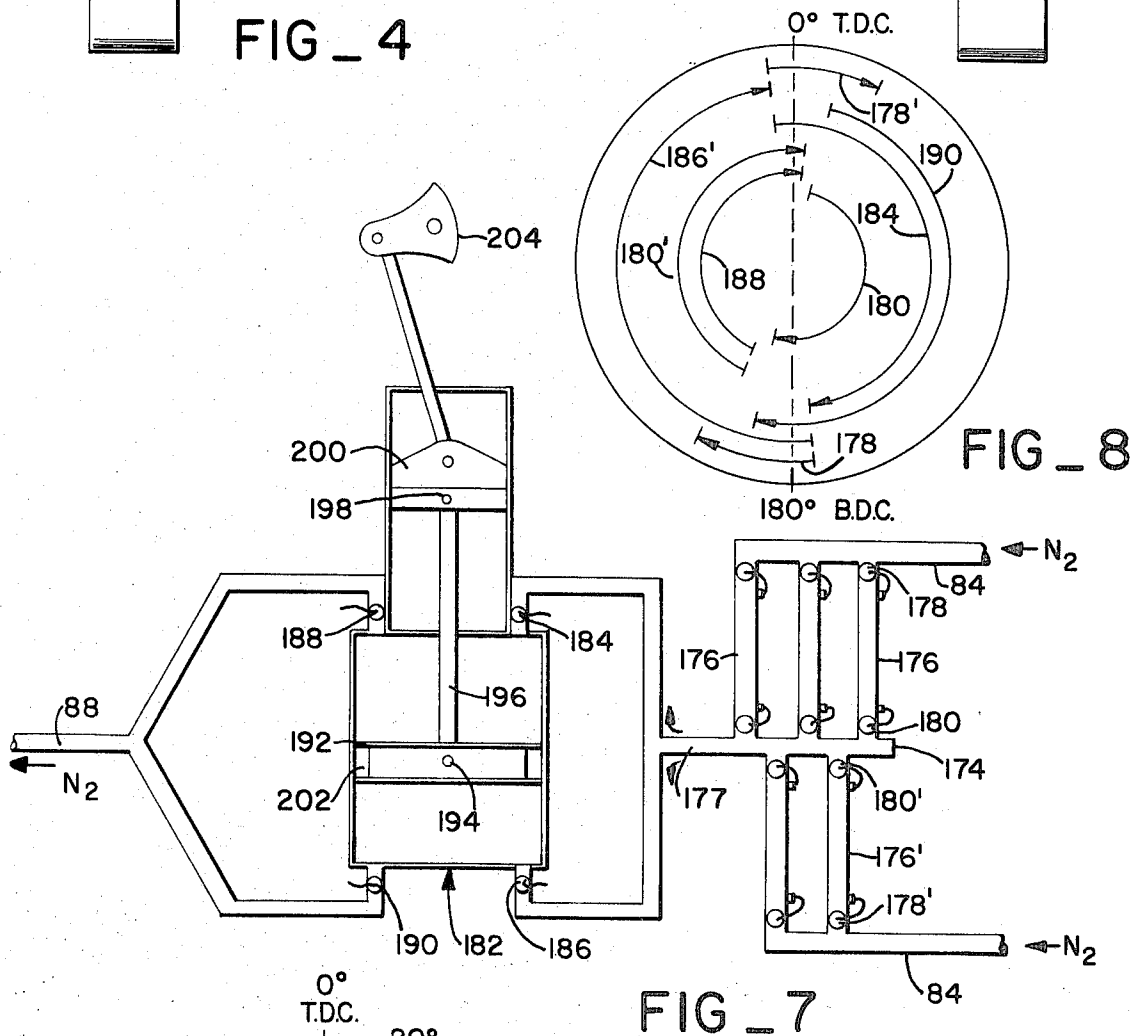
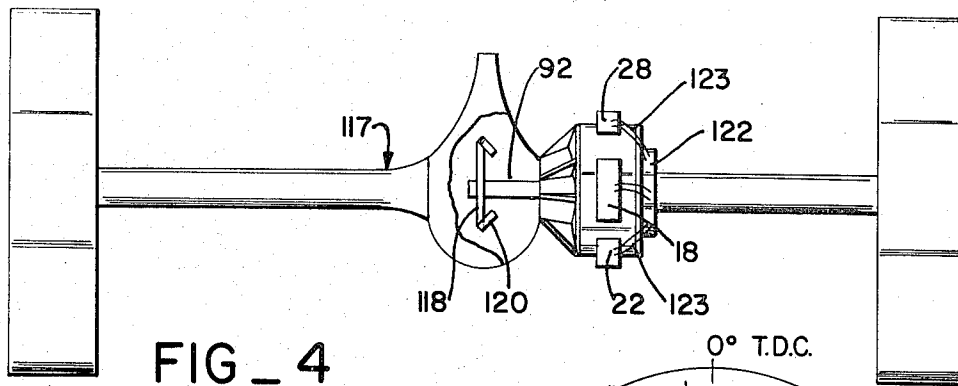


