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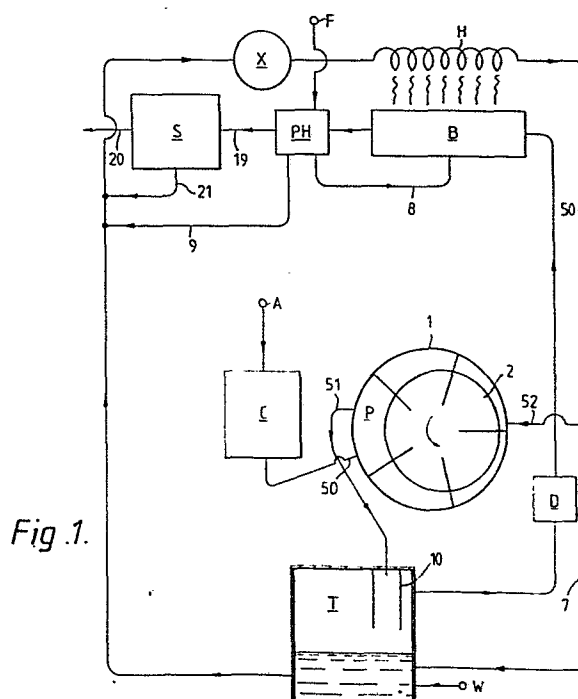
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54 Rotary external combustion engine.

57 A rotary external combustion engine wherein energy is transferred to air acting as a working gas by injection into the air of liquid water at a high temperature and pressure. The liquid water is injected either directly into the working space in the stator or into a preliminary mixing chamber. The water acts as a heat-transfer medium for heating the air. Spontaneous vaporization of the liquid water on injection increases the pressure of the air which drives the rotor before being exhausted. The exhaust water is recovered and recycled. The working space is scavenged and refilled with a fresh charge of air.



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5 The present invention relates to a rotary
external combustion engine i.e. an engine of the type
having a stator and a rotor defining a working space
of variable volume and wherein heat energy for
powering the engine is supplied externally of the
working space. In particular, the invention provides
a novel operating cycle.

10 Many attempts have been made to produce an engine
which combines high thermal efficiency in terms of
converting applied heat energy into useful work, with
acceptable power to weight and power to volume ratios
for the engine. The internal combustion engine has a
good power to weight ratio but a relatively low
thermal efficiency. Of such internal combustion
15 engines, the diesel engine is generally accepted to
have one of the best thermal efficiencies (up to
around 40 per cent). Thermodynamically more efficient
engines based on the Carnot, Stirling and Ericsson
cycles have been built but these have not in general
20 been commercial successes, largely on account of the
problem of providing a small and efficient heat
exchanger enabling the working gas to become quickly
and efficiently heated by the external heat source.

25 The steam engine is a well known form of external
combustion engine but its power to weight ratio is
generally low, owing to its requiring a separate steam
boiler and condenser. The steam engine generally uses
dried steam or other dry vapor as the working fluid.
However, the present invention is not concerned with
30 such an engine but is concerned with an external
combustion engine which uses a gas such as air as the
working fluid.

 The external combustion engine of this invention
may comprise one or more stators and one or more

rotors. Usually, the stator has a cylindrical bore in which the rotor is eccentrically mounted. The rotor may be provided with vanes so as to define between the stator and the rotor at least one working space of crescent-like shape. As the eccentric rotor rotates within the stator, the volume of each working space increases from a minimum to a maximum and then decreases to the minimum again every revolution. The construction of this embodiment is analogous to the construction of a vane-pump. However, other stator and rotor configurations are possible. In particular, the stator need not be cylindrical in cross-section but may be provided with two, three, four, five or more lobes. The rotor also need not be circular in cross section and may be provided with a plurality of ridges which define with the stator the working spaces.

However, in a preferred embodiment, the rotor is of cylindrical cross-section and is provided with two or more vanes slidable in slots provided in the rotor so as to accommodate changes in the spacing between any given point on the rotor and the corresponding point on the stator, as the rotor rotates. Preferably, each vane is provided with biasing means to resiliently bias it against the bore of the stator, thereby sealing each working space. Such biasing means may be in the form of a spring, such as a coil or leaf spring, disposed in the bottom of each slot and operative between the bottom of the slot and the bottom of the respective vane to bias the vane outwardly.

Preferably, sealing means are provided between the axial ends of the rotor and stator to prevent leakage. Such sealing means are well known in the art

and may include O-rings or labyrinth seals. The compression ratio employed may vary widely depending on the particular application of the engine. Thus in some applications a compression ratio as low as 1.5:1 perhaps lower may be employed. In other applications the compression ratio may be as high as 20:1.

Means are provided for inducting gas into each working space. In its simplest form a ram may be provided together with an inlet port to the working space for scavenging the exhaust gas and replacing it with a fresh charge. Alternatively, inducting means may be provided by providing the engine with appropriate valves and inlets such that an induction revolution wherein gas is inducted into each working space is provided between each working revolution wherein the gas is used to do work. However, it is preferred to provide a separate compressor to provide pressurised gas which is inducted into the cylinder every revolution at the appropriate time. Such compressor may be a rotary compressor, such as a vane or turbine compressor. Alternatively, the compressor may be a reciprocating compressor, preferably, the compressors are driven from the engine.

An injector is also provided for injecting pressurized preheated liquid heat-transfer medium into the gas. The purpose of the injected liquid medium is to enable heat transfer from the burner to the gas to be effected quickly and efficiently. Generally, the heated liquid medium is sprayed into the gas in the form of liquid droplets having a large surface area which enable rapid heat transfer to the gas to occur. The liquid medium may be injected into the gas before or after the gas is inducted into the working space. Although the liquid may be injected into unpressurised

working gas, it is well known that greater thermal efficiency is achieved by injecting the liquid medium into the gas when in a compressed state.

5 Since the injected liquid medium allows heat transfer to the gas to be achieved more efficiently, smaller heat exchanger surfaces are required.

10 Consequently, the present invention envisages heating the liquid medium and allowing the gas to become heated by contact with the medium. The heat-transfer medium might be sprayed into the gas in the form of droplets. However, it is preferred that a vaporisable medium be used which flashes to a vapor on injection into the working gas.

15 To avoid confusion the following terms as used herein will be clarified. The gas into which heat-transfer medium has been injected will be referred to generally as wet gas. Gas into which heat-transfer medium has not been injected will be referred to as dry gas. The injected medium may be present in the
20 gas in its liquid or vapor state.

The heating of the liquid medium and its injection into the gas may be achieved in a variety of different ways.

25 Firstly, the liquid medium may be heated in a compact heat exchanger, for example a coil of narrow bore tubing, to a high pressure and high temperature. Since such narrow bore tubing can withstand great pressures, it is possible to heat the medium up to its critical point. For special applications where
30 the rate of heat transfer is to be high, it may be preferred to heat the medium to a temperature and pressure above its critical point. The hot pressurized liquid medium is then injected into the gas in a mixing chamber. A non-vaporising medium is

preferably injected by means of an atomising injector. Internal energy of the medium is rapidly transferred from the hot liquid droplets to the gas, thereby increasing its pressure very quickly. The heated and pressurized wet gas is then fed into the working space where it expands (usually polytropically i.e. non-adiabatically) to drive the rotor.

