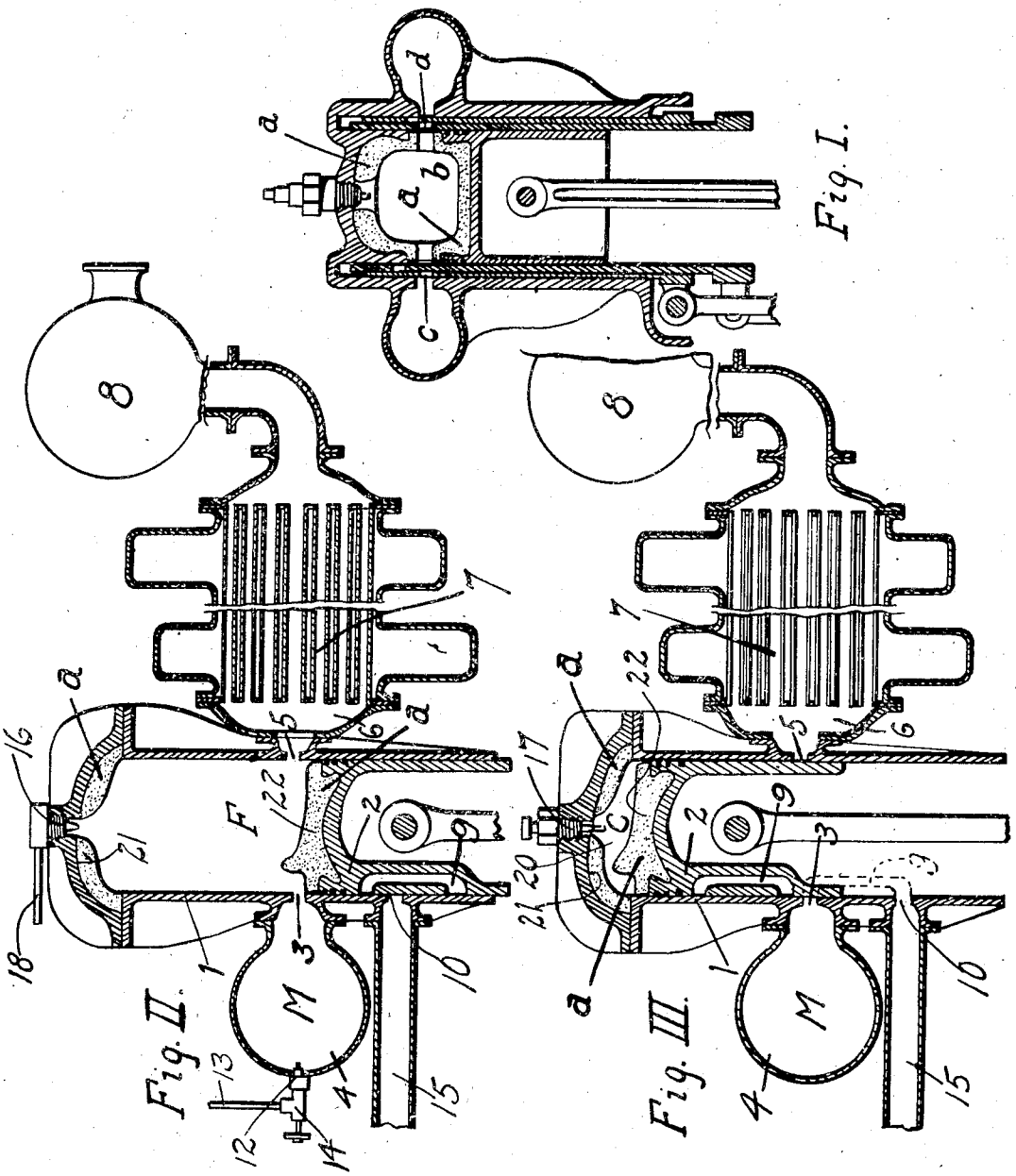
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INTERNAL COMBUSTION ENGINE

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INTERNAL-COMBUSTION ENGINE

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This invention relates to the improvements in internal combustion engines. It has particular reference to improvements in their thermal efficiency but also aims to increase their mechanical efficiency. It also aims to simplify their mechanical design and operation and to increase their possible power output.

As is well known to mechanical engineers, the thermal efficiency of the types of internal combustion engines now used is limited by two factors, first the heat lost in cooling the engine (either with water or air) and second the heat lost in the exhaust, nearly one half of the heat in the consumed fuel being lost by transmission through the cylinder walls to the cooling water or cooling air and approximately one fourth of the heat from the combustion of the fuel being carried away in the exhaust gases. The first of these losses is unavoidable in engines as present constructed on account of the necessity of keeping the engine cool enough to operate and the second is unavoidable on account of the limited possible expansion of the gases within the engine.