FIG. 3



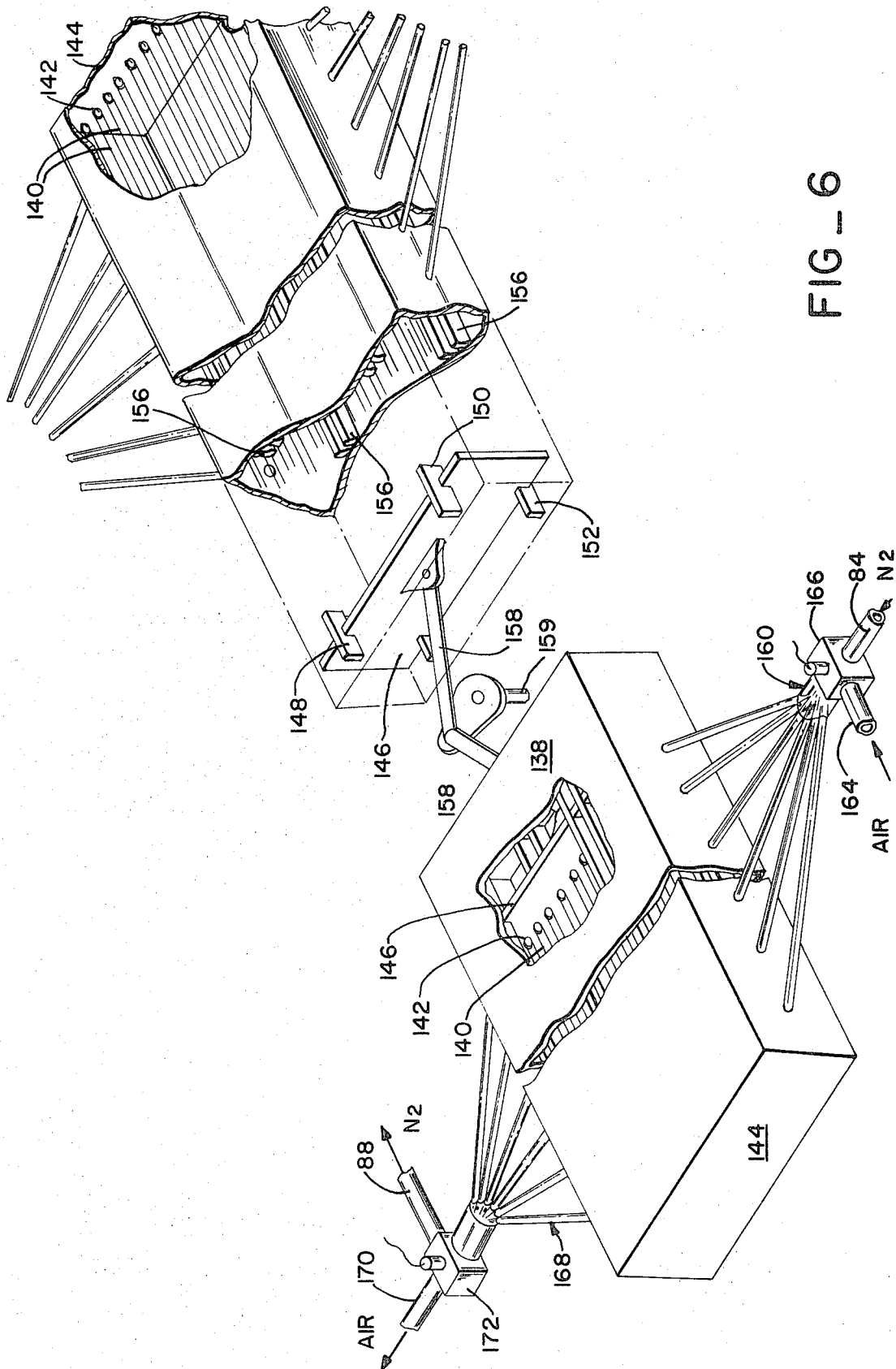


FIG. 6

NITROGEN VAPOR ENGINE

FIELD OF THE INVENTION

This invention relates to thermodynamic open cycle engines and more particularly to engines having expandable chambers.

SUMMARY OF THE INVENTION

One of the most serious contemporary problems is the health hazard originating from the pollution of the atmosphere. The primary source of this air pollution is the unburned combustion products and exhaust gases released by internal combustion engines. The toxic combustion products released by these engines remain suspended in the atmosphere for long periods of time and are ingested into the bodies of all animals.

There has been a conspicuous failure to develop a suitable, practical alternative to the internal combustion, gasoline engine which generates most of the air pollution. Currently, serious attempts are being made to develop a steam engine for automotive use. In addition, there are projects experimenting with batteries and electrical motors. As of yet, though, none of these projects has produced a practical, inexpensive alternative.

This invention contemplates an engine which operates on liquefied, inert gas. This engine does not operate by combustion nor does it release toxic combustion products into the atmosphere. Consequently, the exhaust discharged by this engine would not be harmful to human beings or other animals.

This invention further contemplates an engine that will satisfactorily meet the ever-tightening air pollution control laws regulating the discharge of exhaust from automobiles. Currently, these air pollution control laws are becoming stricter each year and placing more burdens upon the designers of gasoline engines. These stricter requirements have also resulted in substantial increases in the retail price of automobiles.

When comparing between engines, an automobile equipped with a nitrogen vapor engine is substantially lighter than a comparable automobile having a gasoline engine. This invention contemplates an engine which does not require a cooling system with its associated radiator, fan, water pump, and engine coolant. Further, this invention contemplates a substantially smaller engine having much smaller pistons than a comparable gasoline engine. In addition, this engine does not require an elaborate drive line having a clutch, a transmission, and a drive shaft all with their frictional losses. Most likely, the power requirement of this engine is 20% less than a comparable internal combustion engine having a conventional drive line. Finally, this engine can positively eliminate the raucous noise which accompanies unmuffled internal combustion engines.

An engine constructed according to this invention also provides a suitable source of power that can be used in environments heretofore prohibited to gasoline engines. Vehicles constructed according to this invention can be used in ammunition and explosive storage and manufacturing areas. In the past, gasoline engines have been excluded from these areas because of the hazard of explosions caused by the heat and the electrical sparks. An engine according to this invention can also be used within an underground mine shaft where explosive gases are present, the danger of the asphyxiation

of nearby workers exists or the supply of oxygen is limited.

By eliminating the need for gasoline to power automobiles, this engine can conserve the world's petroleum reserves. Crude oil can be diverted from the production of gasoline to the generation of heat and the manufacture of chemicals. In addition, by eliminating the storage of gasoline in automobiles, this engine substantially reduces the hazard of fire and explosion present during automobile collisions.

These and other objects and advantages are met in accordance with the present invention by providing an open-cycle heat engine operable with liquefied nitrogen gas. The liquid nitrogen is obtained from conventional sources and stored at atmospheric pressure and approximately 77°K in an insulated storage tank on the vehicle. The engine cycle operates by first pumping the liquid nitrogen isothermally from a pressure of one atmosphere to approximately 200 atmospheres. Next the nitrogen is passed through a convective heat exchanger thereby heating up the nitrogen isobarically from approximately 80°K to approximately 260°K. From the heat exchanger the nitrogen is then isentropically expanded within an expandable chamber, the piston of which produces shaft work. The nitrogen is further isobarically reheated in a second stage convective heat exchanger from approximately 195°K to approximately 260°K at 100 atmospheres of pressure. The nitrogen is again isentropically expanded in a second stage expandable chamber to produce shaft work. Following the second stage expander, the nitrogen is isentropically recompressed by a pump from approximately 12 atmospheres to approximately 20 atmospheres. The nitrogen is further isobarically reheated and isentropically expanded in subsequent stages producing additional shaft work. The number of stages in any embodiment of this invention depends primarily on the required output power and the desired efficiency.

The nitrogen vapor leaving the last stage of isentropic expansion flows into an exhaust engine. The exhaust engine salvages the last practically obtainable energy present in the nitrogen vapor. One embodiment of the exhaust engine according to this invention is a long, rectangular box having a movable lateral wall or piston and numerous long, narrow gage, highly stressed wires that are strung between the movable lateral wall and a stationary opposing wall. Cold nitrogen vapor from the exhaust and warm ambient air are alternatively directed into the box. The cold nitrogen vapor causes the wires within the box to contract sharply while the warm air causes the wires to expand. The cyclic contraction and expansion of the wires reciprocally drives the movable lateral wall that is also mechanically linked to a crank shaft.