However, in a second most advantageous arrangement, the mixing chamber is dispensed with and the hot high pressure liquid medium which has been heated in the heat exchanger is injected directly into the working space. Thus, a charge of dry gas is generally inducted into the working space at its maximum volume and compressed adiabatically during the subsequent half revolution. When the working space has reached approximately its minimum volume, hot pressurized liquid medium is injected into the compressed and heated gas so as to raise the pressure of the gas still further. The hot pressurized gas expands and cools during the subsequent half revolution. When the working space has reached approximately its maximum volume the gas is exhausted from the working space.

Preferably, the heat-transfer medium is a vaporizable liquid, such as water, which at least partially flashes to vapor immediately it is injected into the working space. Thus, heat transfer between the hot water vapor and the gas is very rapid.

Therefore, it may be seen that in this second arrangement the injected liquid medium is merely acting as a heat transfer fluid which may enable the compressed gas to convert internal energy to mechanical work. If a vaporizable medium is employed, the heat transfer process is particularly effective

provided that most of the heat-transfer medium leaves the working space in the liquid state, so that the latent heat of vaporization is not lost.

5 The present invention is to be distinguished from a steam engine in that the medium is maintained in its liquid form and not allowed to vaporize until it is introduced into the gas. This is in sharp contrast to a steam engine, wherein even if a flash boiler is used, the water is always introduced into the cylinder in the form of steam. In fact, since it is necessary to superheat the steam to remove water droplets in a conventional steam engine, it is not possible to directly flash liquid water into the cylinder of a steam engine since this would give rise to water droplets in the cylinder. However, in the engine according to the present invention, the presence of water droplets in the working space may be tolerated. Indeed in some cases it may be desirable to construct the stator and/or rotor so as to retain liquid medium in the working space after exhaust. Thus, the stator or rotor may be provided with suitable recesses.

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It is necessary that the heated medium be maintained in the liquid state prior to injection. Although this may be achieved by using appropriate sensors to ensure that the temperature at a given pressure never exceeds the liquid boiling point, it has been found that if an orifice of suitable size is connected to the heat exchanger in which the liquid medium is heated and a flow of liquid medium is maintained through the heat exchanger, then the application of heat to the medium does not cause the liquid to boil. Thus, by correct choice of orifice size, complex temperature and pressure sensing devices may be avoided. So long as the orifice provides a

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0043880

pressure drop, the pressure in the heat exchanger will at all times be such that, as the temperature is increased, the pressure of the water in the heat exchanger will also increase and thereby be always
5 below the boiling point. The orifice, of course, will form part of the injection means through which the liquid medium is injected into the gas.

The rate of working of the engine may be controlled by any of several means. It may be
10 controlled by varying the amount of heat transfer medium injected into the stator; for example by using a variable displacement pump. The rate of working of the engine may be controlled by controlling the amount of heat supplied by the burner, for example by
15 controlling the fuel supply to the burner (for a constant liquid volume injection rate).

Usually, the heat-transfer medium is recovered from the exhaust gas after the gas has been exhausted from the working space. The recovered medium, which
20 will still be somewhat heated, may be recycled again to the heat exchanger so that its heat content is not lost. In this way, the medium acts merely as a heat transfer fluid and is not substantially used up.

Water is a preferred heat transfer fluid, not
25 only because it is vaporizable, but also because it has a thermal conductivity which is high compared to the other liquids, for example heat transfer oils. Moreover, as will be explained later, means may be provided for recovering water produced by combustion
30 in the burner. Thus, it may be possible to avoid any need for make-up water since this will be provided by water from combustion in the burner. Of course, it is possible to use other liquids, such as mercury, which has a thermal conductivity 10 times that of water, and

sodium. However, mercury has other obvious disadvantages, such as cost and toxicity. When water is used an oil may be added to form a dispersion, emulsion or solution to assist lubrication of the
5 engine.

In a particularly preferred embodiment of the present invention, the gas is a gas which is capable of taking part in the combustion process which occurs in the burner. In this way, the internal energy of
10 the gas exhausted from the working space is able to be recovered. The gas may be a gas capable of supporting combustion, such as oxygen, air or other oxygen-containing gas, or nitrous oxide. Alternatively, the gas may itself be a combustible gas chosen from all
15 known combustible gases, such as gaseous hydrocarbons, carbon monoxide or hydrogen. Thus, some or all of the exhaust gas may be fed to the burner.

The fuel burnt in the burner itself may be chosen from known combustible fuels such as gasolines, fuel
20 oils, liquefied or gaseous hydrocarbons, alcohols, wood, coal or coke.

It is in general preferred to use various heat recovery means. Thus, the whole engine may be enclosed in a heat insulating enclosure and be
25 provided with heat exchangers to pick up stray heat and transfer it to, for example the compressed gas or to preheat the fuel for the burner. It is also preferred to recover the heat remaining in the burner flue gases and this may be achieved by passing the
30 flue gases through a spray chamber in which a stream of liquid (generally the same liquid as that injected into the engine) is sprayed through the flue gas. When injection of a vaporizable medium is employed, it is preferred that the vaporizable liquid medium be

0043880

sprayed through the flue gases to heat the medium close to its boiling point prior to being passed to the heat exchanger. Moreover, when water is employed as the injected medium, the use of a water spray chamber or a condenser is advantageous in that water from the burner may be condensed out of the flue gases so that it is not necessary to provide make-up water to the engine.

The construction of an engine according to the present invention is considerably simplified in certain respects in comparison with known engines, such as internal combustion engines. Thus, the temperatures encountered in the working space are generally reduced, thereby simplifying sealing of the working spaces. It will be appreciated that power may be provided in the engine of the present invention at much lower temperatures than, for example an internal combustion engine. Moreover, the internal combustion engine is less thermally efficient in that means must be provided to cool the cylinders and prevent seizing up.

Moreover, since the temperatures encountered in the engine are relatively low, for example up to 350°C., it is not usually necessary to construct the cylinder of metal. Plastics such as polytetrafluorethylene (PTFE), fiber-reinforced resins, and other plastics used in engineering, are particularly advantageous due to their cheapness and ease of use. In some constructions the use of plastics materials having a low heat conductivity can be an advantage in ensuring that that portion of the stator at which heat is introduced into the working space is kept at a relatively high temperature, whereas the gas outlet is kept at a relatively low

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temperature. Other heat insulating materials such as wood, concrete, glass or ceramics may also be used.

Power is taken from the engine by means of a shaft attached to the rotor. It will be appreciated
5 that the engine is susceptible of high speed operation and is thus ideal for providing a small power plant suitable for a mobile vehicle. The engine is also ideal for high speed applications such as generating electricity.