It is the object of my invention to greatly reduce both of these losses and to convert the heat thus saved into work. These objects of my invention are obtained first by preventing the escape of a large amount of heat through the walls inclosing the compression space, i. e. through the cylinder head and piston and cylinder wall in the compression space and second by securing a greatly increased expansion of the gases within the cylinder.

The greater part of the heat lost in cooling the present day engine is transmitted through the cylinder head and cylinder wall in the compression space and the piston, due, first to the fact that the gases at their maximum temperature and density are compressed into a relatively small space between the cylinder-head and piston (which form the greater part of the inner surface of the engine in contact with these gases at this time of greater compression and highest temperature and at a time when the rate of piston movement is least) and due, second to the necessity of efficiently cooling the inlet and exhaust valves located in the cylinder head. By my invention I largely eliminate this heat loss by insulating the inner surfaces of the cylinder-head and piston face within the cylinder. In order to do this most efficiently I prefer to eliminate the valves and operate the engine as a two stroke engine and use ports instead of valves, though the insulation may be applied to any two or a four stroke engine of the ordinary type, particularly if the valves are of the "sleeve" type such as in the Knight engine.

In order to convert the heat thus saved into work my preferred type of engine operates with a large ratio of expansion so that the temperature of the gases is greatly reduced before being exhausted and the gases are preferably not exhausted until a pressure approaching atmospheric is reached. These results are secured by admitting only a limited amount of air or fuel mixture to the cylinder to be compressed and burned so that a relatively great ratio of expansion may be secured. This may be done in the ordinary four stroke engine with an automatic cut-off inlet valve of any suitable type, but to secure the maximum power and simplicity my preferred type of engine operates as a two stroke engine exhausting under a suitable vacuum, i. e., at partial atmospheric pressure, and is automatically supplied with a measured amount of air or fuel mixture through a suitable port.

The methods of securing these results in the ordinary types of internal combustion engines and in my preferred type of engine are illustrated in the accompanying drawings wherein,

Figure I is a longitudinal section of a common type of four-stroke cycle sleeve valve engine showing insulation of the combustion space;

Figure II a longitudinal section of my preferred type of two-stroke cycle engine showing the piston at the end of the expansion stroke; and

Figure III a view similar to Figure II but showing the piston at the end of the compression stroke.

The application of internal heat insulation of the compression space to the ordinary 4 stroke engine using sleeve valves is illustrated

in Fig. I which shows a longitudinal section through the cylinder and piston. The heat insulating material (*a*) is attached to the inside of the cylinder-head and part of the cylinder wall and to the inside face or top of the piston within the cylinder in such a manner that at the moment of maximum compression, the compression space (*b*) is entirely enclosed by heat insulating material (*a*) as shown in Fig. I. Because of the insulation of the interior of the compression space in this manner heat can be converted into work. In the ordinary method of operating an internal combustion engine with an expansion ratio of one, only a small part of this saved heat can be converted into work, and the result of such insulation would be mainly to increase the temperature and pressure of the exhaust. For this reason such insulation of the interior of the compression space has never come into practical use. In order to convert into work as much as possible of the heat saved by this insulation the inlet valve (*c*) may be operated in such a manner that only a fraction of fuel mixture necessary to fill the cylinder to its full capacity is taken in on the inlet stroke, i. e. it is operated as an automatic cut-off valve so that any desired fraction of full cylinder capacity of the fuel-mixture (or air) is allowed to enter the cylinder, the amount, i. e. the fraction of the possible maximum, depending on the ratio of expansion it is desired to secure. This is preferably done by opening the valve only during the first part of the inlet stroke, though it may be done by opening the valve during any fractional part of the inlet or suction stroke or even by opening this valve at the beginning of the compression stroke, (providing of course that the valve be not opened at any other time as well and thus destroy the vacuum created in the cylinder).

The operation of the engine would then be as follows: Preferably during a fractional part of the inlet or suction stroke, (or possibly during the first part of the compression stroke) the inlet valve (*c*) is opened, allowing a fraction of the full cylinder capacity of fuel mixture (air and gas, gasoline, alcohol, etc.) to be drawn into the cylinder. This charge is compressed to the maximum allowable pressure during the compression stroke in the compression space (*b*) and ignited (or detonated) at the end of the compression stroke or beginning of the expansion stroke. The exploded mixture is then allowed to do work by expansion and cooling during the expansion or work stroke and is then expelled during the exhaust stroke, at a relatively low temperature and pressure through the exhaust valve (*d*).