A further embodiment of the exhaust engine according to this invention utilizes a double acting piston that is cyclically driven by nitrogen vapor. Cold nitrogen vapor at low pressure from the main engine flows into a bank of heat exchanger tubes. Within the tubes the nitrogen is heated by the ambient air thus raising its pressure. The now warmer and higher pressure nitrogen is alternately directed against the opposing faces of a double acting piston causing the piston to move reciprocally. Connected to the piston is a conventional connecting rod and crank shaft to provide the work output.

In both embodiments of the exhaust engine the last useful energy is removed from the exhaust of the main

engine and the nitrogen is vented into the atmosphere. The output of the exhaust engine drives the main compressor and recompression pump. Thus, the exhaust heat engine takes otherwise unobtainable energy still within the nitrogen and increases the work output and efficiency of the main engine.

Almost any gas which is both a liquid at low temperatures and atmospheric pressure and a vapor at high pressure and atmospheric temperature can drive this engine. Nitrogen is primarily used because of its vast supply in the atmosphere and because it is nearly incombustible. Moreover, nitrogen has better physical properties than most other inert gases. At standard pressure, nitrogen is liquid at -320°F or 77°K which gives liquid nitrogen a greater thermal potential with respect to the atmosphere than either carbon dioxide or oxygen.

The engine according to this invention operates on the thermal potential between the liquefied gas and the atmosphere. During the liquefaction process energy was removed from the gas and stored in the atmosphere. The atmosphere was thereby heated slightly. During the operating cycle of the engine, the liquefied gas is reheated by the atmosphere. Thus, the liquefied gas is acting like a small heat sink for the atmosphere. Shaft work is obtained from the redistribution of energy from the atmosphere to the gas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a three-stage, nitrogen, open-cycle engine according to the present invention;

FIG. 2 is a temperature-entropy graph for nitrogen gas showing the operating characteristics of a three-stage engine according to the present invention;

FIG. 3 is a schematic diagram of a three stage engine according to the present invention;

FIG. 4 is a fragmentary plan view of the engine mounted on an automobile rear axle;

FIG. 5 is a polar diagram of the first stage valve movement plotted against crankshaft position for the engine according to the present invention;

FIG. 6 is a fragmentary perspective view partially in section of an exhaust engine according to the present invention;

FIG. 7 is a fragmentary plan view partially in section of an alternative exhaust engine according to the present invention;

FIG. 8 is a polar diagram of the valve movement plotted against crankshaft position for the valves within the exhaust engine of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A general block diagram of a three-stage open-cycle engine according to the present invention is shown in FIG. 1. Nitrogen gas is used throughout the cycle for the working fluid of the engine. The thermodynamic states through which the nitrogen passes within the engine are diagrammatically shown by reference letters in a temperature verses entropy diagram FIG. 2. The corresponding locations on the block diagram FIG. 1 of these thermodynamic states are also indicated by reference letters. The nitrogen vapor engine according to the present invention operates in the super-heated region above the saturated liquid and saturated vapor lines on the temperature entropy diagram. Thus, the physical state of the nitrogen throughout the cycle can

be characterized as mainly a super-heated vapor at very low temperature.

Reference numeral 12 generally indicates a supply tank in which the reserve supply of liquefied nitrogen is stored. Reference letter A represents the state of liquid nitrogen within the supply tank, at atmospheric pressure and 77°K . Connected to the supply tank 12 is a main compressor 14. The main compressor draws the liquid nitrogen stored in the supply tank 12 and compresses the liquid to a high pressure, state B. The compression from state A to state B is isentropic, or at constant entropy. State B corresponds to a pressure of approximately 200 atmospheres and a temperature of approximately 82°K . From the main compressor 14 the high pressure nitrogen flows into a first stage heat exchanger 16. Within the first stage heat exchanger nitrogen is heated by a flow of ambient air to state C. The heating occurs up to a temperature of approximately 260°K at a constant pressure of 200 atmospheres.

The nitrogen leaves the first stage heat exchanger 16 as a gas and remains in that phase throughout the rest of the cycle.

From the first stage heat exchanger the high pressure nitrogen now at comparatively high temperature flows into a first stage expander 18. Within the first stage expander the nitrogen undergoes an isentropic expansion from state C to state D. Shaft work is extracted from the nitrogen while both its temperature and pressure are lowered. The nitrogen in state D has a pressure of approximately 100 atmospheres and a temperature of approximately 195°K . From the first stage expander 18, the nitrogen flows into a second stage heat exchanger 20. Within the second stage heat exchanger the nitrogen is again heated by a flow of ambient air to state E. This second heating occurs up to a temperature of about 260°K at a constant pressure of about 100 atmospheres. From the second stage heat exchanger 20 the nitrogen next flows in to a second stage expander 22. Within the second stage expander the nitrogen undergoes a further isentropic expansion to state F. Shaft work is again extracted from the nitrogen thus lowering both the temperature and the pressure of the nitrogen. At state F the nitrogen has a temperature of about 150°K and a pressure of approximately 12 atmospheres. From the second stage expander 22 the nitrogen flows into a recompression pump 24. The recompression pump increases the work output of the engine cycle because the pump is driven by a hereinafter described process in which the energy that would have been otherwise wasted in the exhaust of the engine is salvaged. The recompression pump raises the pressure to about 20 atmospheres and raises the temperature to 175°K , point G. The nitrogen next flows into a third stage heat exchanger 26 where the nitrogen is again isobarically heated to state H by a flow of ambient air. At state H the nitrogen has a pressure of about 20 atmospheres and a temperature of approximately 260°K . From the third stage heat exchanger 26 the liquid nitrogen flows into a third stage expander 28 undergoing a third isentropic expansion to state I. Both the temperature and the pressure of the nitrogen are again reduced. The nitrogen leaves the third stage expander at approximately 2 atmospheres of pressure and at a temperature of about 135°K .

From the third stage expander 28 the nitrogen flows into an exhaust engine 30. The exhaust engine salvages the last remaining energy from the nitrogen by a here-

inafter described process. The nitrogen exhaust engine provides the work to drive the recompression pump 24 and the main compressor 14. From the exhaust engine the nitrogen is released into the atmosphere at a temperature of about 108°K.