10 In comparison to a steam engine, the engine of the present invention is less bulky in that a large high pressure boiler is not required since the liquid is heated in its liquid state in a very much smaller heat exchanger. Also, there is no need for a
15 condenser, although a trap or spray chamber to recycle water is desirable. In comparison to the internal combustion engine, the engine of the present invention is capable of greater thermal efficiency, both in terms of the amount of heat converted to work in the stator and also in terms of the amount of heat obtained from
20 the fuel burnt, since complete combustion is rarely obtainable in an internal combustion engine. The burner parameters of the engine of the present invention may be optimised so as to ensure
25 substantially complete combustion of the fuel in the burner, thereby substantially eliminating pollution in the form of unburnt fuel or carbon monoxide.

In comparison to known gas engines, the present invention allows the bulky gas heat exchanger to be
30 replaced by a compact liquid heater.

0043880

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings wherein:

Figure 1 is a schematic view of a rotary external combustion engine according to the present invention;

Figure 2 is a schematic cross-sectional view of a heat exchanger of the engine;

Figure 3 shows a spray device for cooling flue gas from the burner;

Figure 4 shows in partial cross section a stator and rotor assembly of the engine;

Figure 5 shows pressure (P) versus volume (V) and temperature (T) versus entropy (S) relationships for the rotary external combustion engine of the present engine; and

Figure 6 shows the PV and TS diagrams for the known two-stroke internal combustion engine.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In carrying out the invention in one form thereof, the rotary external combustion engine, shown in Figure 1, comprises a stator 1 having a cylindrical bore, an eccentrically mounted cylindrical rotor 2 rotatable within the stator, vanes 3 slidably mounted on the rotor and defining working spaces P, a compressor C for feeding compressed air to working space P. The compressor C may be a rotary compressor. The engine further comprises a pump X for feeding pressurized water to the heating coil H of a heat exchanger, and a spray chamber S for spraying water through flue gases from the burner B so as to cool and wash the flue gases and preheat the water. An optional preheater pH is provided for preheating fuel to the burner and is especially applicable for heavy fuel oils. There is a trap T for recovering liquid water from the wet exhaust gas from the working space.

Atmospheric air A is compressed by compressor C and inducted into a working space of the engine through inlet 50. The working space P has substantially its maximum volume. On rotation of the rotor 2 in the direction indicated in the arrow the air is compressed as the volume of the working space P decreases. When the working space volume is substantially at a minimum hot liquid medium injected from the heat exchanger through inlet 52 so as to heat the compressed gas in the working space. In lieu of injecting the heated liquid from the heat exchanger directly into the stator, it may be injected indirectly by first directing it to a mixing chamber where it is mixed with gas from the compressor C and then supplied to the stator.

The arrangement shown in Figure 1 uses water, which is a vaporizable liquid, as the heat-transfer medium. However, other suitable vaporizing or non-vaporizing liquids might be used.

The injected water is at a high temperature and under a sufficient pressure to maintain it in its liquid state. As the water is injected into the working space P, a portion of the water immediately flashes to vapor which becomes mixed with the compressed air. Rapid heat transfer occurs and the temperature of the compressed air is increased. Further rotation of the rotor 2 allows expansion of the gas as it does work and leads to a reduction in its temperature and pressure.

The compression ratio employed may vary widely depending on the particular application of the engine. Thus in some application a compression ratio as low as 1.5:1 or perhaps lower may be employed. In other applications the compression ratio may be as high as 20:1.

0043880

On further rotation, the working space P reaches outlet 51 through which gas is exhausted. On further rotating of the rotor 2, the working space encounters the inlet 50 once again and the cycle recommences.

5 Exhaust gas from outlet 51 contains liquid droplets and vapor. A trap T is provided in order to recover the liquid water droplets from the exhaust gas from the working space P. Exhaust air and water vapor is then fed to burner B via a dryer D. Any condensate
10 from the dryer is returned to the trap along line 7. Water from the trap is returned to the heating coil H.

Thus, the operation of the engine is as follows. Preheated water from the trap T is fed by means of a high pressure pump X (for example a positive
15 displacement piston pump) to a heating coil H formed of narrow bore tubing. The water is then heated by means of the burner B to a high temperature and pressure, for example 300°C. and 86 bar. The water will generally be heated to temperature below its
20 critical temperature and pressure (220.9 bar and 374°C.), however the pressure will always be such that at any temperature it will maintain the water in its liquid state. The hot pressurized water then passes through a pipe 50a to an inlet 52 to the
25 interior of the stator 1. The inlet 52 communicates with a pair of closely spaced ports 53 which are arranged side by side such that at any given time only one of them is obstructed by a vane 3, thereby ensuring continuity of flow into the working spaces
30 of the rotor/stator assembly (see Figure 4). The working space P in communication with a port 53 contains compressed and somewhat heated air which has been delivered from the compressor C through inlet 50. On entering the working space P a proportion of

the hot pressurized liquid water instantaneously flashes to vapor, thereby increasing the pressure in the working space at substantially constant volume (i.e. along line bc in Figure 5). The hot

5 pressurized air expands, rotating the rotor 2 in the direction indicated by the arrow until the working space P encounters the outlet 51. This corresponds to the line cd in Figure 5 and results in increase in volume with decrease in pressure and temperature,

10 such that some of the water vapor recondenses giving up its latent heat of vaporization. The exhaust gas is then fed through the trap T to the burner.

Figure 2 shows the construction of the heat exchanger, which combines the heating coil H and the

15 burner B. The heat exchanger comprises inner and outer coaxial sleeves 60 and 61, respectively, defining a double path for flue gas from the burner. Insulation 64 is provided around the outside of the heat exchanger. A fuel inlet jet is provided for

20 burning fuel F in air A admitted via an air inlet. Water W passes through a heating coil H which comprises an inner coil 62 and outer coil 63 in the direction indicated by the arrows such that water exits from inner coil 62 at a position close to the

25 highest temperature of the burner. The hot pressurized water is then fed along pipe 50a prior to injection into the working space P.

The heat exchanger may be provided with suitable temperature and pressure sensing devices to ensure

30 that the liquid in the heating coil H is always maintained in its liquid state and not allowed to vaporize. However, it has been found in practice that it is not necessary to carefully monitor the temperature and pressure to avoid vaporization.

35 Thus, it has been discovered that, provided the

heating coil H is always in communication with an aperture through which the liquid is continually passed (i.e. one or other of the inlet ports 53) the application of further heat in the heating coil H causes
5 an increase in temperature and pressure but does not, at least in the case of water, cause the liquid to boil. It is, of course, necessary that the aperture (or ports 53) be suitably sized to maintain the necessary pressure differential across it. However, this may be
10 established by the skilled man by suitable experimentation.

Figure 3 shows a spray device for cooling and washing the flue gases from the burner B and thus recovering some of the heat and some water produced by
15 combustion. It comprises a spray chamber 17 having therein a funnel 18 onto which water is sprayed by spray 41 through the stream of hot flue gases. The flue gases are inducted via inlet 19 and arranged to flow tangentially round the chamber before exiting through
20 the exit 20 as cooled flue gas. The flue gases thus pass through the spray and then through a curtain of water falling from the inside aperture of the funnel 18. Preferably, the flue gases are cooled to below 100°C. so as to recover the latent heat of vaporization of water
25 in the wet exhaust air and also to recover water produced by combustion in the burner. Water at substantially 100°C. exits through the outlet 21 before being fed by metering pump X into the heat exchanger. If necessary, cold feed water W may be introduced into
30 the chamber via a ballcock 40 for maintaining a constant level of water in the bottom of the spray chamber. A recycle pump R and associated ducting 22 is provided for recycling the water through the spray to bring it up to

its boiling point. However, in practice if it is desired to cool the flue gases below 100°C., it may be necessary to withdraw water through the outlet 21 at a substantially lower temperature e.g. 50°C.