The great increase in the thermal efficiency of the engine when operated in this manner will be apparent from the following: During the latter part of the compression stroke, which is the period of greatest density and highest temperature of the gaseous mixture previous to ignition and the time of slowest piston movement and therefore the time of maximum heat transmission to the cylinder and piston previous to ignition, the greater part of the interior of the enclosed space in the cylinder is insulated so as to prevent to a great degree the rapid flow of heat from the compressed gases through the walls of the compression space (the cylinder head and wall and piston) into the cooling medium. At the end of the compression stroke and beginning of the expansion stroke, after the ignition or detonation of the charge, which is the period of maximum density and highest temperature of the charge and also the time of slowest expansion and therefore the period of maximum heat transmission to the cylinder-head and piston and through them to the cooling medium, the greater part of the interior of the space enclosing the hot gases is insulated in such a manner as to prevent this rapid loss of heat through the cylinder-head and piston and cylinder wall in the compression space. The importance of the insulation of the interior of the compression space during this period at the end of compression and beginning of expansion will be apparent from the following: The heat transfer is proportional to at least the first power of the difference in temperature between the gas and the enclosing walls, and according to many investigators is proportional to the square of this temperature difference; the heat transfer is also proportional to the density of the hot fluid; this period of maximum temperature occurs at the time of slowest piston movement which limits the conversion of the heat into work and prevents a cooling of the hot gases by this conversion.

It will thus be apparent that this heat insulation of the interior of the compression space will prevent the loss of a very large amount of heat during the period which corresponds to the period of greatest heat loss in the ordinary uninsulated engine; and will also prevent a large heat loss during the expansion stroke, the amount of this latter saving over the ordinary uninsulated engine being proportional to the average ratio between the area of insulated cylinder wall and the uninsulated cylinder wall and the average temperature of the gases. (There would also be some slight return of heat from the insulating material to the expanding gases.) This heat saving in an insulated engine using ordinary limited expansion would slightly increase the thermal efficiency of the engine by increasing the average temperature (and therefore pressure) of the gases during expansion, and the application of this method of heat insulation to the ordinary four cycle engine would therefore not add considerably to its efficiency. To utilize the greater part

of the heat saved by this method of heat insulation, it is necessary to use an engine having a greater ratio of expansion than the ordinary type of engine of limited expansion, and should therefore preferably be used with an automatic cut-off intake valve, as described, in order to secure a large ratio of expansion so as to convert into work the heat saved by this insulation instead of discharging most of it in the hot high-pressure exhaust gases.

My preferred type of engine is therefore one having the heat insulating feature above described together with a larger ratio of expansion than is obtained in the ordinary limited expansion engine, as otherwise the heat retained in the gases by this insulation is largely lost in exhaust gases of higher than ordinary temperature and pressure. This larger ratio of expansion may be secured by the use of an automatic cut-off valve or other suitable device which admits only a fractional amount of the full cylinder capacity (at atmospheric pressure) of the gaseous medium to be compressed and detonated or burned. In the ordinary type of engine with automatic cut-off inlet valve the amount of gaseous mixture or gaseous medium admitted is easily regulated by the period of opening of the inlet valve which can be accurately controlled.

In order to most efficiently utilize the combination of internal heat insulation with large ratio of expansion, I prefer, however, to use an engine operating on the two stroke principle, or cycle, and thus do away with valves and substitute ports therefore, thus greatly simplifying the engine and approximately doubling its power capacity. In order to do this I do not use the ordinary type of scavenging and precompression now used in ordinary two-stroke engines, but I utilize an entirely different principle or cycle which is much more simple and efficient and which allows the use of a large ratio of expansion which it is impossible to secure with the ordinary two stroke engine without automatic cut-off, and which large expansion ratio is necessary to secure the maximum efficiency of my invention. My method or principle of operation consists in exhausting the gases at the end of the expansion or power stroke under a vacuum (of any desired proportion of complete vacuum) and immediately thereafter admitting a definite measured amount of gaseous fuel mixture (or air) to the cylinder to be compressed and burned or detonated. In order to reduce to a minimum the power used in evacuating the exhaust gases after expansion, these gases are preferably passed through a cooler (radiator or heat inter-changer) to reduce their volume to the minimum before being drawn through the vacuum device. It will be apparent from the foregoing that my method or principle of two stroke operation is entirely different to the ordinary two stroke cycle now used.

The manner of construction and the method of operation of my preferred type of engine is described in the following: Figs. II and III show longitudinal sections through the engine in which the various parts are indicated by the following notations: the cylinder, (1); the piston, (2); heat insulating material, (*a*); inlet port, (3); measuring chamber (4); exhaust port (5); exhaust gas passage (6); exhaust gas cooler (7); vacuum pump (or other vacuum producing device) (8); transfer port (9); measuring chamber inlet port (10); gasoline jets (12); gasoline pipes (13); gasoline regulating valve (14); pipe from carburetor to measuring chamber inlet valve (15); fuel oil inlet spray (16). Fig. II shows the piston near the end of the expansion stroke and Fig. III shows the piston at the end of the compression stroke.