The various components of a three-stage nitrogen vapor engine according to the present invention are shown in FIG. 3. The nitrogen supply tank 12 is a very heavily insulated spherical tank, that is vented to the atmosphere. To reduce the evaporation of nitrogen because the tank is vented, the tank is constructed with double walls. The annular space between the walls is filled with a suitable insulating material and a vacuum is drawn therebetween. The tank can be constructed from either fiberglass or steel. The capacity of the tank determines the operating radius of any vehicle on which the engine is mounted. For routine urban use, a tank having a 15 cubic foot storage capacity is adequate.

The nitrogen supply tank 12 is connected to the main compressor 14 by a fuel line 32. Although the fuel line 32 is not subjected to high pressure because it is on the inlet side of the engine, the fuel line is subjected to substantial vibration from the vehicle because the storage tank 12 is remotely located from the engine. Consequently the fuel line must be constructed from materials that are sufficiently flexible at low temperatures to withstand the vibration. The fuel line is well insulated by conventional insulating materials. The insulation prevents the liquid nitrogen from vaporizing in the fuel line before the nitrogen is introduced into the main compressor 14.

The main compressor 14 is a multiple piston, positive displacement, hydraulic pump having a variable stroke. The compressor has a variable output to accommodate the varying mass flow of nitrogen through the engine. To eliminate the vaporization of the nitrogen before its compression, the compressor is heavily insulated like the supply tank 12 and the fuel line 32. The pistons and the bores within the compressor are lubricated by a surface coating of solid lubricant, such as flame impinged molybdenum. The multiple chambers within the compressor are sealed by Teflon gaskets backed by metallic springs which apply the lip pressure. The compressor pump is driven by the nitrogen exhaust engine 30 hereinafter described.

The compressor 14 has a stop valve 34 in fuel line 32 on the suction side of the compressor. The stop valve 34 isolates the compressor from the supply tank 12. The valve 34 is shut during shut-down but is opened during the start-up and running of the engine. The compressor 14 is connected to the first stage heat exchanger 16 by a fuel line 38. The fuel line 38 and all subsequent piping downstream from the compressor 14 are uninsulated. After the nitrogen has been compressed, all heating of the nitrogen from the discharge side of the compressor 14 onward is encouraged because such heating adds energy to the nitrogen and to the cycle.

In the fuel line 38 on the discharge side of the compressor 14 is a check valve 36. The check valve is of the ball check type and requires no external control, working only by the differential pressure across its seat. The check valve prevents the nitrogen in fuel line 38 from flowing backward from the first stage heat exchanger 16 to the nitrogen compressor 14, thereby both preventing the heat exchanger 16 from over pressurizing

the compressor during an accidental over-expansion within the first stage heat exchanger and also trapping the pressure within the heat exchanger during shut-down.

5 Connected to the discharge side of the compressor 14 by fuel line 38 is the first stage heat exchanger 16. The first stage heat exchanger is a conventional, air-cooled, tubular heat exchanger. The nitrogen passes within the tubes and is heated by natural convection. 10 Natural convection is sufficient because when the vehicle is stationary the engine does not consume fuel and thus does not require any heat transfer. When the vehicle is moving and consuming fuel, the heat exchanger transfers sufficient heat from the flow of ambient air around the exposed tubes, which are located in the path of the air stream passing by the vehicle. The heat exchanger tubes can be constructed from any suitable metallic material, such as steel or stainless steel.

The ice which forms on the tubes of the heat exchanger from the condensation of water vapor in the air is removed by a system of brushes that are cyclically passed through the tube bank. The brushes are mounted on a moving sub-frame that passes between the tubes. The axes of the brushes are parallel to the axes of the tubes. The tubes are cylindrical in cross section and do not have fins which would obstruct the passage of the moving sub-frame. The brushes are cylindrical and have metallic bristles to multiply the heat transfer from the air to the tubes.

30 The first stage heat exchanger has a relief valve 40. The relief valve is a conventional high pressure relief valve and is located on one of the tubes carrying nitrogen. Since the first stage heat exchanger 16 is subjected to the highest pressure in the engine, the relief valve 40 provides pressure protection for the entire system.

The first stage heat exchanger 16 is connected to the first stage expander 18 by a fuel line 42. The fuel line is uninsulated because any heat transfer from the air to the nitrogen within the fuel line adds energy to the cycle. On the fuel line is located a stop valve 44. The stop valve isolates the first stage heat exchanger 16 from the first stage expander 18. The stop valve is shut during shut-down to maintain pressure within the heat exchanger but is open during the start-up and running of the engine.

The first stage expander 18 is comprised of a head 56 and two axially concentric cylinders, an upper cylinder 48 and a lower cylinder 50. The head and cylinders are held together by long steel studs, not shown, which threadably connect to a common block 90. The diameter of the upper cylinder is substantially smaller than the lower cylinder. Within both cylinders travels a unitary piston 52. The piston is cylindrical in shape and has an upper section having a substantially smaller diameter than the lower section. The expansion of the nitrogen occurs within the upper cylinder 48 against the upper, smaller diameter section of the piston. The lower section of the piston having the larger diameter takes up the thrust from the upper cylinder 48. The piston and cylinders can be manufactured from any suitable metallic material such as steel or aluminum. The piston is sealed by a packing 54. The packing is Teflon backed up by a steel spring.

65 Within the head 56 of the first stage expander 18 is a valve block 46 having an inlet valve and an exhaust valve, not shown. Both valves are pressure balanced solenoid operated, spool valves of the type typically used

in hydraulic systems. The operation of the solenoids is controlled by conventional 12 volt D.C. circuits. The inlet and exhaust valves are the same size because although the nitrogen has expanded within the cylinder during the cycle, the exhaust valve remains open for a substantially longer period of time than the inlet valve.

The first stage expander 18 is connected to the second stage heat exchanger 20 by a fuel line 58. The fuel line 58 is uninsulated in order to promote further heat transfer from the surrounding air. The fuel line contains along its length a check valve 60. The check valve is of the ball check type requiring no external control. The check valve prevents the backflow of the nitrogen in the fuel line 58 from the second stage heat exchanger 20 to the first stage expander 18. By preventing this backflow, the check valve maintains the nitrogen pressure within the heat exchanger during shut-down and prevents the heat exchanger from over-pressurizing the expander because of an accidental thermal transient.

The fuel line 58 is directly connected to the second stage heat exchanger 20. The second stage heat exchanger is a conventional, air-cooled, tubular heat exchanger that is unfinned. The second stage heat exchanger is constructed like and operates similarly to the first stage heat exchanger 16. All three heat exchangers 16, 20 and 26 are constructed as one integral unit with a common ice removing system as described hereinbefore. Within the second stage heat exchanger 20 the nitrogen travels within the tubes and is heated by natural convection. The heat transfer area of the second stage heat exchanger is substantially smaller than the area of the first stage heat exchanger because the engine requires less heat transfer at this juncture in the cycle. Quantitatively, the area under the graph of the cycle in FIG. 2 which represents heat in the cycle is less under the line segment DE than under the line segment BC.

