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Chen

[11] **3,807,373**

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[54] **METHOD AND APPARATUS FOR OPERATING EXISTING HEAT ENGINES IN A NON-AIR ENVIRONMENT**

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[52] **U.S. Cl.** .... **123/119 A**
[51] **Int. Cl.** **F02b 33/00**
[58] **Field of Search** .... 123/119 A

[56] **References Cited**

UNITED STATES PATENTS

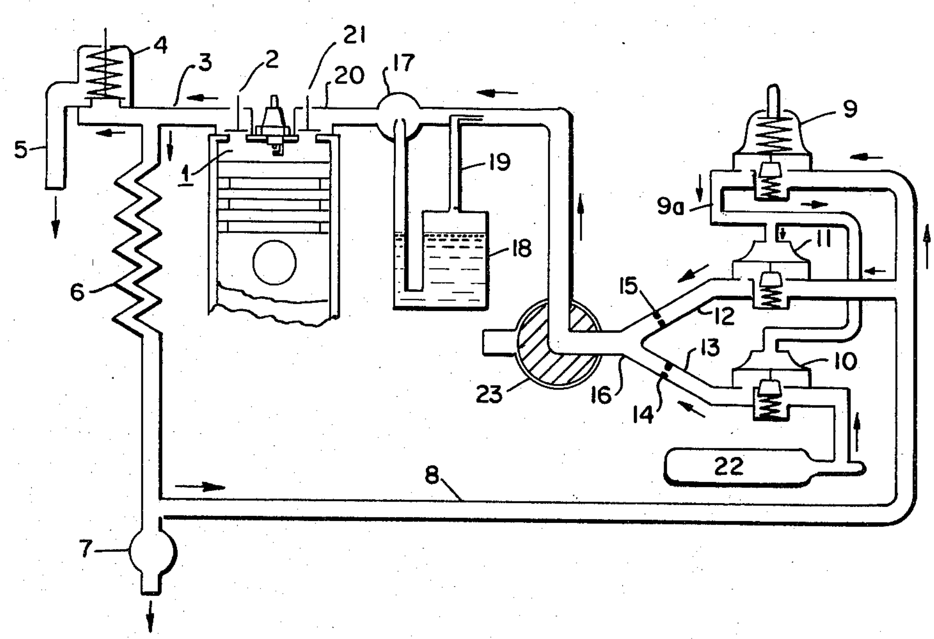
2,017,481	10/1935	Von Opel	123/119 A
2,087,411	7/1937	Lundquist	123/119 A
2,720,856	10/1955	Hoke, Jr.	123/119 A
2,884,912	5/1959	Lewis	123/119 A
3,035,561	5/1962	Siegler	123/119 A
3,166,060	1/1965	Falzone	123/119 A
3,241,536	3/1966	Falzone	123/119 A
3,294,073	12/1966	Bressan	123/119 A
3,677,239	7/1972	Elkins	123/119 A

Primary Examiner—C. J. Husar
Attorney, Agent, or Firm—Mattern, Ware & Davis

[57] **ABSTRACT**

An internal combustion engine operating on a novel heat engine cycle employs four pressure regulators to control the pressures of exhaust venting, recycled exhaust gas, and compressed oxygen, adapting the engine for highly efficient operation in non-air environments e.g. underwater or in outer space. Compact, lighweight portable engines are achieved, readily controlled and affording anti-explosive safety features and highly efficient operation.