The method of operation is as follows: As will be noted in Figs. II and III, the exhaust port (5) is so placed that at the end of the expansion stroke this port (5) is uncovered by the piston (2) just before the main inlet port (3) is uncovered. As soon as the exhaust port (5) is uncovered the exhaust gases are drawn out through the exhaust passage (6), and through the cooler (7) and are discharged through the vacuum pump (8). The degree of vacuum, i. e., the partial atmospheric pressure, which is desired in the cylinder at exhaust, is maintained by the vacuum pump (8). Immediately following this exhausting operation the main inlet port (3) is uncovered by the movement of the piston (2) and the air or fuel mixture enclosed in the measuring chamber at atmospheric pressure expands through the main inlet port (3) filling the cylinder (1) and driving the residual burned exhaust gases out through the exhaust port (5). The cylinder (1) is thus filled to its full capacity (F) with the air-fuel mixture (or air alone) at the partial atmospheric pressure maintained by the vacuum pump (8). At the beginning of the compression stroke the main inlet port (3) is first cut off (or closed) by the movement of the piston (2), and immediately thereafter the exhaust port (5) is cut off (or closed) leaving the measuring chamber (4) filled with air-fuel mixture (or air alone) at the partial atmospheric pressure maintained by the vacuum pump (8). As the compression stroke progresses the fuel mixture (or air) enclosed in the cylinder is compressed, and the transfer port (9) in the piston (2) covers the measuring-chamber inlet port (10) and the inlet port (3) which allows the measuring chamber to fill with the air-fuel mixture (or air) which flows in through the inlet port (10) through the transfer port (9) and through the inlet valve (3) into the measuring chamber (4) until this chamber is filled with the

air-fuel mixture (or air alone) at atmospheric pressure. The movement of the piston (2) continues to the end of the compression stroke compressing the fuel mixture (or air) to the desired compression in the compression space (C). The fuel mixture is then exploded and the expansion stroke takes place expanding the hot gases to the full cylinder capacity (F) at the moment that the exhaust port (5) is uncovered. As described before, as soon as the exhaust port (5) is uncovered the exhaust gases are drawn out through the cooler (7) and discharged by the vacuum pump (8) which is arranged to maintain a partial pressure (P) of any desired fraction of the atmospheric pressure, i. e., to maintain any desired vacuum. As the piston (2) continues to the end of its stroke the inlet port (3) is uncovered and the air-fuel mixture (or air) in the measuring chamber (4) expands into the cylinder (F) driving out the residual burned exhaust gases and filling the cylinder with the fuel-air mixture (or air) at the partial pressure maintained by the vacuum pump (8) as previously described. The measuring chamber (4) has no opening into it except the port (3) so that it acts as a definite measuring device as noted, first filling with air-fuel mixture (or air) at atmospheric pressure when the transfer port (9) covers both the ports (3) and (10), and then allowing this measured quantity of air-fuel mixture (or air) to expand into the evacuated cylinder when the port (3) is uncovered by the piston (2) at the end of the expansion stroke.

For correct operation of the engine using a carburetted mixture the engine should be designed so that no fuel mixture is drawn into the exhaust but the amount of mixture should just fill the cylinder (F) and drive out the residual gas left at the end of the exhaust stroke and beginning of compression stroke. In order that this be the case there must be a definite proportion between the different parts of the engine depending on the ratio of expansion used, which in turn depends on the partial atmospheric pressure or vacuum under which the engine operates. These considerations also enter into the calculation of the compression space (C).

The theory of the design of the engine is as follows:

Let P = partial atmospheric pressure maintained by the vacuum device (8).

Let M = volume of the measuring chamber (4).

F = volume of full cylinder capacity—i. e. volume of maximum space in cylinder (1) at beginning of exhaust.

C = volume of compression space.

R = ratio of compression, i. e. volume of air—fuel mixture (or air) at atmospheric pressure divided by its volume at maximum compression.

E = ratio of expansion, i. e. the ratio of full cylinder volume F to the volume of gases admitted reduced to atmospheric pressure, i. e. ratio of expansion as compared with the expansion secured in ordinary non-cut-off engines which have an expansion ratio of 1, i. e. in which the volume of gases at end of inlet stroke = volume of gases at end of expansion stroke.