The second stage heat exchanger 20 and the second stage expander 22 are connected by a fuel line 62. The fuel line 62 is uninsulated to promote further heat transfer from the surrounding air. The fuel line 62 contains a stop valve 64. The stop valve isolates the second stage heat exchanger 20 from the second stage expander 22. The stop valve is shut during shut-down to maintain the nitrogen pressure within the heat exchanger but is opened during the start-up and running of the engine.

The second stage expander 22 is comprised of a head 212 and a single cylinder 214. The head and the cylinder threadably engage each other and are retained in place by long steel studs, not shown, which threadably connect to a common block 90. Within the cylinder 214 travels a piston 102. The piston is sealed by a packing 216. The packing is a Teflon ring backed up by a steel spring. The nitrogen expansion occurs within the chamber 218 formed by the cylinder walls, the head, and the top surface of the piston. Within the head 212 is a valve block having an inlet valve and an exhaust valve, not shown. Both valves are pressure balanced, solenoid operated, spool valves of the type typically used in hydraulic systems. These valves are constructed and operate in a similar manner as the valves within the head 56 of the first stage expander hereinbefore described.

The second stage expander is connected to the recompression pump 24 by a fuel line 66 which is uninsulated. The recompression pump 24 is a multiple piston

positive displacement, hydraulic pump with a variable stroke to control the output. The recompression pump has a variable output in order to accommodate the varying mass flow rates of nitrogen at differing engine speeds and power settings. The pistons and bores (not shown) within the recompression pump are lubricated by surface coatings of solid lubricants, such as flame impinged molybdenum. The cylinders and pistons within the recompression pump are sealed by Teflon seals backed by metallic springs. The recompression pump is driven by the exhaust engine 30 hereinafter described. The recompression pump is primarily used in this thermodynamic cycle to increase the work output of the engine and consequently the overall efficiency. The increased output when using a recompression pump results because the recompression pump is driven by the energy that would otherwise have been lost to the atmosphere in the exhaust.

The recompression pump 24 is connected to the third stage heat exchanger 26 by a fuel line 68, which is uninsulated. In the fuel line on the discharge side of the recompression pump 24 is a check valve 70. The check valve 70 is a ball check valve similar to check valve 36 and is located to prevent the backflow of the nitrogen in fuel line 68 from the third stage heat exchanger 26 to the recompression pump 24. By preventing this backflow, the check valve maintains the nitrogen pressure within the third stage heat exchanger 26 during shut-down and prevents the third stage heat exchanger from over-pressurizing the recompression pump 24 because of an accidental thermal transient.

The third stage heat exchanger 26 receives the nitrogen discharged by the recompression pump 24 through the fuel line 68. The third stage heat exchanger is a conventional air-cooled, tubular heat exchanger that is unfinned. Within the third stage heat exchanger the nitrogen travels within the tubes and is heated by natural convection. The third stage heat exchanger is constructed like and operates similarly to the first and second stage heat exchangers 16 and 20 described hereinbefore. All three heat exchangers are constructed as one integral unit with a common ice removing system.

The third stage heat exchanger 26 and the third stage expander 80 are connected by a fuel line 72. The fuel line is uninsulated to promote further heat transfer. The fuel line contains a stop valve 74. The stop valve 74 isolates the third stage expander from the third stage heat exchanger. The stop valve is shut during shut-down to maintain the nitrogen pressure within the third stage heat exchanger but is opened during the start-up and running of the engine.

The third stage expander 80 is comprised of a head 80 and a single cylinder 78. The head and the cylinder threadably engage each other and are retained in place by long steel studs, not shown, which threadably connect to a common block 90. Within the cylinder 78 travels a piston 76. The piston is sealed by a packing 82. The packing is a Teflon ring backed up by a steel spring. The construction and operation of the third stage expander is similar to the second stage expander 22 hereinbefore described. The nitrogen expansion occurs within the chamber 83 formed by the cylinder walls, the head, and the top surface of the piston. The chamber 83 is larger than the second stage chamber 218 which is, in turn, larger than the first stage chamber 48. This increase in chamber size accommodates the increase in specific volume of the nitrogen between

the stages. Within the head 80 is a valve block having an inlet valve and an exhaust valve, not shown. Both valves are pressure balanced, solenoid operated, spool valves of the type typically used in hydraulic systems. These valves are constructed and operate in a similar manner as the first and second stage valves hereinbefore described.

The third stage expander is connected to the nitrogen exhaust engine 30 by a fuel line 84. The fuel line 84 is uninsulated to promote further heat transfer. The fuel line contains a check valve 86. The check valve 86 is a ball check valve similar to check valve 60 and is located to prevent backflow from the exhaust engine 30 to the third stage expander 28. By preventing this backflow, the check valve prevents the exhaust engine from over-pressurizing the third stage expander. From the exhaust heat engine 30, the nitrogen leaves the engine through fuel line 88 and is exhausted to the atmosphere.

Although only three expanders and three heat exchangers are shown and described, it should be obvious that additional or fewer expanders and heat exchangers can be combined. Likewise, the number of pumps may be increased or decreased and the construction, operation and sequence of the valves can be varied without departing from the scope of the invention.

The three expanders 18, 22 and 28 are housed on a common block 90. The three cylinders are disposed in a radial configuration with a 120° separation between the axis of each cylinder. Within the block 90 is a single, common, longitudinal crank shaft 92. The crank shaft 92 has a single throw 94 because of the three cylinders. The main bearings for the crank shaft are tapered roller bearings, not shown. Attached to the crank shaft 92 are three connecting rods 96, 98 and 100. The connecting rods mechanically couple the pistons 52, 102 and 76 to the crank shaft 92 by wrist pins 104, 106 and 108, respectively. The bearings 110 for the three connecting rods on the crank shaft are double sealed, needle bearings with inner and outer races. The bearings 112, 114 and 116 for the connecting rods at wrist pins are bronze or graphite-filled Teflon bearings. Internal oil lubrication is not required because the engine is designed for a maximum speed of 800 rpm. Hence, the main bearings and the rod bearings 110 are lubricated by conventional grease fittings, not shown.