14 Claims, 5 Drawing Figures



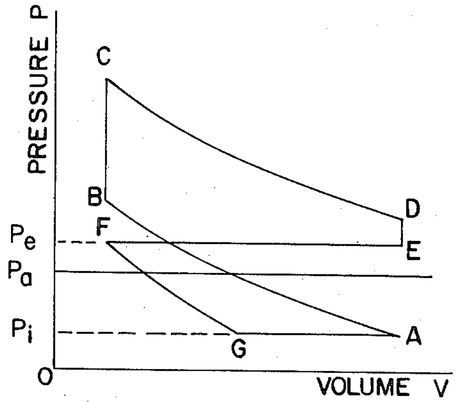


FIG. 1

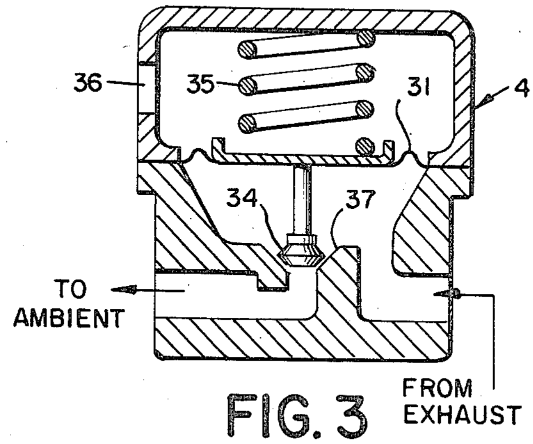


FIG. 3

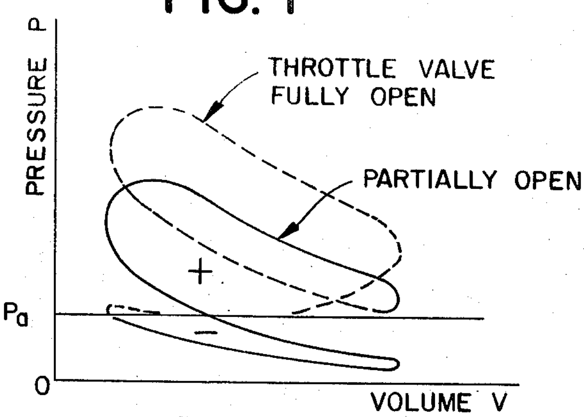


FIG. 4

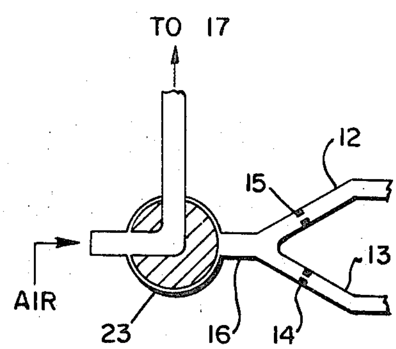


FIG. 2A

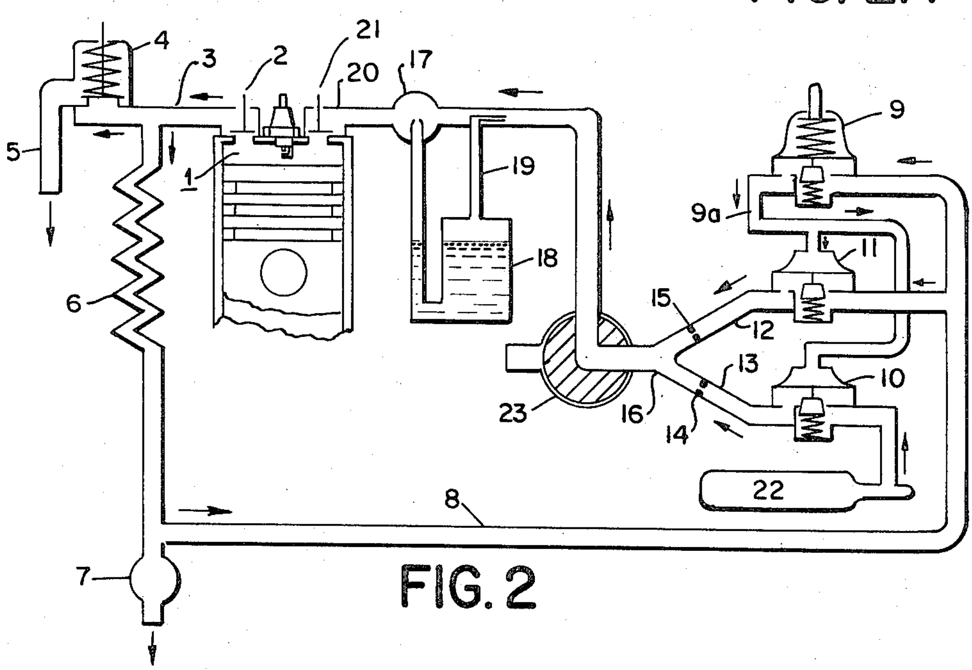


FIG. 2

METHOD AND APPARATUS FOR OPERATING EXISTING HEAT ENGINES IN A NON-AIR ENVIRONMENT

BACKGROUND OF THE INVENTION

This invention relates to a method of operating existing internal combustion and other heat engines in non-air environments.

Except for further means found in the present century for the controlled release of nuclear energy in atomic fission processes, all existing heat engines are devices that transform heat energy developed from the combustion of fuel with the air into mechanical energy. The working substance or energy-transform medium used in the process of transformation in many cases is air itself, as in the internal combustion engine, or sometimes another medium such as water, mercury or some chemical compound used in a turbine system, for example.