Then it is readily seen that if the air or fuel-mixture in the measuring chamber (4) is to expand to just fill the full cylinder, which is the case for correct and ideal operation, the following must be true:

$$P=\frac{M}{F+M} \quad \text{----------(1)}$$

$$E=\frac{1}{P} \quad \text{----------(2)}$$

and substituting in the above

$$E=\frac{F+M}{M} \quad \text{----------(3)}$$

It is also seen that the fraction or proportion of air or fuel-mixture in the measuring-chamber (4) which is transferred to the cylinder (1) under these conditions is equal to $\frac{F}{F+M}$. If all of the air or fuel mixture in the measuring chamber (4) was transferred to the cylinder (1) during each cycle the compression space C would be equal to $\frac{M}{R}$ but since only a fraction of M equal to $\frac{F}{F+M}$ is actually transferred, then C is smaller in just this proportion and

$$C=\frac{M\times F}{R(F+M)} \quad \text{----------(4)}$$

From these equations the general proportions of the engine may be calculated, as shown below. Assume $E=3$, i. e. an expansion three times as great as that secured in the ordinary non-cut-off engines, is desired, and also assume that a ratio of compression (compared with atmospheric pressure) of 4 is to be used, i. e. $R=4$.

Substituting in Equation (3) above,

$$F=2M \quad \text{----------(5)}$$

Substituting in Equation (4) above,

$$C=\tfrac{1}{6}M \quad \text{----------(6)}$$

and from (5) and (6)

$$C=\tfrac{1}{12}F \quad \text{----------(7)}$$

From the foregoing it will be seen that the engine may readily be designed for any combination of any desired compression and expansion. The equations given above are however only illustrative of the theory of the engine and in practice would be empirically modified to suit the operating conditions,

which would be slightly different to the simple theoretical conditions assumed above, due to the temperature and volume changes caused by the heating and expansion of the gases by friction and heat from the cylinder walls, etc. The foregoing equations do however illustrate clearly the theory of the operation of my engine.

If the engine is to be operated by the injection of the fuel into the compressed air at the end of the compression stroke and beginning of or during the first part of the expansion stroke, so that the engine operates under an approximately complete or extended expansion two stroke Diesel (i. e. Brayton) cycle, the measuring chamber may be made slightly larger than indicated by the above calculations as the excess air would merely be drawn through the cylinder giving a better scavenging or removal of the burned waste gases (and there would be no loss of fuel as would be the case if a fuel mixture was used). As this would throw a larger burden on the vacuum pump (8) and would therefore require a larger pump (8) and more power, the size of the measuring chamber (4) should therefore not be made much larger than indicated by the foregoing calculations. If M is made larger than the calculated size, the calculations for the other parts of the engine should still be made with the assumption that M is of the size indicated to just fill the cylinder i. e. the correct calculated size. It should also be noted that it is possible to use a piston-head in said measuring chamber so arranged that the volume of the measuring chamber may easily be changed to suit any desired condition of operation. For example to reduce the compression in starting an engine using high compression, as in the increased expansion Diesel cycle just described, the volume of the measuring chamber could be temporarily made small so that the engine could be started under low compression. Other examples might be cited, for example a considerable change in altitude would cause a change in the compression pressure which could be remedied by changing the volume of the measuring chamber. It might also be desirable to change the volume of gas admitted to some engines under different conditions of operation (such as in the case of automobile engines) which might be done very readily by means of the piston arrangement described.

From the foregoing it will be seen that by insulating (i. e. covering with poor heat conducting material) the inside of the walls inclosing the compression space and at the same time using an increased expansion ratio (i. e. a ratio of expansion larger than 1) the heat saved by the insulation may be very largely converted into work and the thermal efficiency of the internal combustion engine may be greatly increased. This may be accomplished in the four-stroke cycle engines by the use of an automatic cut-off inlet valve to cut down the amount of fuel mixture or air taken into the cylinder so as to secure an increased ratio of expansion as previously described. This may also be accomplished in an ordinary type of the two-stroke cycle engine by using automatic inlet and exhaust valves instead of ports and operating the engine as follows: The detonated mixture is allowed to expand to the full capacity of the cylinder i. e. to the end of the expansion stroke at which point the exhaust valve opens allowing the pressure to come to atmospheric in the cylinder. During the first part of the return stroke of the piston (normally the compression stroke) the inlet valve is not opened but the exhaust port remains open allowing some of the residual burned gases to be driven out. At any desired point in this return stroke the inlet valve is opened allowing the slightly compressed fuel-air mixture to flow into the cylinder and drive out (or displace) the residual waste gases. As soon as the required amount of fuel air mixture has been admitted the exhaust valve and the inlet valve are closed and the fuel mixture is compressed to the end of the stroke, after which it is detonated and allowed to expand as before described. In both of these cases the compression space should be proportioned according to the amount of fuel mixture admitted in order to secure the desired compression before ignition.

From the foregoing it will be apparent that by using internal heat insulation in combination with a greatly increased expansion ratio the efficiency of the Diesel cycle may be largely increased. This may be accomplished by using an automatic cut-off inlet valve so as to cut down the amount of air admitted to the cylinder (and also properly proportioning the compression space) and in this way secure an increased ratio of expansion and thereby convert the greater part of the heat saved by the heat-insulation, into work.

It would also be possible to use the heat-insulation of the interior of the compression space in combination with an increased expansion two stroke Diesel cycle which might be secured by the use of automatic cut-off inlet and outlet valves operated as described above in connection with the two-stroke increased expansion Otto cycle.

My preferred type of engine, i. e. engine using the vacuum-exhaust increased-expansion cycle described above, is especially applicable for use in carrying out an increased expansion two-stroke cycle of the Diesel type (i. e. a two-stroke increased expansion cycle in which the air is first compressed and the fuel thereafter injected into it and burned during the first part of the expansion stroke) as this engine secures the automatic cut-off

and increased expansion without the use of any valves and can therefore be heat-insulated most efficiently and without mechanical difficulty and can operate under high pressures without any trouble from valves. The use of ports instead of valves also makes possible a much stronger and more compact construction. In this cycle air only is admitted to the measuring chamber (4) and expanding through the inlet port (3) when this port is uncovered by the piston (2) at the end of the expansion stroke, drives out the residual waste gases through the exhaust port (5). This air is then compressed to the desired relatively high pressure on the return or compression stroke. During this stroke the transfer port (9) covers the ports (3) and (10) allowing the measuring chamber to fill again with air at atmospheric pressure as previously described. At the end of the compression stroke and during the first part of the expansion stroke the fuel is injected into the hot compressed air through the oil-inlet spray (16) and burns with the air. The expansion or power stroke continues until the movement of the piston uncovers the exhaust port (5) when the expanded gases are drawn out through this port and through the exhaust passage (6), through the exhaust cooler (7) and discharged through the vacuum pump (8). At the end of this stroke the inlet port (3) is uncovered allowing the air in the measuring chamber to flow in and fill the cylinder (1) displacing the residual burned gases, as previously described.

It will be apparent from the foregoing that my preferred type of increased expansion vacuum-exhaust two-stroke cycle engine using either the carburetted mixture, as in the Otto cycle, or fuel injection into the highly compressed air, as in the Diesel or Brayton cycle, described in the foregoing, may be operated without any heat-insulating material being applied to the inside of the compression space (C), i. e. may be used in the ordinary non-insulated form, and that in this form my invention has many advantages over the ordinary two-stroke or four stroke engines of either the Otto or Diesel type. The thermal efficiency is much greater than in these engines, which use a limited expansion ratio of one, owing to the greatly increased expansion (E) possible with my engine. This increased expansion (E) is secured with simple ports and without the use of complicated automatic cut off valves and the use of ports instead of valves greatly simplifies the design of the engine and makes possible the use of higher compression pressures and greatly increases the ease and simplicity of operation, and greatly diminishes the wear and tear and cost of up-keep. The use of the cycle described is made possible by the operation of the engine under an exhaust pressure less than atmospheric (P) which is secured by applying a vacuum to the exhaust by means of any suitably vacuum engine (8) such as a piston pump, rotary vacuum pump, or turbine vacuum pump any of which may be used, the type used in any particular case depending on the size of the engine and the use to which it is put. In order to cut down the power used in thus withdrawing the exhaust at less than atmospheric pressure, the gases should be cooled to as low a temperature as possible before passing through the vacuum device (8). This is done by passing them through a suitable closed heat transfer device, radiator, or counter-current heat interchanger (7) in which the exhaust gases are cooled by means of cold air or water or any suitable cooling fluid, in the ordinary way. If the exhaust gases are thus reduced to atmospheric temperature the volume of gas passing through the vacuum pump (8) is reduced so that theoretically no power is taken up by this operation (except the friction of the pump) since the power thus used is returned in the first part of the compression stroke of the engine up to the point where the gases in the cylinder reach atmospheric pressure. This will be apparent from the foregoing description of the operation of the engine.

The thermal efficiency of my preferred vacuum-exhaust type of engine is very greatly increased by the application thereto of heat insulation of the inside of the compression space, i. e. the inside of the cylinder head (21) and piston-top or face (22) and (in most cases) the cylinder wall in the compression space (20). My preferred form of engine is particularly well adapted to this heat insulation since the cylinder-head and the cylinder wall in the compression space have no valves or valve-openings therein, the ports through which the working fluid are passed in and out of the engine being in the non-insulated and relatively cold portion of the cylinder and piston. Due to the heat insulation and large expansion my engine will run comparatively cold and will require little or no jacket cooling.