5 Figure 4 shows in detail the construction of the rotor/stator assembly. For temperatures up to several hundred degrees centigrade, the assembly may be formed of suitable plastics material, which enables the assembly to be lightweight and to be produced relatively
10 cheaply. However, if higher thermal efficiencies and thus higher temperatures are required, other appropriate materials such as metals may be used. The rotor 2 is eccentrically mounted within the cylindrical bore of the stator 1 and conventional sealing means are provided at
15 the ends of the bore so as to seal the rotor to the stator. Each vane 3 provided on the rotor 2 is slidably disposed in a respective slot 54 and outwardly biased by means of a coil spring or leaf spring 55 (only one shown) disposed in the bottom of the slot. The rotor is
20 mounted on a rotatable shaft (not shown) which extends out of the stator 4 supplying power.

The inlet 52 for injecting the heated pressurized liquid into the working spaces, communicates with a pair of adjacent ports 53 in the end surface of the
25 cylindrical bore of the stator. The use of a pair of ports 53 ensures that while one of the ports is obstructed by the edge of a vane 3, liquid continues to be injected through the other port 53 thereby ensuring continuity of liquid flow from the heating coil H.
30 Thus, abrupt shocks to the high pressure liquid are avoided. Liquid flows continuously through the inlet 52 into whichever of the working spaces is in front of an inlet port 53. Therefore, no complicated valving is required. In lieu of injecting liquid from the heat
35 exchanger directly into the stator, through liquid inlet

52 the liquid may be introduced into a mixing chamber where it is mixed with compressed gas before being injected into the stator through inlet 50. In that case liquid inlet 52 would be eliminated and inlet 50 would
5 be relocated to a position approximately 180°C. from outlet 51, that is to a position essentially the same as that of the inlet 52 shown in Figure 4.

Compressed air is introduced into a working space through inlet 50 which opens directly into the bore of
10 the stator 1. As each working space P comes into communication with inlet 50 it is filled with pressurized air from the compressor C.

The construction of outlet 51 is similar to the construction of the inlet 50. Thus, the outlet 51 opens
15 into the interior bore of the stator and exhausts gas from each working space P in turn during rotation of the rotor. The outlet 51 is disposed approximately 180°C. of rotation away from the injector.

The construction shown in Figure 4 is also
20 advantageous in that it is desirable to maintain the inlet 50 and outlet 51 as cool as possible to reduce the temperature at which gas is exhausted, while maintaining the temperature of the stator in the region of the hot pressurized liquid inlet 52 as high as possible so as to
25 maintain a high temperature at which heat is introduced to the working space. This improves the thermal efficiency with which work is derived from the heat supplied to the working spaces. The use of a material, such as a plastics material of low thermal conductivity
30 for the stator 1 enables a higher temperature differential to be maintained between the inlet and outlet 50, 51 on the one hand and the hot liquid inlet 52 on the other hand. The disposition of the inlet and the outlet approximately 180°C. of rotation from the
35 injection also assist in maintaining this desirable temperature differential.

For improved scavenging inlet 50 and outlet 51 may be more closely spaced, so that for a time each working space communicated with both simultaneously.

5 To retain a small amount of residual water in the stator, recesses, one of which is shown at 56, may be provided. Alternatively, the outlet 51 could be formed to include a plurality of ports arranged along a plane so that the lands between the ports would serve to retain a small amount of residual water. If desired, the rotor,
10 or the vanes thereof, could be formed to include recesses or flanges for retaining a small amount of residual water.

Without wishing to be limited by a theoretical discussion, Figures 5 shows the idealized thermodynamic
15 operation of the engine of Figure 1. Figure 6 shows for comparison the operation of a two-stroke internal combustion engine.

Figure 5 (i) is the PV diagram for the case when hardly any of the injected water flashes to vapor, the
20 majority remaining in the liquid phase as droplets. This will occur when the rate of vaporization is slow compared to the rate of rotation of the rotor.

Figure 5 (ii) is the theoretical PV and TS diagrams for the case when all the injected water vaporizes to the
25 gaseous state. This might occur in a slow working engine.

In Figure 5 (i) air in the working space P is compressed adiabatically (i.e. the gas constant is approximately 1.39) along line ab. The compression is
30 also isoentropic and heats the air. At constant volume liquid water is injected and a small amount of water vapor produced at the same temperature as the compressed air so that the pressure increases along bc. Considering only the air in the working space, there is no change in

T provided the injected water is at the same temperature. As the rotor rotates the wet air expands along cd; however, due to the presence of hot liquid water droplets the expansion is not adiabatic but polytropic (typically the gas constant is between 1.33 and 1.35) so that the curve cd on the PV diagram is flattened. The expansion also produces a fall in T and increase in S. The gas is then exhausted from the working space so that the pressure of gas in the working space falls along da.

10 This replacement of hot pressurized exhaust air by cooler charge air constitutes a fall in both T and S.

Figure 5 (ii) shows the situation wherein all the water flashes to the vapor state. In this case, the rise in pressure along bc is much greater, but the rate of pressure drop along cd is also quicker since the absence of liquid water droplets ensures that the air expands almost adiabatically. Thus the work done (i.e. the area of the figure abcd) in both cases (i) and (ii) is the same.

20 The PV and TS diagrams show the theoretical equilibrium situation when all the injected water is vaporized i.e. in a slow working engine when less than the amount of water required to saturate the air is injected. For the sake of illustration the injected water is at a slightly lower temperature than the compressed air in the cylinder.

As before, air is compressed adiabatically (gas constant is about 1.39) along ab at constant entropy. Typically, the pressure P_a at a is 1 bar and the temperature T_a is 300K (27°C.). At a compression ratio of 6:1 the air pressure P_b and temperature T_b at b rise to around 12 bar and 603K (330°C.).

Liquid water at 573K (300°C.) and 86 bar is then injected into the compressed air and all becomes vapor.



Typically in order to produce a 10 horsepower output about 5 ml of water is injected at b. This causes an increase in pressure along bc (typically $P_c = 25$ bar) and a decrease in temperature due to injection of the slightly cooler water $T_c = 586K$ ($313^\circ C.$). If the water is at the same temperature as the compressed air the line bc on the TS diagram is horizontal. The reduction in entropy along bc of the air in the cylinder arises from the added partial pressure of the water vapor.

As the working space expands, the wet gas expands (gas constant is about 1.34) along cd to a pressure P_d of about 2 bar and a theoretical temperature T_d of about 319K ($46^\circ C$). In practice due to non-theoretical behavior the temperature will be higher e.g. $80 - 90^\circ C$.