In the air environment, the composition of air used to generate heat energy for the transformation, in a practical sense, is essentially constant. It is possible but not practical or economical to change to different compositions of air which otherwise in some cases might be advantageous to us. The pressure of the air varies with the altitude: for example, at 10 miles altitude the pressure is about one tenth of that at the surface of the earth. The decrease of the pressure with the altitude is usually a disadvantage in the use of air, and in airplaines flying at high altitude, superchargers are usually employed.

In non-air environments, such as those underwater or in outer space, no air is available. Because of the large air comsumption in contrast with air environments where air is taken for granted, it is not practical to bring the air to these environments to generate heat for heat engines. Under these circumstances, many expensive and complicated systems other than direct combustion of fuel with air as sources of energy have been developed, such as the fuel cell, battery and motor system used in the first moon missions.

THE PRIOR ART

The substitution of re-cycled exhaust gases for all or part of the inert nitrogen portion of atmospheric air has been proposed for "closed-cycle" engines, employing liquid oxygen or compressed oxygen, and operating without a fresh air supply, as in U.S. Pat. Nos. 881,803; 1,099,445; 2,017,481; 2,895,291; 1,750,919 and 740,864. In such systems, complex and expensive assemblies of extra pumps and exhaust gas purifier devices are used, and explosively dangerous mixtures of fuel in pure oxygen sometimes occur.

Accordingly, the principal object of this invention is to provide a method and apparatus that makes the operation of existing heat engines in non-air environments practical, not only from the viewpoint of system size and weight, but also within the technology and arts of existing processes and materials.

To this end, I recirculate a portion of the combustion products, namely the carbon dioxide and the water vapor, and this is mixed with oxygen to produce a selected composition under the optimized state to sustain the combustion process, selected for the heat engine operating under controlled conditions to achieve certain specific objectives required by each particular application with simple apparatus and procedures.

SUMMARY OF THE INVENTION

The present invention utilizes a novel heat engine cycle with exhaust pressure maintained above ambient and intake pressure maintained below ambient, employing four pressure regulators to govern exhaust venting pressure, recycled exhaust gas pressure and compressed oxygen delivery pressure, matching the latter two pressures for precise control of the intake gas mixture. Intake pressure and intake gas composition are accurately controlled for optimum performance. The recycled exhaust gas pressure is governed by a pilot regulator which is adjusted to govern the power output or speed of engine operation.

It is impossible to generalize the optimized requirements for the best proportioning of the constituents of the combustion-supporting mixture and the optimum pressure-temperature state of the composed mixture, but for each particular application there is usually only one preferred composition of the intake mixture at as specific state which will satisfy the optimized and required performance or will provide the best compromise among several requirements.

It is therefore a further object of this invention to provide means and apparatus to obtain this desired optimum proportioning of the mixture at the desired state.

In prior art devices of similar type, the objective and application are often restricted in limited respects, and many additional components such as pumps, chemical agents and huge containers or vessels are required to make the system work. These additional components add extra weight and size and consume much power from the system, and thus make the system cumbersome, It is important to state that this type of power generating system has its commercial value only in non-air environments. In these non-air environments, whether under water or in space, the diver or the spaceman cannot manipulate himself freely, and lightweight portability is a primary requirement of such systems, in many cases.

It is thus a further object of this invention to make the system compact, and lightweight and easy in operation, with no additional power components, in order to make the system commercially and practically adaptable in non-air environments.

The methods of this invention for operating heat engines in non-air environments can be utilized with all types of existing engines to achieve different objectives or to eliminate certain difficulties while operating in the non-air environment. It is therefore impossible to represent all the applications of this invention by a generalized example. For the purpose of illustration, a specific application is shown here as an example of the adoption of this method and apparatus to make an existing heat engine practically applicable to a non-air environment.

Other and more specific objects will be apparent from the features, elements, combinations and operating procedures disclosed in the following detailed description and shown in the drawings.

THE DRAWINGS

FIG. 1 is a pressure-volume diagram of the theoretical operating cycle of the heat engines of this invention;

FIG. 2 is a schematic diagram of an internal combustion engine for non-atmosphere environments utilizing re-cycled exhaust gas to dilute compressed oxygen in the intake mixture, and incorporating the preferred features of the invention;

FIG. 2a is a fragmentary portion of the schematic diagram of FIG. 2, showing a three-way valve switched for engine operation in a normal atmosphere environment;

FIG. 3 is a cross-sectional diagram of the exhaust regulator employed in FIG. 2; and

FIG. 4 is a comparative pressure-volume diagram of the operation of a conventional engine showing the conventional way of regulating engine output by a throttle valve.