The mechanical operation of my engine is similar in a general way to the method of operation of ordinary forms of present-day internal combustion engines, though it admits of a much greater variety and flexibility in the design and operation. This will be apparent from the foregoing. Some of the minor differences are mentioned in the following: If the engine uses the ordinary air-fuel mixture from a carbureter this is admitted to the measuring chamber through the inlet pipe (15) which runs from the carburetor (not shown) to the measuring chamber inlet valve (10). A suitable valve may be placed in the line (15) in order to regulate the flow of carburetor air-fuel mixture and to close the line entirely which may at times

be necessary to bring the vacuum in the engine up to the required point when starting. If desired the gasoline (or other fuel) may be passed into the measuring chamber (4) through suitably placed fuel conveying pipes (13) and jets (12) and mixed with the air in the measuring chamber (4). The flow of gasoline (or other fuel) to the measuring chamber (4) may be secured by the action of the vacuum or by forced feed, the amount being preferably regulated by a suitable pump or other feeding device (not shown) or by an automatic regulating valve (14) in the fuel supply pipe (13). If the engine is operated by compressing the air and injecting the fuel into the hot compressed air during the first part of the power, stroke (i. e. using an increased-expansion two-stroke Diesel, i. e. Brayton, cycle) the fuel is injected into the compression space (C) through the fuel supply pipe (18) and jet or spray device (16). This liquid fuel may be forced into the cylinder through the spray (16) alone or mixed with a small amount of air by any suitable pumping device or by means of compressed air. The spark plug (or plugs) (17) for detonating or igniting the air-fuel mixture may be placed in any desired position entering the compression space (C). With ordinary carbureted mixtures it would preferably be placed in the middle of the cylinder head (in the place occupied by the fuel spray (16) in the drawing) and in the case of fuel injection into the compressed mixture would be placed near the angle where the cylinder head and cylinder wall meet (not shown). All the pipes, valves, jets, sprays, spark plugs, etc., are shown dotted in Figs. II and III as their particular arrangement or use may be varied without in any way changing the nature of the invention or the principle of its operation. The fuels mainly mentioned have been liquid hydro-carbons but the engine may use any form of liquid or gaseous fuel.

Though my invention secures a great increase in thermal efficiency, as compared with internal combustion engines now used when using ordinary air to burn the fuel, the utility and efficiency of my invention is greatly increased when air enriched in oxygen (or pure oxygen) is used to burn the fuel instead of ordinary air. Though enriched air (or oxygen) is not used commercially at the present time for this purpose due to the relatively high cost of production of oxygen, it is probable that in the near future it will be used, as the cost of separating the oxygen from the nitrogen of the air will probably be greatly reduced in the near future. The use of enriched air (or oxygen) will greatly increase the thermal capacity and efficiency of internal combustion engines, but its use will require an engine able to resist the higher temperatures and pressures thus secured and an engine which will also be able to efficiently convert the greatly increased amount of heat supplied to the engine into work. Both of these requirements are met by my engine, as the excessive loss of heat is prevented by the insulation of the interior of the compression space and the heat is very efficiently converted into work due to the very large ratio of expansion which is made possible with my engine.

From the foregoing it will be apparent that, due to the very wide scope of my invention, the description given above is necessarily somewhat general and that the drawings are necessarily diagrammatic and for this reason I do not desire to be limited entirely by the description and drawings given except as interpreted in the claims given below.

No claim is made herein to the subject matter required to be divided out of this case by the United States Patent Office, such subject matter now appearing in my divisional applications Serial Numbers 413,367 and 413,368, filed December 11th, 1929.

Having described my invention what I claim as new and desire to patent is:

1. In internal combustion engines the combination of a heat-insulating lining of the compression space together with means for expanding the burned gases to a volume substantially greater than the volume of the gases supplied, measured at atmospheric pressure, substantially as described.

2. In two-stroke cycle internal combustion engines the combination of a heat-insulating lining of the compression space together with means for expanding the gases of combustion to a volume substantially greater than the volume of the gases supplied. measured at atmospheric pressure, substantially as described.

3. In internal combustion engines the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the gaseous portion of the fuel mixture in each cycle to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, and means for compressing said gas previous to combustion to pressures in common use for said fuel mixture, substantially as described.

4. In two-stroke cycle internal combustion engines the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the gaseous portion of the fuel mixture in each cycle to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, and means for compressing said gas previous to combustion to pressures in common use for said fuel mixture, substantially as described.

5. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston with a closed gas-measuring chamber,

an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, a supply port through the wall of the cylinder, and a transfer passage in the skirt of the piston communicating simultaneously with said inlet port and said supply port during the compression stroke and expansion stroke after the covering of said exhaust and inlet ports by the piston.

6. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston which have the surfaces which enclose the compression space lined with material of low heat conductivity, with a closed gas-measuring chamber, an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, and a supply port through the wall of said cylinder, a transfer passage in the skirt of said piston communilating simultaneously with said supply port and said inlet port during the compression stroke and expansion stroke while said exhaust and inlet ports are covered by the piston.

7. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston with a closed gas-measuring chamber, an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, a supply port through the wall of the cylinder, and a transfer passage in the skirt of the piston communicating simultaneously with said inlet port and said supply port during the compression stroke and expansion stroke after the covering of said exhaust and inlet ports by the piston; the volumes of the measuring chamber, full cylinder space and compression space being proportioned to each other and to the vacuum applied through said exhaust port, substantially as described.

8. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston which have the surfaces which enclose the compression space lined with material of low heat conductivity, with a closed gas-measuring chamber, an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, and a supply port through the wall of said cylinder, a transfer passage in the skirt of said piston communicating simultaneously with said supply port and said inlet port during the compression stroke and expansion stroke while said exhaust and inlet ports are covered by the piston, the volumes of the measuring chamber, full cylinder space and compression space being proportioned to each other and to the vacuum applied through said exhaust port, substantially as described.

9. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston with a closed gas-measuring chamber, an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, a supply port through the wall of the cylinder, and a transfer passage in the skirt of the piston communicating simultaneously with said inlet port and said supply port during the compression stroke and expansion stroke after the covering of said exhaust and inlet ports by the piston, the volumes of the measuring chamber, full cylinder space and compression space being proportioned to each other and to the vacuum applied through said exhaust port, said combination of parts being arranged to operate substantially as described.

10. In a two-stroke cycle internal combustion engine the combination of a cylinder and piston which have the surfaces which enclose the compression space lined with material of low heat conductivity, with a closed gas-measuring chamber, an inlet port through the cylinder wall connecting with said measuring chamber, an exhaust port through the cylinder wall, an exhaust channel connecting said exhaust port with means for applying a vacuum thereto, said inlet port and said exhaust port being uncovered by the piston only at the end of the expansion stroke and beginning of the compression stroke, and a supply port through the wall of said cylinder, a transfer passage in the skirt of said piston communicating simultaneously with said supply port and said inlet port during the compression stroke and expansion stroke while said exhaust and inlet ports are covered by the piston, the vol-

umes of the measuring chamber, full cylinder space and compression space being proportioned to each other and to the vacuum applied through said exhaust port, said combination of parts being arranged to operate substantially as described.

11. In internal combustion engines in which the fuel is injected into the combustion gas after compression of the latter to a high pressure, the combination of a heat-insulating lining of the compression space together with means for expanding the burned gases to a volume substantially greater than the volume supplied, measured at atmospheric pressure, substantially as described.

12. In two-stroke cycle internal combustion engines in which the fuel is injected into the combustion gas after high compression of the latter, the combination of a heat-insulating lining of the compression space together with means for expanding the gases of combustion to a volume substantially greater than the volume of the gases supplied, measured at atmospheric pressure, substantially as described.

13. In internal combustion engines in which the fuel is injected into the combustion gas after high compression of the latter, the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the combustion gas in each cycle to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, and means for compressing said combustion gas to a high pressure previous to injection of the fuel, substantially as described.

14. In two-stroke cycle internal combustion engines in which the fuel is injected into the combustion gas after high compression of the latter, the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the combustion gas to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, and means for compressing said combustion gas to a high pressure previous to the injection of said fuel, and means for expanding the gases of combustion to a volume substantially greater than the volume supplied measured at atmospheric pressure, substantially as described.

15. In internal combustion engines the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the gaseous portion of the fuel mixture in each cycle to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, means for compressing said gaseous mixture previous to combustion to pressures in common use for said fuel mixture, and means for expanding the gases of combustion to a volume substantially greater than the volume supplied, measured at atmospheric pressure, substantially as described.

16. In two-stroke cycle internal combustion engines the combination of a heat-insulating lining of the compression space together with means for limiting the supply of the gaseous portion of the fuel mixture in each cycle to a regulated fraction, substantially less than one, of a full cylinder, measured at atmospheric pressure, means for compressing said gaseous mixture previous to combustion to pressures in common use for said fuel mixture and means for expanding the gases of combustion to a volume substantially greater than the volume of the gases supplied, measured at atmospheric pressure, substantially as described.

17. In two-stroke cycle internal combustion engines in which the fuel is injected into the combustion gas after compression of the latter the combination of a heat-insulating lining of the compression space together with means for limiting the gaseous portion of the fuel mixture to a regulated fraction, substantially less than one, of a full cylinder measured at atmospheric pressure, means for compressing said combustion gas to a high pressure previous to the injection of said fuel, and means for expanding the gases of combustion to a volume substantially greater than the volume of the gases supplied, measured at atmospheric pressure, substantially as described.

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