The engine is mounted at the rear of a small automobile. Referring specifically to FIG. 4, the block 90 of the engine is disposed so that the crank shaft 92 is parallel and elevated above the rear axle 117 of the automobile. The drive shaft and universal joints to the rear axle have been removed. At the remote end of the crank shaft directly over the differential gear box 119 is a sprocket 118. The sprocket is keyed to the crank shaft in order to withstand the high torque required for starting the automobile. Attached to the sprocket 118 is a roller chain 120. The roller chain can be either a multiple strand roller chain or an inverted tooth, silent chain. The chain 120 connects directly to a sprocket mounted on the ring gear carrier, not shown, within the differential gear box 119 in place of the conventional bevelled ring gear or crown wheel. The sprocket 118 is the same size as the sprocket within the differential gear box so the engine has a one-to-one drive to the rear axle. If a change in gear ratio is desired, sprocket 118 can be easily changed. This power train configuration eliminates the driving pinion within the differen-

tial, the drive shaft, the universal joints, the transmission and the clutch which are all required on conventional gasoline powered automobiles.

At the other, lateral end of the engine, remote from the sprocket 118, is the valve timing assembly 122. Within the valve timing assembly 122 are slip rings, not shown, that are attached to the crank shaft 92 to provide the electrical timing contact for the valves. This timing contact is used to open and shut in proper sequence the inlet and exhaust valves within each valve block on the expanders. The timing sequence of the valves with respect to the crankshaft position is varied by using slow twist, multiple threads in the slip rings that permit the slip rings to be rotated infinitesimally around the crank shaft. The valve timing assembly 122 is connected to the solenoids on the respective valve blocks by the electrical cables 123.

Referring to FIG. 5, the valve timing for the first stage cylinder showing the cycling of the inlet and exhaust valves is plotted against crank shaft position on a polar graph. When the crank shaft is at top dead center (T.D.C.) or the zero degree mark in FIG. 5, the piston 52 is at the top of its stroke and both the inlet and exhaust valves are shut. As the crank shaft travels a small angle past zero degrees top dead center and the piston commences its downward stroke, the inlet valve opens. The inlet valve always opens at the same crank shaft angle regardless of the throttle setting or engine speed. However, the inlet valve remains open for a variable interval. In this embodiment of the present invention, the point at which the inlet valve closes is controlled by the throttle setting. The speed of the engine and the torque it develops are directly proportional to the volume of nitrogen introduced to each cylinder. By varying inlet valve closing time, the size of the charge of nitrogen introduced into the cylinder is regulated and thus the engine is able to vary in speed. For a greater throttle opening, the inlet valve closes later. At a maximum throttle setting, the inlet valve closes no later than 20° past TDC. After the inlet valve shuts, the charge of nitrogen within the cylinder expands and the piston is forced downward. When the piston is at the bottom of the stroke, the bottom dead center point (BDC) or 180° of crank shaft rotation, the exhaust valve opens. The exhaust valve remains open through the next 180° of crank shaft rotation as the piston returns upward. The exhaust valve shuts just before TDC and just before the piston reaches the top of stroke. The exhaust valve opens and shuts invariably at the same points during each rotation of the crank shaft. The inlet and exhaust valves are so sequenced that at TDC neither valve is open. Just prior to TDC the exhaust valve shuts and just after TDC the inlet valve opens. This timing is required so that at no time are both valves simultaneously open. In that case, the incoming nitrogen would blow out the exhaust line without undergoing expansion in the cylinder.

The operation and sequencing of the valves in the second and third stage expanders are analogous to the first stage expander and differ only in a phase angle of 120° of crank shaft rotation. Whereas the first stage inlet valve opens soon after TDC, the second stage inlet valve opens soon after TDC + 120° and the third stage inlet valve opens soon after TDC - 120°. The other valves open and close similarly.

The electrical solenoid control of the sequencing of the valves permits the engine to start either in a forward

or reverse direction. In fact, the engine can develop maximum speed in either direction. Moreover, any inaccuracy in the sequencing between the crank shaft and the motion of the valves merely results in the throttle being in a slightly different position than the throttle ordinarily would be for the same torque output. This timing problem is common to internal combustion gasoline engines and is primarily caused by the speed of the valves being constant while the speed of the engine varies. However, while improper timing causes improper operation of an internal combustion engine, improper timing on a vapor engine only causes a change in throttle position.

The nitrogen vapor engine has a priming system that is used to charge up the system with nitrogen prior to operation. Basically, the priming system fills each one of the heat exchangers with nitrogen. Once the heat exchangers are filled, the nitrogen heats up from the ambient air and system pressure builds up rapidly. The nitrogen priming system consists of a small hand pump 124. This hand pump takes a suction on fuel line 32 at the outlet of the nitrogen storage tank 12 and the hand pump discharges through fuel lines 126, 128 and 130. These fuel lines are connected to the heat exchangers 16, 20 and 26 in each stage. On each one of these fuel lines 126, 128 and 130 is a solenoid operated stop valve respectively 132, 134 and 136 which is used to control the flow of nitrogen during priming. These valves are normally shut and only opened when the system is being primed.

The start-up of the nitrogen vapor engine is initiated by filling the nitrogen supply tank 12 with liquid nitrogen. Stop valve 34 is shut and the priming pump stop valves 132, 134 and 136 are opened. Next the priming pump 124 which takes a suction directly on the fuel line 32 leading from the supply tank 12 fills the heat exchangers 16, 20 and 26 with nitrogen. The heat exchanger outlet stop valves 44, 64 and 74 are shut to allow the priming pump to build up pressure within the heat exchangers. Once the heat exchangers have been primed, the priming pump valves 132, 134 and 136 are shut. The nitrogen gas pressure within the heat exchangers builds up rapidly because the heat exchangers were at ambient temperature before filling. When the pressure is sufficiently high, the heat exchanger outlet valves 44, 64 and 74 are opened, thus charging the fuel lines to the inlet sides of each one of the cylinders. At this point, the engine is ready to operate although at reduced power.

To operate the engine after being filled with nitrogen, the throttle motion causes one of the inlet valves to one of the cylinders to open. The initial position of the crank shaft determines which inlet valve opens. As soon as this first nitrogen charge is introduced into a cylinder that charge causes the piston within that cylinder to rotate the crank shaft. Before the crank shaft has turned 120°, another inlet valve has opened. The second cylinder then begins to contribute to the crank shaft rotation. Once the crank shaft is turning, the normal timing circuits sequence the valves. After another 120° of crank shaft rotation the third inlet valve opens, and after a complete revolution all valves have cycled. The throttle motion also starts the main compressor 14 that quickly builds up the nitrogen pressure throughout the engine. As soon as the pressure is up to normal, the engine is capable of operating at maximum power.

The priming pump is required only when the system has been opened to the atmosphere and warm, humid air has been admitted into the engine. If the engine has been operating on nitrogen, and if the nitrogen pressure can be maintained within the heat exchangers during shutdown, then the priming pump is not needed. In this case merely opening the throttle is all that is necessary for starting up. The motion of the throttle will open an inlet valve and the crank shaft will start to turn.

To shut down the nitrogen engine, the heat exchanger exhaust valves 44, 64 and 74 are shut electrically. When these valves shut, the charge of nitrogen within each heat exchanger is retained therein. The reverse backflow out of the heat exchangers is prevented by the ball check valves 36, 60 and 70 in the inlet fuel lines to each heat exchanger.

The operating characteristics of the nitrogen engine are very similar to those of a steam locomotive. The engine develops maximum torque at zero speed and has very flat torque response as the engine speed increases. The flat torque response terminates when a speed is reached where the nitrogen flow losses become significant. Horse power is a linear function of speed in the region of constant torque response. The engine operates up to a maximum speed of approximately 800 rpm. The consumption of fuel increases as speed increases if constant torque is maintained. The efficiency of the engine is a direct function of the size of the charge of nitrogen admitted into each cylinder. This charge size is controlled by the throttle opening. When the optimum size charge is admitted into the cylinders, the engine will accelerate until the rolling resistance, the air drag and the frictional resistance of the whole drive line balance the torque available.

In order to extract the last remaining energy from the nitrogen before it is exhausted to the atmosphere, the nitrogen engine utilizes an exhaust engine 30. More specifically, one embodiment of the nitrogen exhaust engine is shown in FIG. 6. Reference numeral 138 generally indicates a long, rectangular box that is well insulated in the inside. The box has a remote end wall 144 and a central end wall, not shown, which oppose each other. Near the central end wall within the box is a sliding plate or piston 146. The sliding plate has four longitudinal runners 148, 150, 152 and 154. These runners fit into longitudinal guides 156 that are located on the interior surfaces of the upper and lower sidewalls of the box. The longitudinal runners in combination with the longitudinal guides permit the sliding plate 146 to slide reciprocally along the longitudinal axis of the box while remaining perpendicular to the sides of the box. The sliding plate can freely traverse the interior of the box from one end wall to the other end wall without tipping or wedging between the sidewalls.

Rigidly attached to the interior facing side of the remote end wall 144 and the interior facing side of the sliding plate 146 are numerous pulleys 142. Strung between these pulleys are a plurality of wires 140. These wires are strong, of small diameter, and highly stressed. The wires are rigidly attached to either the end wall 144 or the sliding plate 146. Each wire is strung over at least one pulley so that each wire makes at least two transits of the length of the box. To minimize the number of attachment points for the wire ends because the wires are under substantial tension, it is preferable to have each wire make numerous transits of the box.

On the exterior facing side of the sliding plate 146, the side obverse to which the pulleys are mounted, is a pin and connecting rod 158. The connecting rod is attached to a crank shaft 159. The crank shaft 159 can be either directly connected to the main compressor 14 or the recompression pump 24 or can be connected to an electrical generator of the conventional type. The linear motion of one sliding plate is directly and reciprocally counterbalanced by another sliding plate located directly opposite in a corresponding box. Both sliding plates are connected to the common crank shaft 159 by identical linkage. Each box is of similar construction and is disposed with respect to each other so that one box pulls against the other box in order to keep all the wires within both boxes tight. A substantial tension of the wires can thus be maintained.

Reference numeral 160 generally indicates an intake manifold for inducing the nitrogen vapor into the exhaust engine 138. The intake manifold consists of a nitrogen fuel line 84 coming directly from the third stage expander 80. Accompanying the nitrogen inlet 84 is an air inlet 164. The air inlet leads directly from the exterior of the automobile where the air inlet is pointed into the oncoming airstream. Both the nitrogen fuel line 84 and the air inlet 164 are connected to a valve block 166. Within the valve block is a solenoid operated, control valve, not shown, which selectively and individually ducts either air or nitrogen into the intake manifold 160. The intake manifold terminates at numerous intake orifices in the sidewall of the box 138. These orifices lead directly into the interior of the box.

On the other side of the box 138 opposite from the intake manifold 160 is an exhaust manifold 168. The exhaust manifold is connected to numerous exhaust orifices on the opposing sidewall from the intake orifices. The exhaust manifold terminates at a valve block 172. Within the valve block is another solenoid operated, control valve, not shown, that selectively and individually directs the exhaust from the box either into a nitrogen exhaust pipe 88 or an air exhaust pipe 170. Both of these pipes ultimately discharge into the atmosphere.

Although only two boxes are shown and described, it should be obvious that additional boxes and manifolds can be combined to achieve greater engine efficiency. Further, one box can be used alone if some spring or tensioning mechanism is used to maintain the tension on the wires. A double acting piston or a series of plates which reciprocally drive each other can be more efficient although they are not required to practice this invention.

The exhaust engine operates by sequentially alternating the fluid flow through each box 138 between cold nitrogen and relatively warmer, ambient air. The cold nitrogen causes the wires within the box to contract and the warm air causes the wires to expand. The expansion and contraction of the wires translates into linear motion of the sliding plate 146. Because the wires have small cross section, are kept under high stress, and have a long length, the movement of the sliding plate is substantial. Two boxes can operate together by introducing into one the warmer air while introducing into the other the colder nitrogen. Thus, while in one box the wires are contracting, in the other box the wires are expanding. The inlet and exhaust valves to each box are so timed that the two sliding plates reciprocally oscillate and counterbalance each other. The sliding plates

are mechanically connected around a common crank shaft 159 so the linear motion of the sliding plates is translated into rotational motion of the crank shaft.

An alternative embodiment of the exhaust engine according to the present invention is shown in FIG. 7. This embodiment utilizes a plurality of small heat exchangers and a double acting piston. More specifically, reference numeral 174 generally indicates an intake manifold. The intake manifold consists of several identical arms or heat exchanger tubes 176 mounted on a common header 177. Located at the end of each heat exchanger tube 176 remote from the header is an inlet valve 178. Located at the central end of each heat exchanger tube 176 near the header is an exhaust valve 180. Both the inlet and outlet valves are solenoid actuated stop valves which can completely isolate each tube 176 from the header 177 and from the fuel line 84. Nitrogen from the third stage expander is induced into the intake manifold 174 through the fuel line 84. The nitrogen is selectively introduced into one of the heat transfer tubes 176 by sequentially cycling the inlet valves 178.

The header 177 leads directly to the double acting piston assembly 182. The piston assembly has an upper inlet valve 184 and a lower inlet valve 186. These inlet valves are solenoid actuated stop valves that control the entrance of nitrogen into the piston assembly. In addition, the piston assembly has an upper exhaust valve 188 and a lower exhaust valve 190. These valves are also solenoid actuated stop valves of the conventional type. These exhaust valves control the exit of nitrogen from the piston assembly through exhaust line 88. Within the piston assembly, reference numeral 192 indicates a movable piston which reciprocally oscillates between the upper and lower chambers of the piston assembly. The piston 192 is sealed by a Teflon ring 202, backed up by a metallic ring, not shown. The Teflon ring 202 primarily prevents the leakage of nitrogen pressure between the upper and lower cylinders and provides a bearing surface for the piston 192 as it oscillates within the cylinder. The piston has a wrist pin 194 which attaches the connecting rod 196 to the piston. The connecting rod further attaches to another wrist pin 198 mechanically connected to an upper piston 200. The upper piston 200 guides the double acting piston 192 and absorbs the rod thrust during the reciprocal motion of the piston 192. The upper piston 200 is connected to a crank shaft 204 with conventional mechanical linkage. The crank shaft 204 can be either directly connected to the main compressor 14 or to the recompression pump 24 or can be connected to an electrical generator of the conventional type.

Although only one intake manifold and one double acting piston assembly are shown and described, it should be obvious that additional manifolds and additional piston assemblies can be combined to achieve greater engine efficiency. Moreover, the design, operation, and sequence of the valves can be varied without departing from the scope of this invention.

In operation, moderately cold nitrogen exhausted from the main engine at approximately atmospheric pressure enters the exhaust engine through the fuel line 84. The nitrogen flows into one of the duplicate heat exchanger tubes 176 through an open inlet valve 178. The complementary exhaust valve 180 is controlled by a temperature sensor, not shown, sensing the heat exchanger tube temperature. When the temperature sen-

sor controlling the exhaust valve registers that the cold nitrogen is entering the tube, the temperature sensor shuts the exhaust valve. The inlet valve is controlled by a pressure sensor, not shown, that senses the pressure within the tube between the inlet and exhaust valves. When the pressure builds up sufficiently within the heat exchanger tube, the pressure sensor controlling the inlet valve shuts it. Thus, both inlet valve 178 and exhaust valve 180 are shut entrapping a charge of cold nitrogen in the tube therebetween. In the meanwhile, atmospheric air at ambient temperature is either continuously ducted or naturally circulated by the heat exchanger tubes. This atmospheric air convectively heats the charge of nitrogen within each tube and raises its pressure to a maximum, approximately three atmospheres. At the appropriate time, depending on the timing of the crank shaft, the pressure within the tube and the relative pressure among the other tubes, the exhaust valve 180 opens to charge the header 177 and to force the piston 192 to the opposite end of the cylinder. When the piston has moved within the chamber to the end of its stroke, the corresponding exhaust valve opens to exhaust the nitrogen from that chamber and to allow the return travel of the piston. The process then repeats itself as the header 177 discharges into the opposite chamber and nitrogen forces the piston into a return stroke.

The time required for each tube to heat sufficiently in order to generate the necessary pressure is relatively long compared with the other processes in the engine. Hence, there are numerous heat exchanger tubes accompanying each piston assembly so each tube has ample time to reach its maximum pressure before being opened onto the header.

Referring to FIG. 8, the sequence of valve operation for the double acting piston assembly 182 is shown plotted against degrees of crank shaft rotation on a polar diagram. At top dead center (TDC) of crank shaft rotation or 0°, the piston 192 is at the top of its stroke and the upper chamber volume of the piston assembly is at a minimum. At bottom dead center (BDC) of crank shaft rotation or 180°, the piston is at the bottom of its stroke and the upper chamber volume of the piston assembly is at a maximum. By the design of the piston assembly when the upper chamber volume is at a minimum, the lower chamber volume is at a maximum and vice versa.

At TDC the following valves are already open: the inlet valve 178' and the exhaust valve 180' to one heat exchanger tube 176' and the upper inlet valve 184 and the upper exhaust valve 188 to the upper chamber. With these valves open there is a direct open path between inlet fuel line 84 and the exhaust line 88. This open path allows nitrogen from the inlet fuel line 84 to purge the open heat exchanger tube, the header, and the upper chamber.

Soon after TDC the upper exhaust valve 188 shuts. The heat exchanger exhaust valve 180' also shuts from the temperature drop from the cold nitrogen entering the tube 176. Next, the exhaust valve 180 for a different heat exchanger tube opens pressurizing the header. Simultaneously, the lower exhaust valve 190 for the lower chamber also opens. With valves 180, 184, and 190 open and valves 178, 186, and 188 shut, the piston begins its downward power stroke under the force of

the nitrogen from tube 176.

Before BDC the upper inlet valve 184 shuts and both the inlet valve 178 to the currently operating heat exchanger tube 176 and the lower inlet valve 186 to the lower chamber open. These valves open a new purge path through the operating heat exchanger tube, the header, and the lower chamber.

Soon after BDC the lower exhaust valve 190 to the lower chamber shuts along with the heat exchanger exhaust valve 180. Next, the exhaust valve 180' for a different heat exchanger tube opens pressurizing the header simultaneously with the opening of upper exhaust valve 188 of the upper chamber. With valves 180', 186, and 188 open and valves 178', 180, 184, and 190 shut, the piston begins its upward power stroke under the force of the nitrogen from tube 176'.

Before TDC the lower inlet valve 186 to the lower chamber shuts and both the inlet valve 178' to the currently operating heat exchanger tube 176' and the upper inlet valve 184 to the upper chamber open, returning to the initial condition.

Although only two heat exchanger tubes are described in the sequence diagrammed in FIG. 8, it is intended that all of the tubes are to be used sequentially as the pressure in each reaches a maximum value.

Although several embodiments of the present invention have been shown and described, it will be obvious that other adaptations and modifications can be made to this invention without departing from the true spirit and scope of the invention.

What is claimed is:

1. An improved thermodynamic method of producing mechanical energy from a fluid, said method comprising the steps of:

- a. insulatively storing said fluid at a temperature substantially below ambient;
- b. isothermally pumping said fluid to a pressure above atmospheric pressure;
- c. performing at least twice the sequential steps of:
 - i. isobarically heating said fluid by passing said fluid through a heat exchanger having an exterior surface in thermal contact with ambient; and
 - ii. isentropically expanding said fluid in an expansion engine to produce mechanical energy; and
- d. isentropically compressing said fluid after one of said steps of isentropically expanding said fluid and before the succeeding step of isobarically heating said fluid.

2. The method of claim 1 further including the step of removing accumulated ice from said exterior surface of at least one of said heat exchangers to maintain the thermal transfer efficiency thereof.

3. The method of claim 1 further including the steps of:

- e. converting to mechanical energy the thermal energy remaining in said fluid after the last of said steps of isentropically expanding said fluid; and
- f. using the mechanical energy obtained by step (e) to perform step (d) of isentropically compressing said fluid.

4. The method of claim 3 further including the step of using a portion of the mechanical energy obtained by step (e) to perform step (b) of isothermally pumping said fluid.

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