As an example, this invention and its method and apparatus readily adapt an internal combustion engine for use as a power source for an underwater hand-held power tool or to propel a scuba diver. The requirements for this particular application are generally compactness, light weight and low oxygen consumption. In addition to the above, the specific requirements are as follows:

1. The maximum temperature in the cylinder of the internal combustion engine after ignition should be no higher than in existing engines, so that no special materials are required.

2. The maximum pressure rise in the cylinder should be no more than the difference between the maximum and ambient pressures in existing engines (because the ambient pressure deep underwater could be very high) so that no development work will be involved.

3. No additional pumps should be required for exhaust or intake.

4. Fuel should be easy to obtain and low in cost. Since the fuel is minor in weight and volume, it is not necessary to use gasoline if other cheap and easily obtainable fuel is found to be advantageous.

5. No additional procedure or powered auxiliary is required for the regulation and operation of the engine other than those used in the air environment.

To satisfy the first requirement, that the maximum temperature in the cylinder should be no higher than in the existing internal combustion engine operating in the air environment, it is necessary to determine the proportioning of the recirculating combustion products, the carbon dioxide and the water vapor, with respect to oxygen. These are proportioned so that the best performance characteristics, such as cycle efficiency and oxygen consumption, are obtained, while still satisfying the first requirement. The determination of the composition of the best performance combustion supporting mixture is not within the scope of this invention. The basic engineering in thermodynamics and gas dynamics provide the necessary knowledge to determine this. The engineer who performs this calculation should keep in mind that this invention provides means and apparatus able to blend whatever proportions of the constituents are called for, and he should take full advantage of this composition variation.

To satisfy the second, or maximum pressure rise, requirement, it is necessary to determine the initial pressure in the cylinder before the compression takes place. Again, this can be found by the basic engineering knowledge of thermodynamics and gas dynamics. The engineer who performs this work is urged to keep in mind that this invention provides means and apparatus such that the initial pressure can be made to vary over a wide range from zero pressure to a maximum of exhaust pressure.

To satisfy the third requirement, that no pumps be required, it is necessary that the exhaust pressure be designed to be higher than the ambient pressure so that no pump is required. For the intake, two of the constituents are re-cycled from the exhaust. Since the exhaust pressure is always higher than the intake pressure, thus no pump is necessary for these two constituents. As for the other intake constituent, the oxygen, no pump is required if bottled compressed oxygen is chosen for the oxygen supply. As far as this example is concerned, the bottled compressed oxygen is easily obtainable on the market everywhere, and is easier to handle than liquid oxygen. Besides, with the means provided by the invention, the specific oxygen consumption is so low that the whole system is compact and portable with bottled compressed oxygen.

For the fourth or low-cost fuel requirement, fuels with less carbon and tar formation such as alcohol are preferred. This is because there are three pressure regulators which are used to regulate both the intake pressure, and thus the initial pressure, and also to regulate the composition of the combustion-supporting mixture. These regulators may not function correctly if carbon or other combustion products are deposited and accumulated in a regulator's valve system. Gasoline may also be used if a filter is used for the recirculating exhaust gases before they enter the regulators.

Further and more specific objects of the invention including those as described in the fifth requirement of the example will be apparent from the description of the system drawings.

The foregoing discussion has supplied the basic information for the structure of a new cycle for the new system which is dependent upon the means and apparatus provided by the invention. It may become clearer if the new cycle is represented by a pressure-volume diagram as shown in FIG. 1. This P–V diagram shows what is happening inside the cylinder of the engine of the new system, which may be contrasted with the standard Otto cycle of an internal combustion engine operating in the air environment in which the exhaust pressure, the intake pressure and the ambient pressure are very close to each other.

Referring now to FIG. 1, P_a is the ambient pressure. P_e is the exhaust pressure, and P_i is the intake pressure. As stated above, P_e is maintained above the ambient pressure P_a by a backpressure regulator, described hereafter. Point D is at the end of the expansion stroke. The pressure at point D has to be designed higher than that of P_e in order to be able to complete the exhaust process. Point C is the theoretical maximum pressure, assuming combustion takes place as a constant volume process. Due to the fact that the combustion does not actually take place as a true constant volume process, the actual maximum pressure is usually 70 percent of the theoretical value, depending on the engine, fuel and many other factors. It is justified to use this theoretical pressure to determine the maximum pressure level at point C if the pressure rise above the ambient pressure of the existing engine is also determined on the same basis. Therefore, the pressure ranges for both point D and point C are fixed for a given ambient pressure. By a careful cycle analysis, the composition of the intake mixture and the value of the intake pressure are determined not only to satisfy these requirements but also to achieve optimum cycle efficiency and minimum oxygen consumption as well. To summarize the new cycle, A–B is the compression process, B–C is the combustion process, C–D is the expansion process, D–E–F is the exhaust process, and F–G represents the reexpansion of the residual gases in the cylinder until the pressure reaches the level of intake pressure, P_i. This does not happen in the existing engine while operating in the air. It is necessary in the new system because there could be a large pressure differential between the exhaust and the intake for underwater applications. G–A represents the actual intake of fresh mixture.