The gas is then scavenged from the working space along da as before causing a decrease in temperature, pressure, and entropy of gas in the working space.

In the TS diagram P_a to P_d indicate the constant pressure curves. The net area of the two closed figures in the TS diagram represents the heat added to the air. In the case shown this is negative since injection of the water cools the air. When the water is at the same temperature as the compressed air at b the areas of the two closed figures on the TS diagram cancel out i.e. no heat is added.

Figure 6 shows PV and TS diagrams for the known two-stroke cycle internal combustion engine for comparison. It is analogous to the cycle of case (ii) above. The line ae represents the opening of the exhaust valve before the end of the stroke in a conventional two-stroke engine.

The external combustion engines shown are capable of high efficiency. Theoretically, cold air A, cold fuel, and cold water W (if necessary) are inducted into the



engine, and cold flue gases are vented. Therefore, almost all the heat given out by the burner may become converted into work.

5 It will be appreciated that the engine of the present invention may be simply constructed since it requires no valves and does not require high strength materials. The high rotational speeds obtainable make the rotary external combustion engine ideally suited for application to vehicles, where a high power to weight
10 ratio is needed. Thus, the rotary external combustion engine according to the present invention features power to weight and power to volume ratios comparable to internal combustion engines but having a superior thermal efficiency. Moreover, since it is possible to arrange
15 the combustion conditions in the burner to an optimum, it is possible to achieve almost complete combustion of the fuel to carbon dioxide and water and thus avoid carbon monoxide or unburnt fuel impurities in the exhausted flue gases. In particular, since the combustion occurs
20 substantially at atmospheric pressure, there is almost no generation of nitrogen oxides during the combustion process. Therefore, this engine represents an improvement over internal combustion engines not only in terms of thermal efficiency but also as regards pollutant
25 emissions.

Moreover, the engine is capable of utilizing a wide variety of fuels, for example gasoline, fuel oil, gaseous or liquefied hydrocarbons (including methane, butane and propane), alcohols and even solid fuels such as wood coal
30 or coke. The burner parameters may be adjusted to ensure substantially complete and pollution-free combustion. Furthermore, such an engine could be made to run more quietly than conventional internal combustion engines.

While it is contemplated that this invention will be
35 carried out by manufacturing new engines incorporating



0043880

the features disclosed in this invention, it may also be carried out by converting some existing rotary motive devices to operate in accordance with the principles of this invention. For this purpose a kit may be supplied

5 incorporating the necessary components for making such a conversion. Such a kit would include a heat exchanger, including a fuel-air burner, for heating water to the necessary temperature and pressure; a heat insulated stator and rotor, the stator having an inlet for gas and

10 an outlet for wet exhaust gas; a compressor for inducting gas into the stator; a pump for transmitting water from the stator to the heat exchanger, an injector for injecting liquid water under pressure from the heat exchanger into the stator, a metering device for

15 controlling the amount of water injected into the cylinder, and a separating chamber for separating condensed water from dry saturated vapor. The kit could also include, optionally, a mixing chamber for mixing compressed gas and liquid heat transfer medium.

CLAIMS

1. A rotary external combustion engine wherein energy is transferred to a working gas from a heated liquid heat-transfer medium, which comprises

5 a stator, a rotor within the stator, a working space defined by the stator and rotor, the volume of the working space being variable by rotation of the rotor from a minimum to a maximum volume;

a heat exchanger for heating the heat transfer medium
10 externally of the working space under a pressure such as to maintain the medium in the liquid state, the heat exchanger having an inlet for receiving heat-transfer medium and an outlet for delivering heated liquid heat-transfer medium;

induction means for inducting gas into the working
15 space;

an injector arranged to inject heated liquid medium into the gas before expansion of the gas in the working space; and

an outlet from the stator for exhausting (which is
20 controlled to exhaust) heat transfer medium and working gas from the working space when the working space is near its maximum volume.

2. An engine according to claim 1 wherein the injector is mounted in the stator so as to inject heated liquid
25 medium directly into the working gas in the working space.

3. An engine according to claim 1 which further comprises a mixing chamber having an inlet for working gas, the injector being mounted in the chamber for injecting heated liquid medium into the gas, prior to the wet gas being
30 inducted into the working space.

4. An engine according to claim 1, wherein the injector is provided with two inlets circumferentially spaced apart such that during rotation of the rotor at least one of the inlets remains unobscured by the rotor at all time.

35 5. An engine according to claim 1, wherein the gas is compressed before the heated liquid medium is injected into the gas.

6. An engine according to claim 1 wherein the injector is an atomising injector, which atomises the injected liquid medium so as to facilitate heat transfer to the gas.
7. An engine according to claim 1 wherein the working gas is capable of undergoing or supporting combustion, the outlet from the stator being connected to the burner for feeding exhaust gas to the burner.
8. An engine according to claim 1 having a compression ratio between approximately 1.5:1 and 20:1.
9. An engine according to claim 1 wherein recycle means are provided for recycling the exhausted heat transfer medium to the heat exchanger.
10. An engine according to claim 9 wherein the recycle means comprises a spray chamber having an inlet for heat transfer medium and an inlet for flue gases connected to the heat exchanger, the chamber having a spray for spraying liquid heat transfer medium through the flue gas from the burner so as to preheat the liquid medium, the chamber further having an outlet connected for feeding heat-transfer medium to the heat exchanger, and an outlet for flue gas.
11. An engine according to claim 1 which further comprises speed control means arranged to control the rate of working of the engine by controlling the amount of liquid heat-transfer medium injected.
12. An engine according to claim 1 which further comprises speed control means adapted to control the rate of working of the engine by controlling the temperature of the injected heat-transfer medium.
13. An engine according to claim 1 wherein the stator and rotor are so constructed that some liquid medium is retained in the working space after the exhaust of heat transfer medium.
14. A rotary external combustion engine wherein heat energy is transferred to air acting as a working gas by means of heated pressurised liquid water at a temperature greater than the boiling point of water at atmospheric pressure, which comprises

a stator, a rotor within the stator, a working space defined by the stator and rotor, the volume of the working space being variable by rotation of the rotor from a minimum to a maximum volume.

5 a heat exchanger for heating the liquid water externally of the working space to a temperature above the boiling point of water at atmospheric pressure, the heat exchanger having

- 1) an inlet for receiving liquid water and an outlet
10 delivering heated water,
- 2) at least one tube for containing said liquid water, and
- 3) a fuel-burner disposed for heating the liquid water
in said at least one tube;

15 pressurising means connected to said at least one tube of the heat exchanger for maintaining said heated water in the liquid state;

induction means connected to the stator for inducting air into the working space when the volume of the
20 working space is near its maximum volume;

an injector mounted on the stator and connected to the outlet of the heat exchanger for receiving heated pressurised liquid water, the injector being arranged to inject heated pressurised liquid water into the working
25 space when the working space is near its minimum volume; and

an outlet from the stator for exhausting cooled water and air from the working space when the working space is near its maximum volume, the majority of said cooled water
30 being exhausted in the liquid state.

15. A rotary external combustion engine wherein energy is transferred to a working gas from a heated liquid heat-transfer medium, which comprises

a stator, a rotor within the stator, a working space
35 defined by the stator and rotor, the volume of the working space being variable by rotation of the rotor from a minimum to a maximum volume;

means for heating the heat transfer medium

externally of the working space under a pressure such as to maintain the medium in the liquid state;

induction means for inducting gas into the working space;

5 an injector arranged to inject heated liquid medium into the gas before expansion of the gas in the working space; and

 an outlet from the stator for exhausting heat transfer medium and working gas from the working space.

10 16. A method of operating a rotary external combustion engine having a stator and a rotor therein defining a working space, wherein energy is transferred to a working space from a heated liquid heat-transfer medium, which comprises

- 15 1) inducting working gas into the working space;
 2) generating externally of the working space heated heat-transfer medium under a pressure such as to maintain the medium in the liquid state;
 3) before or after induction, injecting heated
20 liquid medium into the working gas so as to raise the internal energy of the gas;
 4) allowing the wet gas containing the heat-transfer medium to expand thereby driving the rotor; and
 5) exhausting wet gas from the working space.

25 17. A method according to claim 16 wherein the heat transfer medium is selected from the group consisting of water, oil, sodium, mercury, and mixtures thereof.

 18. A method according to claim 16 or 17 wherein the heated liquid medium is injected into the working gas in
30 the working space.

 19. A method according to any of claims 16 to 18 wherein the heated liquid medium is injected into the working gas in a mixing chamber before the gas is inducted into the working space.

35 20. A method according to any of claims 16 to 19 carried out under conditions of temperature and pressure such that at least part of the injected liquid medium vaporises on injection.

21. A method according to any of claims 16 to 20 wherein the working gas is a gas capable of supporting combustion.

22. A method according to claim 16, wherein the heat transfer medium is water, the recovered exhaust water is recycled to the engine, heat is supplied to the medium by means of a fuel-air burner and water is condensed from the flue gases from the burner to make up any losses in the recycled water.

23. A kit of parts for converting a rotary motive device to a rotary external combustion engine according to claim 1, which comprises

- means for heating liquid under pressure;
- a heat insulated stator and rotor, the stator having an inlet for gas and an outlet for wet exhaust gas;
- a compressor for inducting gas into the stator;
- a pressure pump for feeding liquid to the heat exchanger;
- an injector for injecting liquid under pressure directly or indirectly into the stator;
- a metering device for controlling the amount of liquid injected; and
- a reservoir for containing recycled liquid.

24. A kit of parts for converting a rotary motive device to a rotary external combustion engine according to claim 1, which comprises

- a heat exchanger including a fuel-air burner for heating water under pressure;
- a heat insulated stator and rotor, the stator having an inlet for gas and an outlet for wet exhaust gas;
- a compressor for inducting gas into the stator;
- a pressure pump for feeding water to the heat exchanger;
- an injector for injecting liquid water under pressure directly or indirectly into the stator;
- a metering device for controlling the amount of water injected; and
- a separating chamber for receiving exhaust gas and separating dry saturated vapor and gas from liquid.

1/4

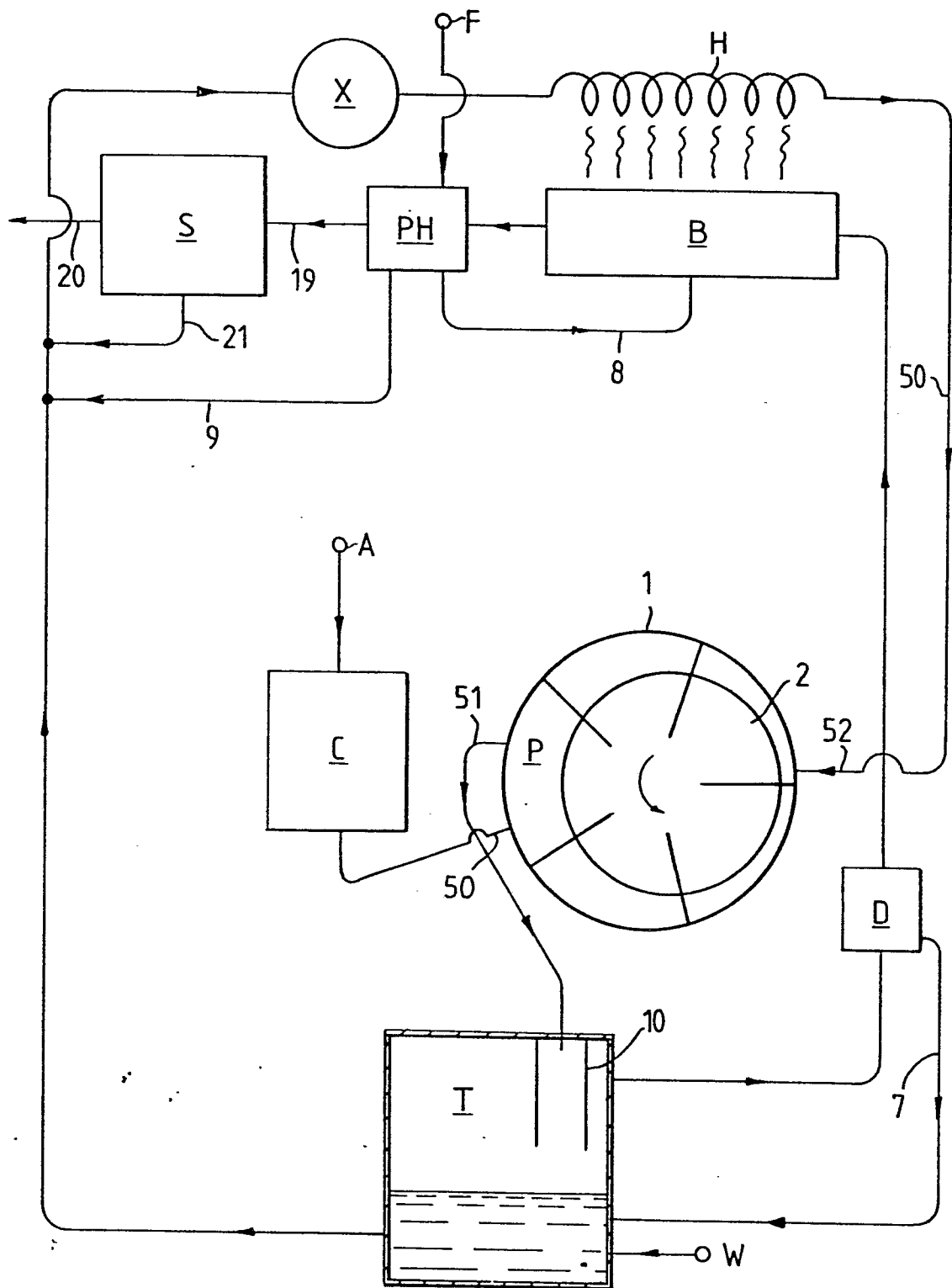


Fig. 1.

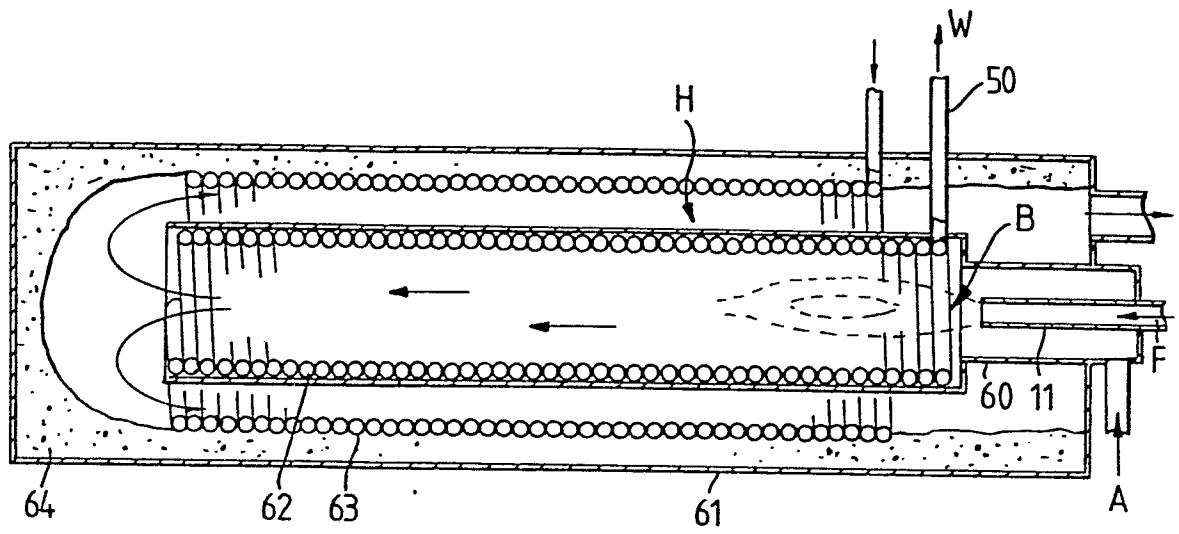


Fig. 2.

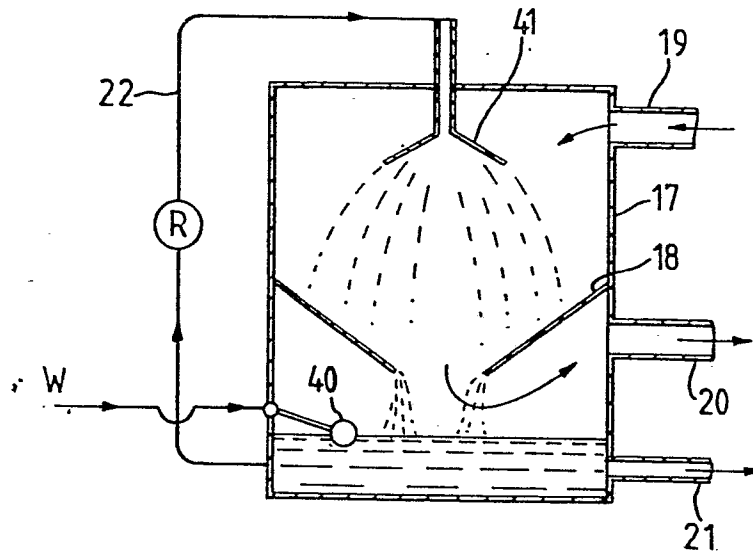
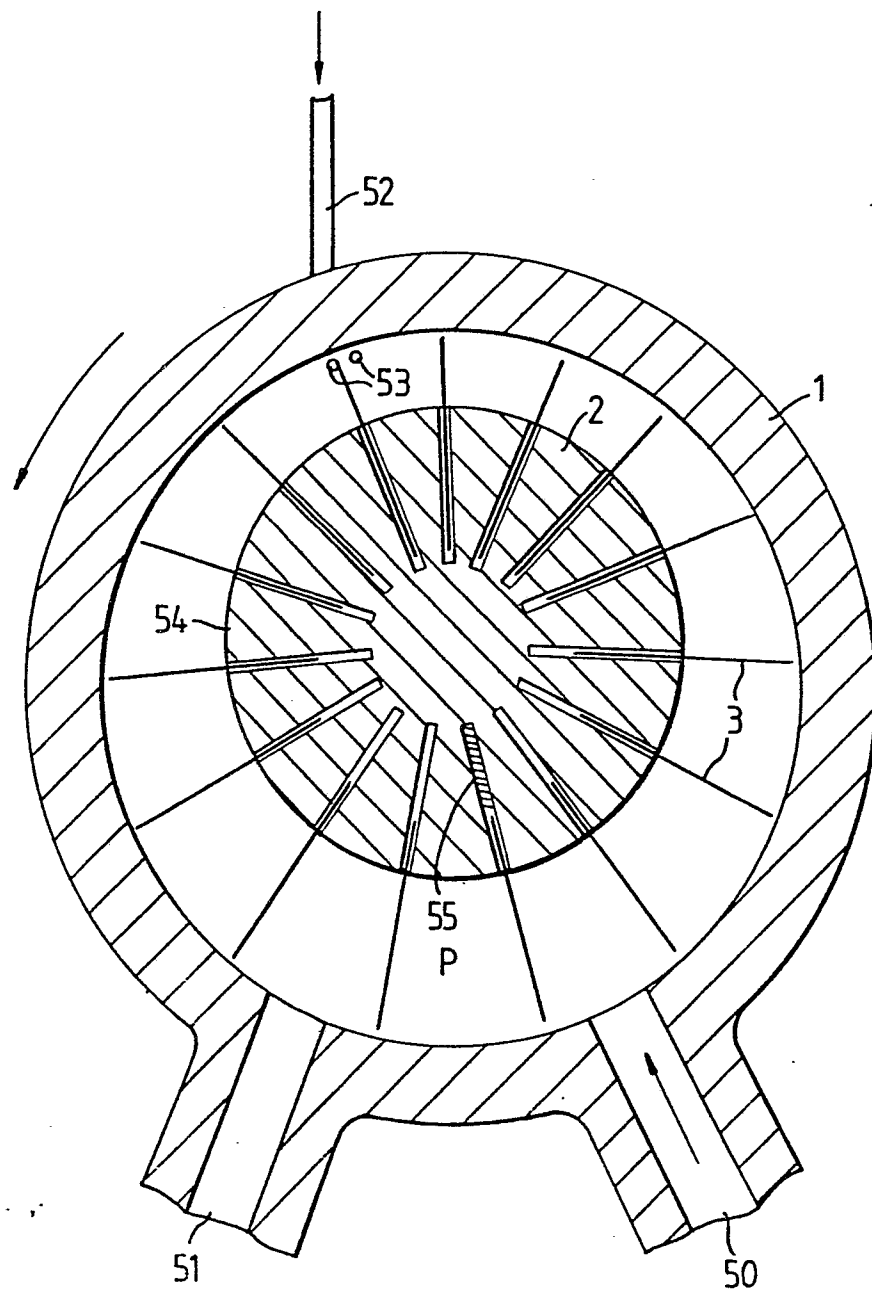


Fig. 3.

*Fig.4.*

4/4

Fig. 5.

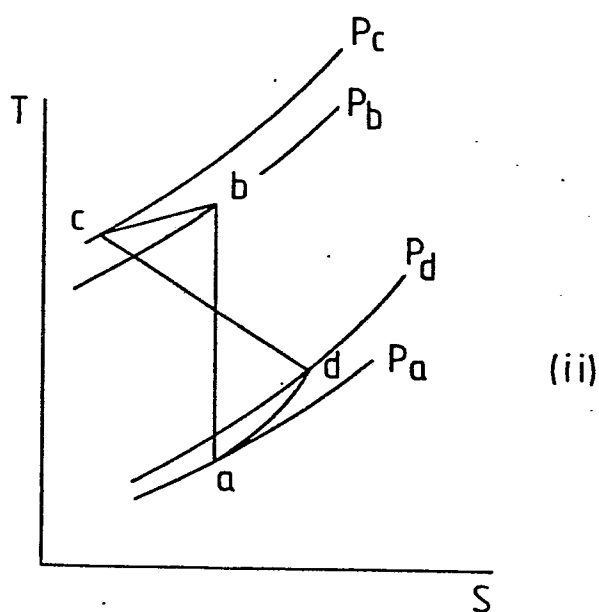
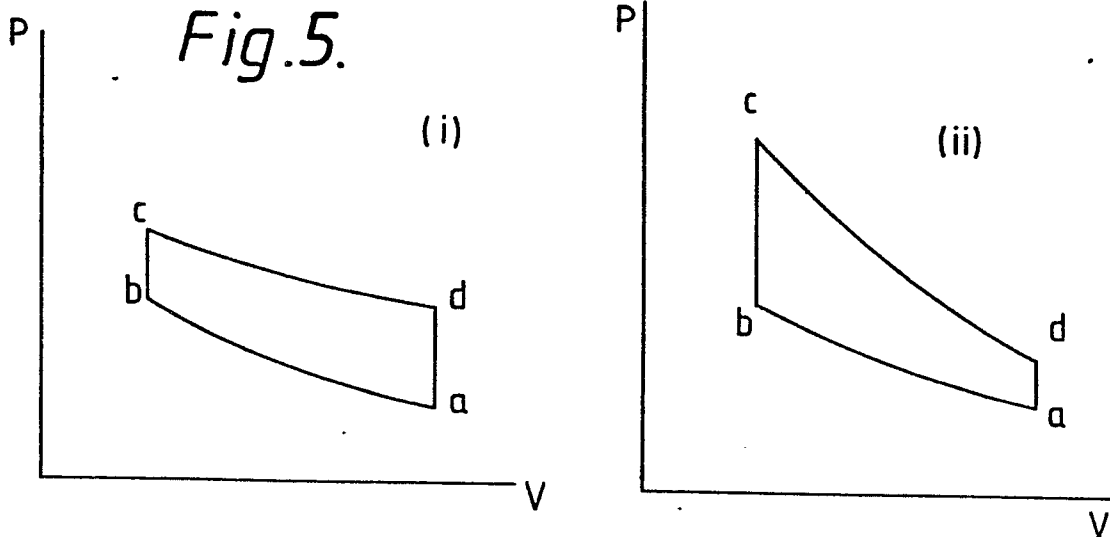
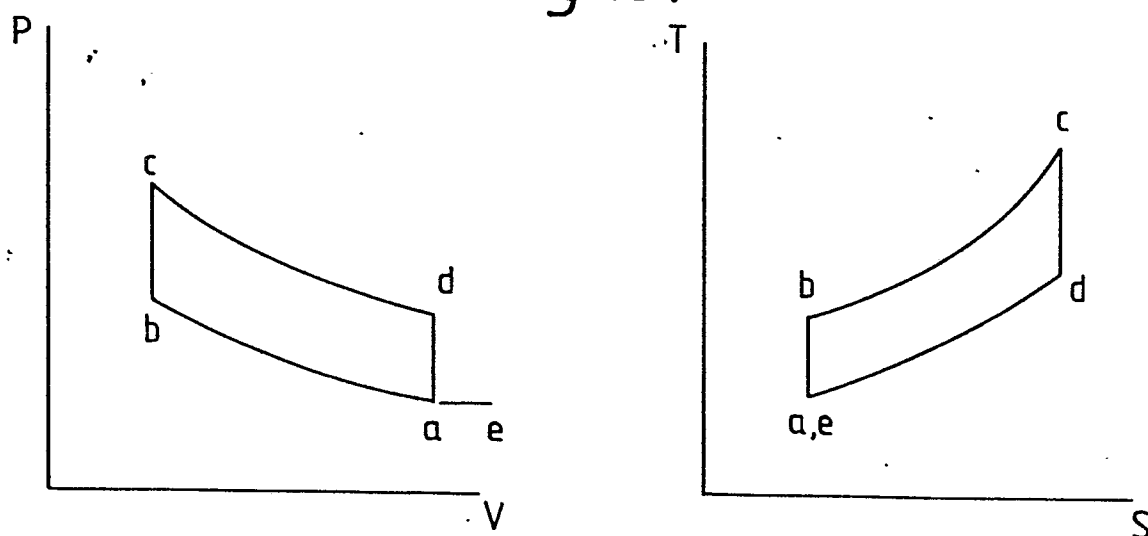


Fig. 6.





DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	<u>US - A - 3 806 286 (GRANBERG)</u> ☒ figure 2; column 2, lines 6-67 ☒ --	1,14,4	F 01 K 21/02 F 01 C 1/344
	<u>GB - A - 1 540 057 (DRIVER)</u> ☒ page 1, lines 1-78; page 3, lines 88-129 ☒ --	1,14,16	
	<u>US - A - 3 936 252 (MAHER)</u> ☒ figure 2; column 2, lines 1-62 ☒ --	1,14	TECHNICAL FIELDS SEARCHED (Int. Cl.) F 01 K F 01 C F 02 G
	<u>FR - A - 2 404 737 (UNISCREW)</u> ☒ page 2, line 2 to page 4, line 40 ☒ & US - A - 4 261 169 --	1,5,7,9,10,14,19	
A	<u>GB - A - 765 216 (BOLESTA)</u> ☒ page 1, lines 1-71 ☒ --	1	
	<u>US - A - 4 143 516 (LONG)</u> ☒ column 1, lines 28-55; column 3, line 1 to column 4, line 22 ☒ --	1,15,16,17,19	CATEGORY OF CITED DOCUMENTS X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
A	<u>US - A - 2 708 827 (LAMARCHE)</u> ./.	1	
☒ The present search report has been drawn up for all claims			&: member of the same patent family, corresponding document
Place of search The Hague		Date of completion of the search 23-09-1981	Examiner WASSENAAR



European Patent
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EUROPEAN SEARCH REPORT

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Application number
EP 80 30 4649
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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	≡ column 1, line 1 to column 3, line 15 ≡ -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl. ³)