As far as the system is concerned, FIG. 2 is a schematic view of each component and of the system as a whole.

Referring to FIG. 2, 1 is the combustion chamber of the engine, and 2 is the exhaust valve. After delivering their energy at the end of the expansion process, the gases in the cylinder exhaust through the valve 2 into exhaust pipe 3. A backpressure regulator 4 is used to maintain the exhaust system at a predetermined pressure above the ambient pressure. Excess exhaust gases are forced out of the system by the pressure of the exhaust through the regulator 4 and a vent pipe 5. The remaining exhaust gases flow through a cooling coil 6 in which the carbon dioxide is cooled down and the water vapor condensed. Liquid water is removed through a "steam-trap" type check valve 7, leaving in recycle conduit 8 only the water vapor at the vapor pressure corresponding to the ambient temperature. Therefore the composition of the recirculating exhaust gases depends on the ambient temperature.

Practically speaking, the percentage of water vapor in the recirculating exhaust gases at this point is extremely low as compared with carbon dioxide. The specific heats of both carbon dioxide and water vapor are high, thus the specific heat ratios are low. Therefore they are not good working substances to be used in the internal combustion engine for high cycle efficiency. Comparatively, the water vapor is worse than the carbon dioxide. In the exhaust gases, the proportion of carbon dioxide and water vapor is dependent upon the type of fuel chosen, which is often determined by other factors. For internal combustion engines operating in the air we do not care about the composition of the exhaust after it has delivered its energy. In this application, we have to utilize part of the exhaust gas, and it is desirable to take the least possible amount of water vapor into the cylinder during the recycling. In case for some reason more water vapor is preferred, then instead of rejecting all the condensed water through the check valve 7, a portion of it can be taken into the cylinder either in the same way the fuel is introduced, or by some other means such as a gas injector.

The cooling process is required in the new system because it is necessary to maintain the initial termperature of the mixture within the designed range. An ordinary back pressure regulator may also be used if it is placed after the cooling coil because it has a rubber diaphragm which can not stand high temperature. In this case a larger capacity cooling coil is required because it is now handling the cooling of both the recycling and rejected exhaust gases. The low water content recycling gas is also preferred because it simplifies the system.

After it is cooled down, the recycled gas (now containing mainly carbon dioxide and negligible water vapor) passes through tube 8 to the inlet of pilot pressure regulator 9. The output pressure of this pilot pressure regulator is fed in two divided streams through a branched pilot pressure conduit 9a to the top of two regulators 10 and 11 so that the output pressure of regulators 10 and 11 vary with the pilot pressure and are equal to each other. Regulator 10 regulates the pressure of the oxygen from the oxygen tank 22 to the supply tube 13, and regulator 11 regulates the pressure of the recycling exhaust gas from the exhaust system to the tube 12. Accordingly, the pressure of the oxygen in tube 13 and the pressure of the recycling gas in tube 12 can be varied at any level and are always equal at any level.

There are several additional inherent advantages realized by this arrangement, as follows:

a. Increasing or decreasing the spring force on top of the pilot pressure regulator diaphragm with a lever or any other means automatically maintains the intake mixture composition and controls the intake pressure. This simplifies the operating process for the regulation of the output of the engine.

b. In the absence of carbon dioxide in the exhaust system, there is no pilot pressure (e.g. after shutdown of the engine) and compressed oxygen is therefore blocked by regulator 10; otherwise the flow of oxygen could be very dangerous because of the risk of explosive mixtures in the system. It is important to have this automatic oxygen-blocking safety arrangement because of the closed system between the cylinder and the regulators, and a dangerous situation would be created if the pure oxygen mixed with fuel and ignited somehow in a closed system.

From the basics of engineering, the mass flow rate through an orifice depends upon the properties of the gas, the pressure, the temperature and the size of the orifice. The pressures of the two gases in tubes 12 and 13 are equal at any level, controlled by the individual regulators 10 and 11, which are both governed by the pilot pressure regulator 9. The temperature is also made the same, and the properties of these constituents are known. It is therefore only necessary to choose the size of the orifices 14 and 15 in the respective conduits 13 and 12 to give us the desired proportioning of the constituents. The gases after leaving the orifices are thus mixed in the right proportions in the mixer 16. The mixture flows through a three-way valve 23 to the carburetor 17 where it picks up the proper amount of fuel for the amount of oxygen. A fuel tank 18 is pressurized by the total pressure of the mixture by Pitot tube 19. The mixture then flows through pipe 20 and the intake valve 21 into the cylinder, ready for the next cycle.

As mentioned above, the pressure of the exhaust system is designed and kept above the ambient pressure at a fixed level by a backpressure regulator 4. One simple and positive way to keep the water out of the engine is to connect the engine-crankcase to the exhaust system so that the pressure within the engine is also above the ambient pressure at all times. To obtain more power out of the power stroke, the pressure in the crankcase should be kept only a few psi, for example 5 psi, above the ambient pressure. It is preferable to have this back pressure regulator **4** automatically adjust itself to maintain the exhaust pressure a few psi above the ambient pressure, which may vary as is the case during diving or rising of an underwater system. This is accomplished by the construction of the regulator **4** as shown in FIG. **3.** Referring to FIG. **3, 31** is the diaphragm of the regulator, **34** is the valve and **37** is the valve seat. This diaphragm, valve and seat isolate the exhaust system from the ambient under normal conditions. A spring **35** exerts a fixed force on the diaphragm to keep the valve **34** against its seat **37.** Only when the pressure in the exhaust system exceeds a predetermined level does the force exerted by the pressure below the diaphragm exceed the spring force. When this happens, the valve **34** begins to unseat to let the excess of exhaust gas escape, thus reducing the exhaust pressure back to the predetermined level. A hole **36** is in the regulator's housing above the diaphragm. This hole provides the communication to the ambient so that the pressure above the diaphragm is always equal to the ambient pressure while the spring provides the extra force to maintain the exhaust pressure above the ambient pressure at a fixed level at all times, independent of the ambient pressure itself.

This invention also provides means and apparatus for alternative modes of operation, so that the system can be operated either with the oxygen supplied from the tank while under the water or taking air from the atmosphere while on the surface of the water, by simply switching a three-way valve **23** from one position to the other. This will increase the range of operation without adding extra weight and size to the system because the fuel consumption is negligible. FIG. **2a** shows the three-way valve at a first or air-atmosphere position, where the oxygen and the recycling exhaust gas are blocked to the intake of the system, which takes its air from the atmosphere. It will be noted that the exhaust system will be charged up by the exhaust gases in the same manner as when operating the system underwater. Therefore the exhaust gas is there to make it available whenever the system is switched to be operated with compressed oxygen. While operating with air, the exhaust gas contains nitrogen in addition to the carbon dioxide and the water vapor. Since the nitrogen has a lower specific heat than that of carbon dioxide, the pilot pressure has to be set at a lower level to compensate for the difference of composition of the recycling gas during the initial stage of switching back to compressed oxygen for non-air atmosphere operation. Detailed power regulation will be described below. Within a matter of seconds, the nitrogen will be diluted and displaced by the carbon dioxide after the system is switched to oxygen supply.

In some other types of application, such as using the engine to drive a drill or an impact wrench underwater, the operation of the engine is usually intermittent. The exhaust system has to be charged up with carbon dioxide in order to provide the supply of recycling gas. There are two ways to accomplish this. The first way is to make the spring force on top of the diaphragm of the back pressure regulator **4** adjustable so that the spring force can be set to the corresponding depth where it is intended to be operated and then the exhaust system charged with carbon dioxide by engine operation before the system is taken down. The second way is to charge the system with carbon dioxide on its way down to maintain the fixed pressure above the ambient at any depth by attaching a small carbon dioxide cartridge to the system, connected to conduit **8,** for example.

Furthermore the invention provides an improved method of regulating the power output to achieve better efficiency, as compared to the usual throttle control for regulating an internal combustion engine's power output. As a result of this new and improved method, the maximum power output per cycle is obtained for the amount of oxygen and fuel input. In other words, no oxygen and fuel is wasted for the purpose of regulating the engine power output. The ordinary way of regulating the engine power utilizes a throttle valve. When less power is required, the throttle chokes the intake passage to permit less air-fuel mixture to be taken into the cylinder. This will reduce the power output by reducing the initial pressure; at the same time it will increase the pumping work which is a "negative" work, used to cancel part of the positive work developed during the power stroke. A comparison of the full-choked and fully opened throttle modes of operation is shown in the P–V diagram of FIG. **4,** where + and − signs identify regions of positive and negative work.

The new method of this invention uses no throttle valve in the system. This is equivalent to the case of an ordinary engine with its throttle valve fully open at all times, from no load to full load. The regulation of the power output is accomplished by regulating the spring force of the pilot pressure regulator **9.** This is done by changing the degree of compression of the spring through a plunger and a linkage similar to the linkage normally used to control the throttle valve.

To exemplify the adoption of the method and apparatus provided by the invention, a single-cylinder internal combustion engine system of ¾ h.p. for underwater operation at a depth of 60 feet was designed, manufactured and demonstrated with the following specification:

Engine:
- Bore — 1.437 in. dia.
- Stroke — 1.25 in.
- Compression Ratio — 5.75
- Displacement — 2.00 cu. in.

Cycle:
- Exhaust pressure — 48 psia.
- Intake pressure — 17.7 psia.
- $P_{B=139}$ psia.
- $P_{C=746.4}$ psia.
- $P_{D=92.35}$ psia.

Fuel: Gasoline

Oxidant: Compressed oxygen

Since the foregoing description and drawings are merely illustrative, the scope of the invention has been broadly stated herein and it should be liberally interpreted to secure the benefit of all equivalents to which the invention is fairly entitled.

I claim:

1. The method of operating an expansion process heat engine having an expansion zone as a closed system in a non-air environment comprising the steps of:

A. recycling a portion of the exhaust gas from the expansion zone after reaction at a pre-selected recyling pressure above the ambient pressure for reintroduction to the heat engine cycle while discharging the remainder of the exhaust gas outside the system,

B. reducing the pressure of the recycled exhaust gas from said recycling pressure to an intake pressure below the ambient pressure,

C. passing the recycled exhaust gas and fresh supply gas through separate cooperating metering orifices, both opening into a mixing zone and thereby proportioning the constituents to form a predetermined intake composition,

D. regulating the pressures of both the recycled exhaust gas and the fresh supply gas at points upstream from the metering orifices to adjust said predetermined intake composition, and

E. delivering the mixture of recycled exhaust gas and fresh supply gas from the mixing zone to a reaction zone.

2. The method defined in claim **1** wherein a control portion of the recycled exhaust gas is diverted to operate pilot regulating means performing said pressure regulating step, said control portion being itself adjustably metered to govern the power output of the heat engine cycle.

3. The method defined in claim **1** wherein the heat engine is an internal combustion engine in which the fresh supply gas is oxygen, and wherein the pressure of the mixed intake gas is diverted downstream from said mixing zone to expel fuel at a predetermined rate into the advancing stream of intake gas in a carburetion zone.

4. The method of claim **3** wherein the recycled exhaust gas is cooled to condense water vapor therein to liquid water, and wherein at least the major part of said liquid water is thereafter removed from the closed heat engine system.

5. Apparatus forming a closed cycle heat engine system operating in a non-air ambient environment comprising:

A. an expansion chamber assembly wherein fresh intake gas mixed with recycled exhaust gas is expanded to convert its heat energy into mechanical energy, said chamber assembly being provided with an exhaust port and an intake port,

B. an exhaust conduit connected to the exhaust port and having an exhaust regulator therein maintaining the exhaust gas in the exhaust conduit at a recycling pressure above the ambient pressure,

C. a recycle conduit connected to said exhaust regulator and having a recycle gas regulator therein delivering recycled exhaust gas via a mixing chamber to said intake port at a reduced intake pressure below the ambient pressure,

D. a pressurized source of fresh supply gas connected by a supply gas conduit to said mixing chamber, with a supply gas pressure regulator interposed in the supply gas conduit delivering said supply gas to said intake port at said reduced intake pressure below ambient pressure,

E. and a pilot regulator operatively associated with the recycle gas regulator and the supply gas pressure regulator and connected to adjust the output pressures of both the recycle gas regulator and the supply gas regulator to govern the resultant intake pressure at said intake port.

6. The apparatus defined in claim **5** wherein the pilot regulator is a pressure regulator connected to the recycle conduit whose output pressure is connected as the control pressure to the recycle gas regulator and the supply gas regulator, whereby lack of exhaust gas pressure in the recycle conduit blocks admission of fresh supply gas to the mixing chamber and the intake port, whereby mixture of fresh supply gas with fuel is prevented to eliminate explosion hazards.

7. The apparatus defined in claim **5** wherein metering orifices of predetermined cross-sectional area are interposed respectively between the mixing chamber and the supply gas regulator and between the mixing chamber and the recycle gas regulator, whereby the constituents of the mixture supplied to the intake port are proportioned in a pre-determined ratio.

8. The apparatus defined in claim **5**, further including a three-way valve alternatively connecting said mixing chamber to said intake port, and connecting external atmosphere to said intake port, thereby adapting said apparatus for alternative operation in an air environment.

9. The apparatus defined in claim **5** wherein the exhaust regulator is provided with

A. an external exhaust vent for discharging excess exhaust gas outside the system,

B. a regulator valve connecting the recycle conduit to said exhaust vent, and

C. a valve actuator counterbalancing the sum of a differential biassing force and the ambient pressure against the exhaust gas pressure in said exhaust conduit, discharging excess exhaust gas through said exhaust vent whenever said exhaust gas pressure exceeds the ambient pressure by an amount exceeding said differential biassing force, and thereby continuously maintaining the recycling pressure in said recycle conduit at a predetermined level exceeding the ambient pressure, regardless of ambient pressure fluctuation.

10. The method of operating an expansion process heat engine having an expansion zone as a closed system in a non-air environment comprising the steps of:

A. recycling a portion of the exhaust gas from the expansion zone after reaction at a preselected recycling pressure for re-introduction to the heat engine cycle while discharging the undesired excess exhaust gas outside the system,

B. regulating the pressure of the recycled exhaust gas from said recycling pressure to a predetermined intake pressure,

C. passing the recycled exhaust gas and fresh supply gas through separate cooperating metering orifices, both opening into a mixing zone and thereby proportioning the constituents to form a predetermined intake composition,

D. regulating the pressures of both the recycled exhaust gas and the fresh supply gas at points upstream from the metering orifices to adjust the intake pressure of the engine to change its power output while maintaining said predetermined intake composition substantially constant, and delivering the mixture of recycled exhaust gas and fresh supply gas from the mixing zone to a reaction zone.

11. The method defined in claim **10** wherein a control portion of the recycled exhaust gas is connected to operate adjustable pilot regulating means performing said pressure regulating step, the pressure of said control portion being controlled by adjustment of the pilot regulating means to control the state of the intake mixture at the predetermined composition to govern the power output of the heat engine cycle, whereby there is achieved a higher cycle efficiency than is available with conventional heat engine throttle power controls.

12. The method defined in claim **10** wherein a portion of said recycled exhaust gas has its pressure reduced by an adjustable pilot regulator and is then connected to the plenum chambers of pressure regulators respectively governing the pressures of the recycled exhaust gas and the fresh supply gas entering the separate metering orifices.

13. The method defined in claim **1** wherein the heat engine is an internal combustion engine in which the fresh supply gas is oxygen, and wherein the pressure of the mixed intake gas is diverted downstream from said mixing zone by a pitot tube sensing the total pressure of the advancing mixed gas stream and creating a positive pressure differential, applied to a body of liquid fuel, relative to a fuel carburetor nozzle exposed to the static pressure of the mixed stream, aspirating fuel through the fuel carburetor nozzle into the advancing mixed stream at a predetermined rate.

14. Apparatus forming a closed cycle heat engine system operating in a non-air ambient environment comprising:

A. an expansion chamber assembly wherein fresh intake gas mixed with exhaust gas recycled after it

has been reacted with fuel is expanded to convert its heat energy into mechanical energy, said chamber assembly being provided with an exhaust port and an intake port,

B. an exhaust conduit connected to the exhaust port and having an exhaust regulator therein maintaining the exhaust gas in the exhaust conduit at a predetermined recycle pressure,

C. a recycle conduit connected to said exhaust regulator and having a recycle gas regulator therein delivering recycled exhaust gas via a mixing chamber to said intake port at a predetermined intake pressure,

D. a source of fresh supply gas connected by a supply gas conduit to said mixing chamber, with a supply gas pressure regulator interposed in the supply gas conduit delivering said supply gas to said intake port at said predetermined intake pressure,

E. and a pilot regulator associated with the recycle gas regulator and the supply gas pressure regulator and connected to adjust the output pressures of both the recycle gas regulator and the supply gas regulator at the same desired pressure level to govern the resultant intake pressure at said intake port.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,807,373 Dated April 30, 1974

Inventor(s) Hsin Sheng Chen

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

Page 1, 76 , in the address "Hasbrouch" should read --Hasbrouck--

In the Abstract, line 7,"lighweight" should read --lightweight , --

Column 2, line 24, "as" should read --a--

Column 2, line 40, "," should read --.--

Column 4, line 46, second "of" should read --in--

Column 5, line 62, "termperature" should read --temperature--

Column 10, line 3, "mixture" should read --mixing--

Signed and sealed this 1st day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents