E-FILED
Wednesday, 21 December, 2005 01:01:24 PM
Clerk, U.S. District Court, ILCD

Caterpillar Inc. v. Entec Engine Corporation and Clyde C. Bryant

CATERPILLAR INC.'S COMPLAINT FOR DECLARATORY RELIEF

EXHIBIT "B"
Part III

Operation of 4-Stroke New Cycle Air-Cooled Engine

The operation of the engine is the same as any of Operational Designs 1 through Design 6, as first described for the basic engine of FIG. **2** and which also pertains to engine of FIG. **1** through **7** for greater torque, power, and durability with low fuel consumption and ultra low polluting emissions.

Alternatively and preferably, the operation of the engine of FIG. **5** is the same as the operation of the engine of FIG. **2**, FIG. **2**-C, FIG. **3** and FIG. **4** with optionally chilled air for primary charge through valve **16**-B with the supplementary, secondary air charge being introduced through valve **16**-A as a very dense cool charge.

Cooler Working Cycle

In Operational Design 1 through Design 6, described for engine of FIG. **2**, the low, or near 2:1 or less compression ratios (the latter being in Design 4) greatly reduces the amount of heat-of-compression in mode 1, which is Design 4 can be near zero.

In mode 2 operation, the injection of cooled, compressed, supplementary supercharging air, which preferably is during the compression stroke, cools the air charge in all six Operational Designs by the heat exchange effect and by the absorption effect of expanding air, as is true of all compressed gases when expanded. In all modes, 1, 2 and steady-state mode 3 for Designs 2 through 6, the primary portion of air charge is heated less as the compression ratio or the "effective" compression ratio is reduced. The density of the air or air-fuel charge is adjusted selectively from less than normal, to normal or to above normal in all Operational Designs by the injection of the supplementary, secondary air charge. For mode 2 and 3, the later the supplementary air charge is injected in the compression stroke in Designs 1 through 3 and 5 and 6, the smaller will be the "effective" compression ratio for that second portion of air, for again, low heat-of-compression and in Design 4, the compression ratio is near 2:1 for little or no heat of compression. Because of the overall cooler-working cycle, the engine can be operated with air-cooling or "compression" air chill-cooling at such a time the liquid cooling system should be damaged.

Auxiliary Cooled Operation

At such a time that the liquid cooling system should be compromised, operation of the engine would continue in the same manner with a few additional steps. This would allow the vehicle to continue to perform in battle and to return home. This cooling system can be also used on any Otto or Diesel Cycle engine.

Pressurized air flow to cylinder head inlet **4** is begun by opening a valve to dedicated compressor and cooler system or by increasing compressor **2** speed in FIGS. **1**, **2**, and **2**-C, where a valved branch (not shown) of high pressure conduit B in FIG. **5** would deliver adequate compressed air to port **4** or alternatively to a metering or expansion valve **4'**, opening to inlet port **4**, and perhaps by cutting in another stage of compression or another compressor.

Valves from an air conduit, from C and B on conduits **113** and **114** from coolers **11** and **12**, all in FIG. **2**-C, to expansion valve **4'**, opening to inlet **4** of engine of FIG. **5** optionally is opened and compressed air or expanding compressed air chills as it expands internally by the expansion valve **4'** from inlet port **4** to air-rail **5**. This allows the air to be conducted as it expands and distributes to and through cooling "evaporator" channels **6** of FIG. **5**, which are finned **6'** in FIG. **6** and situated on the outer side of the cylinder sleeve **12** between the cylinder sleeve **12** and the cylinder block **12'** as shown in FIG. **6**. The expanding compressed air then is ducted into air rail **7** which collects the air from all channels, and directs it to an air conduit **8** which conducts the air to the atmosphere or to exhaust manifold **9** and to the atmosphere. Part of the expanding air can be sent first through channels around the exhaust valve seat and through other problem areas of the engine. If the air cooling channels suggested for cooling the cylinder liners cool too much, other areas of the engine more appropriate for air cooling channels may be chosen, as one alternate cooling route is depicted by **6** in FIG. **7** and FIG. **10**.

While the engine is operating liquid cooled, all of the high-pressure air goes to high pressure conduit B with conduit A being alternatively being fitted with expansion valve **10'**, going to intake valve **16**-B during intake stroke, as in FIG. **2**-C. While operating in mode 2 or 3 with compressed secondary supercharging air, injected preferably with pressure adjusted in conduit B, goes directly into the power cylinders through inlet valve **16**-A during the compression stroke, even as late as during combustion.

When the liquid cooling system fails, a valve is turned on conduits F and G (not shown) which diverges from conduits **113** and **114** or from conduits **113'** and **114'** of FIG. **2**-C or any other compressed air source, which supplies highly compressed air, which is cooled or chilled. This air is pumped by a conduit branch (not shown) from conduits **113'** and **114'** or **113** and 114 and preferably into metering or expansion valve **4'** at inlet 4 of engine head. Now incoming air, which has been cooled and increased in pressure and density, passes through expansion valve **4'** alternatively, which can have a variable size opening, which can be controlled by the ECM-**27**, at inlet **4**, to air rail **5**, conduits **6**, air rail **7**, air conduit **8** and exhaust manifold **9** and to the atmosphere or the air can go from conduit **8** directly to the atmosphere. The engine head and block are then cooled by the compressed air or alternatively by the chilling effect of the absorption of heat by the expanding air, as it does work in expanding through valve **4'** or valve **10'**, pressure-drop-distributor **11** and distributor tubes **17***a* and **27***a*, as in FIG. **2**-C. Alternatively, the engine is further cooled by the primary air charge injection through expansion valves **10'** upline to inlet valves **16**-B, as described for FIG. **2**-C and FIG. **4**, which provide chill cooling, and in the engines of FIG. **3**, FIG. **4**, FIG. **7** and FIG. **10**, optionally having chilled air being injected through cylinder walls, as described for these engines, operating under description for FIG. **2**, FIG. **2**-C, FIG. **3**. and FIG. **4**. As more power is needed, the density of charge can be increased by increasing the pressure on the non-expanded charge from conduits **113"** and **114"** to high pressure inlet valve **16**-A. These lines **113'** and **114'** are alternatively fitted with pressure regulators D and E.

The engine can also be fitted with diminutive cooling fins **13**. The cooling fan, if still operating, will assist in the cooling. Also, the fan of any existing heater, FIG. **11** or **11**-B, item **27**, can divert cool pumped air to the now empty water jacket of the engine. In addition, the pistons may be cooled by splash-oil cooling, in which oil-cooling radiator will be small and can be protected by engine components and armor.

The New Cycle Engine is inherently cooler operating as a study of the working cycle shows and can be cooled very effectively by pumping compressed air or expanding chilled air through conduits in cylinder head and block, as described herein.

The efficiency of the engine is improved by compressing and cooling a large portion of the charge air, all in Design 4,

outside of a hot firing cylinder and by more complete combustion because of better mixing of the fuel/air charge. Efficiency is also improved by the extended expansion process in Design 3 through Design 6 and by thermodynamic improvements inherent in a denser air charge. Fuel economy is further improved by a greater power-to-weight ratio.

The engine may be operated preferably in the single mode (3) operation, or alternatively and selectively in mode 1 or mode 2.

Power is increased by the improved thermodynamics of a denser charge, which also allows more fuel to be utilized and by more complete combustion and by reduced compression work.

Emissions are less because of low peak temperatures and pressures and by more complete combustion. In both current and HCCI Diesel engines, particulates (both smoke and nano-particles) are very significantly reduced by the more complete combustion due to the pre-mixing (homogenization) of fuel/air charge before ignition and by the low temperature oxidation process. HC and aldehydes are reduced by injected air sweeping out piston ring crevices and other close tolerance areas between piston and cylinder wall.

Durability is improved by the overall cooler working cycle and low peak temperatures and pressures, and in some duty cycles, lower RPM allowed by higher torque.

Air compressor(s) would be compact, low profiled and armored, with conduits being of high tensile strength. Some of the compressed air can be diverted and expanded in cooling jackets around the compressor(s) and oil cooler, if the latter is used. The chief advantage of optional operation of modes 1 or 2 is that at any time ancillary compressor **2**, coolers **11** and **12** are damaged, the vehicle operates in mode 1 to allow the vehicle to continue functioning with adequate power and to return home.

Results

1) Low peak temperatures and pressure
2) A homogeneous combustion charge
3) A denser charge
4) Greater efficiency
5) Greater engine durability

Advantages

1) Lower polluting emissions
2) Greater power
3) Greater torque
4) Increased vehicle range
5) Longer engine life
6) Multi-fuel capability
7) Greater reliability

The ability to auxiliary-cool the engine on demand, coupled with multi-fuel capabilities and increased vehicle range, greatly reduces logistics problems for the military on both land and sea.

Referring now to FIG. **6**, there is shown a cross-section of a partial engine block **12'** and a cylinder liner **12** containing passages **6** on the exterior of the cylinder liner **12** between cylinder liner **12** and engine block **12'** for passage of pumped or compression chilled air of which passages **6** have fins or wire mesh, **6'** arranged for transferring heat from the cylinder liner to the passing expanding air.

4-Stroke, Air-Cooled Engine Operating in Operational Design 1–6

Referring now to FIG. **7**, there is shown a perspective view (with portions in cross-section) of the cylinder block and head of engine similar to the engine of FIG. **3**, operating in a 4-stroke cycle, operating in either system of Operational Design 1 through Design 6, as described for engine of FIG. **2**, FIG. **2**-B, FIG. **2**-C and FIG. **5** and representing a second embodiment of the apparatus of the present invention from which a second method of operation can be performed and will be described. Among its other components, this embodiment is seen as showing a means of controlling engine temperatures by expanding highly compressed air through port **4** and cooling channels in engine or alternatively through expansion valve **4'**, as described for expansion valve **10'**, pressure-drop-distributor **11** and evaporator tubes **17***a* and **27***a* in FIG. **2**-C and FIG. **11**-B, throughout passages in the engine, at such a time liquid cooling system has failed, and showing an optional automatic valve **2'**, providing means of better mixing of air-fuel charge and of managing initial pressure ratios in the engine and for closing inlet port from conduit B while intake valve **16**-A is closing. Alternatively, chilled charge air can be supplied to operate the engine as described for FIG. **2**, FIG. **2**-C, FIG. **3**, FIG. **4**, FIG. **5** and FIG. **11**-B, using any high-performance compressed-expanded-air cooling system, optionally combined with expansion valve **4'** or **10'** and associated apparatus as described for engine of FIG. **2**-C, FIG. **3** to FIG. **5** and FIG. **2**-D for current technology 2-stroke and 4-stroke Otto and Diesel Cycle engines.

Military Model of 4-Stroke Triple Mode Engine

The operation of the engine of FIG. **7** is the similar to that of FIG. **2**, FIG. **2**-C, FIG. **3** and FIG. **5**, with some exceptions. The preferred method of operation is that of FIG. **2**-C, operating in any of Operational Designs 1–6 and preferably operating in mode 2 as described for the same engines.

Operation of 4-Stroke New Cycle Engine

The operation of the engine is the same as any design from Design 1 through Design 6 with features described for the engine of FIG. **2**, also suitable for FIG. **2**-B, FIG. **2**-C, FIG. **4** or FIG. **5** for greater torque, power, and durability with low fuel consumption and ultra low polluting emissions. The engine of FIG. **7** operates in a first mode and an optional second mode as described for engines of FIG. **1**–FIG. **4**.

Mode 2 Operation

Mode 2 is the preferred means of operation of the engine for military duty due to the ease of switching to a more reliable mode of operation at such time that ancillary compressors or intercoolers may become disabled. While operating with greater power (mode 2), switching to mode 1 converts the engine to the same power output as a conventional engine, while still providing reliability and high fuel economy.

Cooler Working Cycle

The New Cycle Engine is inherently cooler operating as a study of the working cycle shows, and can very effectively be air-cooled or chilled air cooled by pumping cool, highly compressed air through inlet port **4** or alternatively through an expansion valve to **4'** low pressure conduits "evaporator" in cylinder head, walls and block, as described heretofore in FIG. **5** and FIG. **6**.

The efficiency of the engine is improved by compressing a large portion of the air charge outside of a hot firing cylinder, by more complete combustion because of better

mixing of the fuel/air charge, by improved thermodynamics of the denser charge and by the extended expansion process in Operational Designs 3 through 6. Fuel economy is further improved by a lighter engine (greater power-to-weight ratio).

Power is increased by the improved thermodynamics of a much denser charge, which also allows more fuel to be utilized, by higher efficiency, by more complete combustion and by reduced compression work. (In all Designs, the supplementary, secondary charge is injected cooled, very dense, not being expanded, and the operation of which is better described for the engines of FIG. **2** and FIG. 2-C.).

NO_x emissions are less because of low peak and overall temperatures and by more complete combustion. In addition, particulates (both smoke and nano-particles) are significantly reduced in both the spark ignited and HCCI engines (fueled by gasoline or diesel oils) by the more complete combustion due to the pre-mixing (homogenization) of fuel/air charge before ignition. In any of the Designs, piston ring crevices and other close tolerance areas between piston and cylinder wall can be cleaned out by injected air (see FIG. **5** or FIG. **11**-B) for lower HC and formaldehyde.

Durability is improved by the overall cooler working cycle and low peak temperatures and pressures and by lower RPM allowed by greater torque. Other than the exceptions described for high-pressure supplemental, secondary charge air injection, operation and auxiliary cooling for FIG. **7** are the same as that of FIG. **2**, FIG. **2**-B, FIG. **2**-C engines operating in any of the Operational Designs 1 through 6.

Results

1) Low peak temperatures and pressure
2) A homogeneous combustion charge
3) A denser charge
4) Greater efficiency
5)Greater engine durability

Advantages

1) Lower polluting emissions
2) Greater power
3) Greater torque
4) Increased vehicle range
5) Longer engine life
6) Multi-fuel capability
7) Greater reliability

The ability to auxiliary chill-cool the engine air charge on demand, coupled with multi-fuel capabilities and increased vehicle range, greatly reduces logistics problems for the military on both land and sea. The expansion valve **10'** of FIG. 2-C, and FIG. **5** can be used to cool the engine and to chill the charge air of the 4-stroke (high-pressure stream only for the 2-stroke engine) and in both, can be combined with a fast acting cylinder intake valve into one unit for a two functions-in-one valve.

2-Stroke Air-Cooled Engine Operating in Operational Designs 8(a)–8(d)

Referring now to FIG. **8**, there is a perspective view (with portions in cross-section) of the cylinder block and head of an internal combustion engine, operating in a 2-stroke cycle and representing a first 2-stroke embodiment of the apparatus of the present invention from which still another method of operation can be performed and will be described. Among its other components, this embodiment is seen as alternatively having a conventional air charging and engine cooling system for mode 1 operation or having a highly compressed air or compression air chilled air supercharging and engine cooling system (mode 2 operation.)

Military Model 2-Stroke New Cycle Engine

The operation of the 2-stroke engine is somewhat similar to the basic 4-Stroke New Cycle Engine System for greater torque, power, and durability with low fuel consumption and ultra low polluting emissions. The operation of this particular design is as follows:

Operation of the 2-Stroke New Cycle Engine with primary and supplemental, secondary air charge (For Engines of FIG. **8**, FIG. **9** and FIG. **10**).

The preferred mode of operation is mode 2 in which the engine is capable of immediately switching to mode 1 operation at such time ancillary compressors and/or intercooler systems for producing the supplementary air charge may become inoperative eg., in battle support. In mode 1, a vehicle will still have the power of a conventional engine to continue its mission and to return home safely.

Operational Design 8(a)

Piston **22** is at (BDC) (after power stroke) and high-pressure inlet valve **16**-A is closed.

A Roots Type Blower and conduits (not shown) supplies lightly compressed air for scavenging and cylinder charging to inlet ports **11** of cylinder **12**, or alternatively, conduit **27***a*, as in FIG. **2**-C supplies air to inlet ports **11**, optionally expanded through expansion valve **10'**, pressure-drop-distributor **11**, evaporator tubes **17***a* and **27***a* for exhaust scavenging, cooling and charging of cylinder **12** with fresh chilled air. (If compression chilled, the low pressure charge to intake valve **16**-B can be expanded to a cold 5–10 psig pressure, more or less.)

Mode 1

Exhaust valve **8**-B is open. Exhaust Blow-Down has already occurred and fresh cooled or optionally chilled air from ports **11** is still entering the cylinders. Piston **22** begins to rise in the compression (1st) stroke and as piston **22** closes inlet ports **11**, exhaust valve **8**-B closes to trap as large volume of air as possible. This produces a normal optionally cool or chilled compression ratio which is equal to the expansion ratio. The compression (1st) stroke continues and near TDC, fuel is added, if not present, and the charge is ignited for the power (2nd) stroke and at near BDC or the appropriate point, exhaust valve **8**-B opens for the exhaust blow-down and fresh scavenging, charging air enters ports **11**, now open, and another cycle begins. This completes one normal power cycle.

Optional Mode 2 for Greater power

Exhaust valve **8**-B is open. Exhaust blow-down has already occurred and the cylinder **12** has been scavenged and charged by fresh air entering ports **11**. Piston **22** begins to rise in the compression stroke, closing ports **11** as exhaust valve **8**-B closes. High pressure air inlet valve **16**-A opens at any point deemed feasible during compression stroke to inject a dense, cool, high velocity, supplementary, secondary air charge, which is externally compressed in one or more stages as from conduits **113'** and **114'** in FIG. **2**-C and into inlet conduit B in FIG. **8**. Compression continues and near TDC, fuel being present, the charge is ignited and the power (2nd) stroke occurs for great power and low polluting emissions. At the appropriate point, exhaust valve **8**-B opens and the cylinder is scavenged and filled with fresh, cool charge. This completes one very powerful and clean power cycle.

The supplementary supercharging air can be compression-expansion chilled, as from expansion valve **10'**

and conduit 27'*a*–27*f* of FIG. 2-B. Depending on the temperature and pressure before being expanded, the pressure passing intake valve **16**-A during the compression stroke, can be adjusted to as much as a very cold 5–7 atmospheres pressure. If the secondary charge comes from conduits **113'** and **114'** in FIG. **2**-C, with no expansion as described for FIG. **2**-C, it would be injected through intake valve **16**-A somewhat less cooled, but much greater in density and pressure. The pressure to conduit **16**-A may be reduced or may require a pressure control valve D and E on conduits **113'** and **114'** as in FIG. **2**-C.

Optional Mode 3

Modes 1 and 2 are combined by eliminating intake valve **16**-A deactivator with the engine always operating with a supplementary, secondary air charge injection.

Operational Design 8(b)

Mode 1

In this design, one power cycle has ended. Exhaust valve **8**-B is open. Exhaust Blow-Down has already occurred and fresh cooled air from Roots Blower or similar blower types or air chilled from conduits 27'*a*–27*f*, FIG. **2**-C and ports **11** has scavenged and is still charging cylinder **12**. Exhaust valve **8**-B closes and piston **22** begins to rise in the compression stroke, closing inlet ports **11** and trapping as large a charge as possible. But, in this Design 8(b), the combustion chamber is very large, resulting in a very low (substandard) compression ratio for the cylinder. For example, rather than, say a 20:1 compression ratio, this design would produce a compression ratio of perhaps 10:1 or less. For a gasoline engine, the compression ratio may perhaps be 5:1 or less.

Piston **22** rises in the compression (1st) stroke and near piston TDC, fuel is added, if not present. The charge is ignited for the power (2nd) stroke and at the proper point in the power stroke, exhaust valve **8**-B opens for the exhaust Blow-Down and at bottom of power (2nd) stroke ports **11** are uncovered to admit scavenging and charging air to begin another cycle. (With this substandard compression ratio, the heat-of-compression for the primary air charge can be as little as 1/5 that of normal engines for low heat-of-compression and low emissions. This completes one clean power cycle for mode 1 auxiliary operation, e.g., for continuing in battle and returning home safely if auxiliary air compressor-cooler system is damaged. (Mode 1 operation is especially feasible when the primary air charge is boosted significantly in pressure).

Mode 2, Preferred

Exhaust valve **8**-B closes, as the compression stroke begins closing cylinder ports **11** and **12** being charged with fresh air. Somewhere during the compression stroke, valve **16**-A opens and injects a very dense high-pressure, non-expanded, cooled supplementary, secondary air charge as from conduits **113'** and **114'** of FIG. **2**-C or optionally chilled air from conduit **27***a* of FIG. **2**-C. The supplementary supercharging secondary air charge can bring the density of the total charge to that of a normal engine, say with the nominal 20:1 compression ratio. The secondary charge can produce, selectively, even 40:1 compression ratio density or a much greater density and can greatly supercharge the engine with low peak temperatures and pressures, which with the better mixing of the cool charge produces much greater power with ultra low emissions. (The amount of heat-of-compression for the supercharging secondary air charge depends on what point in the compression stroke that portion is injected.) The "effective" compression ratio for the supplementary portion of the charge can be as low as 2:1 or 3:1 for again ultra low compression ratio. Yet, as stated, the charge density can have the density (compactness) of a 40:1 compression ratio or even much higher.

Mode 3

Modes 1 and 2 are combined for simplicity to form mode 3. This is accomplished by eliminating the system for temporarily deactivating intake valve **16**-A and/or compressor **2** operation, as is done in mode 1 operation.

Optional Design 8(c). Mode 1

A power cycle is completed and for some distance after closing of ports **11** by piston **22**, in the scavenging, charging (1st) stroke, the exhaust valve **8**-B stays open during the first part of the compression stroke to expel a portion of the fresh air charge in order to trap a smaller-than-normal volume of charge air and then exhaust valve **8**-B closes. The compression (1st) stroke continues and near piston TDC, fuel is added, if not present and ignited, producing the power (2nd) stroke and at near BDC or at the appropriate point, exhaust valve **8**-B opens and exhaust Blow-Down occurs by blower or compressor, and cylinder is scavenged and filled with cool, fresh charge air which can be cool or chilled. This completes one cycle for adequate cruising power with an extended expansion process and low polluting emissions.

Mode 2

When more power is needed, the following takes place: After scavenging and charging cylinder **22**, at any point in the compression stroke deemed appropriate after closure of exhaust valve **8**-B, inlet valve **16**-A opens and quickly closes, injecting very dense, temperature adjusted supplementary charge air as from conduits **113'** and **114'** of FIG. **2**-C, or optionally expansion chilled, supplementary, secondary air or air-fuel charge from conduit **27'***a* of FIG. 2-B. The compression stroke continues. Fuel is added, if not present, and near TDC of piston **22**, the charge is ignited and the power (2nd) stroke occurs for great power with low peak temperatures and with low polluting emissions with the expansion ratio still being greater than the effective compression ratio.

Capturing a subnormal initial charge produces a substandard "effective" compression ratio with a very low heat-of-compression. A denser than normal supplementary, secondary cool air or cold charge produces low heat-of-compression also, and together still produces an extended expansion ratio. As in the 4-stroke engine, the effective compression ratio and hence, the amount of heat-of-compression for the supplementary, secondary charge depends on the point in the compression stroke the secondary charge is injected. The compression ratio for the supplementary, secondary air charge can be as low as 2:1 or 3:1 with a charge density equal to 20:1 or 40:1 or greater.

Should ancillary compressor **1** or **2** or intercooler system become damaged while operating in mode 2, the engine instantly switches to mode 1 operation and continues to operate with normal engine power to continue operation and to return home. This makes mode 2 operation the preferred system for the military.

Mode 3

This method of operation of the engine of FIG. **8**)*c*) is by eliminating the deactivator for intake valve **16**-A, thus combining mode 1 and 2 into a simple operating mode 3 system, except for military for which mode 2 is preferred.

Operational Design 8(d), Mode. 1

In another alternative Operational Design, a power cycle is completed and piston **22** continues to rise in the scavenging-charging (1st) stroke as exhaust valve **8**-B remains open to near TDC, where it closes after cooling cylinder and expelling nearly all of the fresh, cold charge which was induced into cylinder **12** by way of inlet ports **11**. At the point near TDC, that exhaust valve **8**-B closed, high-pressure intake valve **16**-A opens and closes, injecting the entire working air charge which is very dense, cool and of high velocity and either pre-mixed with fuel or injected simultaneously with fuel, with the engine having a cool effective compression ratio of perhaps 3:1 or 2:1 or less. The charge is ignited near TDC as soon as intake valve **16**-A closes for the power stroke with an extended expansion ratio. (This Operational Design 4 of FIG. **2** engine is the easiest design in which to air cool the engine structure. The latter system is much like putting a cartridge in a rifle and firing same for each power stroke. The secondary and only air charge in this design can be the highly compressed, cool air as from conduits **113**' and **114**' of FIG. **2**-C or can be expansion chilled as from conduit **27**'*a* as in FIG. **2**-B. In Operational Designs 8 through 10, fuel is injected, if not present, at any point deemed proper and near TDC the charge is ignited by spark, compression, modified HCCI or true HCCI.) (The air or air-fuel injection occurs just far enough before piston TDC to allow the charge injection and ignition to occur at the opportune point before or at TDC to produce the most power and efficiency.)

The burning gases depress the piston in the power (2nd) stroke for great power with both fuel consumption and polluting emissions greatly reduced. The new Cycle Engine is inherently cooler operating as a study of the working cycle shows and the engine block and head can very effectively be cooled by pumping cool highly compressed air through port **4** or alternatively, first through expansion valve **4**' in FIG. **8**, to conduits in cylinder head, cylinder walls **6** in FIG. **6** and block, all of which are low pressure, and act as evaporator tubes as described herein for the engine of FIG. **5**.

The efficiency of the engine is improved by (a) thermodynamic improvements of increased charge density, by (b) compressing all of the air charge outside of a hot firing cylinder, by (c) more complete combustion due to better mixing of the fuel/air charge and by (d) the extended expansion process in Operational Designs 4 and in Operational Design 8(c).

Power is increased by (a) the improved thermodynamics of a denser charge, which also allows more fuel to be utilized, by (b) more complete combustion and by (c) reduced compression work.

Emissions are less because of (a) low peak temperatures and pressures, by (b) more complete combustion and by (c) particulates in Diesel engines (both smoke and nanoparticles) being significantly reduced by the more complete combustion due to the pre-mixing (homogenization) of fuel/air charge before ignition.

Durability is improved by the overall cooler working cycle and low peak temperatures and pressures and in some duty cycles, by low RPM allowed by greater torque.

In each of the 2-stroke engines of FIG. **8**, FIG. **9**, and FIG. **10**, the expansion valves **10**' which are alternative, can alternatively have variable openings (nozzle(s)), preferably controlled by the EMC-**27** to maintain optimum engine temperature and density in regards to polluting emissions and power requirements. For greater power, if utilizing chilled charge air, expansion valve **10**' nozzles may be opened further to direct a more dense charge into ports **11**, or alternatively, by opening valve R and allowing some or all of the high pressure effluent to bypass expansion valve **10**' by way of conduit X as in FIG. **2**-C. This will bring a denser and less expanded air or air-fuel charge into valve **16**-A, but may require pressure regulator on conduit **27**'*a*–**27***f*, FIG. **2**-B. Either of these two systems, either separately or in combination preferably by EMC-**27**, which receives signals from sensors in the combustion chamber of cylinder **12** and perhaps other locations. (The alternative system of supplying denser, non-expanded, supplementary charge air to intake valve **16**-A as in FIG. **2**-C to engine of FIG. **8** can be as shown from conduits **113**' and **114**' of FIG. **2**C with, perhaps optional pressure regulators D and E.) In this system the expanded chilled air (scavenging only) is from conduits **27**'*a*–**27**'*f* as shown also in FIG. **2**-C.

Results

1) Low peak temperatures and pressures
2) A homogeneous combustion charge
3) A denser charge
4) Greater engine durability

Advantages

1) Lower polluting emissions
2) Greater power
3) Higher efficiency
4) Greater torque
5) Increased vehicle range
6) Longer engine life
7) Multi-fuel capability
8) Greater reliability

The ability to auxiliary-cool the engine on demand or continuously, coupled with multi-fuel capabilities, the ability to continue operation after damage to supplementary air systems and increased vehicle range, greatly reduces logistics problems for the military on both land and sea.

2-Stroke Air-Cooled Engine Operating in Operational Design 9

Referring now to FIG. **9**, there is shown a perspective view (with portions in cross-section) of the cylinder block and head of an internal combustion engine operating in a 2-stroke cycle, and representing a second 2-stroke embodiment of the apparatus of the present invention from which still another method of operation can be performed and will be described. Among its other components, this embodiment is seen as having one atmospheric air intake, with one high pressure charge-air route B, a common air-rail and ports **11**-B leading from an optional Roots Blower and conduits (not shown), or alternatively, from compressor **1** and conduit **32** to provide an optional air charging system, or alternatively, a charge air cooling system with items **10**', **11**', **17** and **27**'*a* as in FIG. **2**-C to inlet ports **11** of power cylinder **22** of FIG. **9**. The high pressure supplementary charge air route conduit B and intake valve **16**-A is supplied by conduits **15**-A of FIG. **2**, or optionally, conduits **114**"–**113**" as in FIG. **2**-C or by conduits **27**'*a*–**27**'*f* of FIG. **2**-B. Other components are an exhaust valve **8**-B and conduits **9** to the atmosphere. Also provided are the power and engine head and block air cooler system, including chill cooling by expansion valve **4**' as described for FIG. **5**, FIG. **7** and FIG. **8**.

Military Model of 2-Stroke New Cycle Engine

The operation of the 2-stroke engine, using charging Operational Design 8 through Design 10, is the same as described for the basic 2-Stroke New Cycle of FIG. **8** Engine's four alternate Operational Design systems 8-A through 8-D for greater torque, power, and durability, with low fuel consumption and ultra low polluting emissions. This engine, FIG. **9**, offers triple mode operation of the 2-Stroke new cycle engine with primary and supplementary, secondary air charge, the same as engine of FIG. **8** with the exception that an automatic one-way valve offers improvements as described for engine of FIG. **7**.

Additionally, auxiliary valve **2'**, which is automatic, will prevent charge-air back-flow from cylinder **7**. This feature will prevent any back-flow from occurring during the compression or expansion strokes of the engine of this invention. This feature can also be used to establish the initial pressure ratio of the engine, either variable or constant. When secondary charge air is being received through intake valve **16**-A, the intake valve **16**-A can be kept open during the compression stroke to near TDC of piston **22**, since automatic valve **2'** closes at such time the pressure in cylinder **12** approximates the pressure in intake runner conduit B. Therefore, the pressure differential between cylinder **12** and intake runner B will allow closure of automatic valve **2'**, even though intake valve **16**-A may still be open, allowing the initial pressure ratio of cylinder **12** to be controlled by the pressure of any charge air coming through intake runner B, which in turn is controlled by valves **3**, **5**, and **6** (as described for engines of FIG. **1** to FIG. **7**) and compressor speed for engines having a single stage of pre-compression. Valves **3**, **4**, **5** and **6** and compressor speed would control the initial pressure ratios for engines having two stages of pre-compression. There are also fast acting intake valves, some of which open and close in 40 degrees crank angle. The new Cycle Engine is inherently cooler operating, as a study of the working cycle shows, and can very effectively be cooled by pumping compressed, cool air or compressed air that is expanded through a expansion valve **4'** which chills conduits (evaporator) in cylinder head, walls and block, as described herein for the engine of FIG. **5**.

The efficiency of the engine is improved by (a) thermodynamic improvements inherent in greater charge density, by (b) compressing a large portion or all of the air charge outside of a hot firing cylinder, by (c) more complete combustion because of better mixing of the fuel/air charge and by (d) the extended expansion process in Operational Designs 8(c) and 8(d).

Power is increased by (a) the improved thermodynamics of a denser charge, which also allows more fuel to be utilized, by (b) more complete combustion and by (c) reduced compression work.

Emissions are less because of (a) low peak temperatures and pressures, by (b) more complete combustion and (c) particulates (both smoke and nano-particles) in diesel fuel use are significantly reduced by the more complete combustion due to the pre-mixing (homogenization) of fuel/air charge.

Durability is improved by the overall cooler working cycle and low peak temperatures and pressures and by low RPM, the latter allowed by higher torque.

Results

1) Low peak temperatures and pressure
2) A homogeneous combustion charge
3) A denser charge
4) Greater efficiency
5) Greater engine durability

Advantages

1) Lower polluting emissions
2) Greater power
3) Greater torque
4) Increased vehicle range
5) Longer engine life
6) Multi-fuel capability
7) Greater reliability

The ability to auxiliary-cool the engine on demand coupled with multi-fuel capabilities, much greater power and increased vehicle range greatly reduces logistics problems for the military on both land and sea. In addition, 2-stroke Diesel Cycle engines, of which over fifty different applications are currently used by the military for land and water transportation as well as for stationary use, can be readily retrofitted for the new supplementary cold air supercharged power cycle and compressed air or compression-expansion chilled engine cooling, as described for FIG. **8**.

2-Stroke Air-Cooled Engine Operating in Operational Design 10

Referring now to FIG. **10**, there is shown a part sectional view through one power cylinder of a 2-stroke engine at the intake and exhaust valves showing an optional method (adaptable to other embodiments of the present invention) of preventing charge-air back flow and of optionally automatically adjusting the charge pressure-ratio of the cylinder during the air charging process, and a system for providing a supplementary, secondary charge air injection directly through valve-in-head and through the cylinder wall for better mixing of charge and reducing formaldehyde formation.

Military Model of 2-Stroke New Cycle Engine

The operation of the 2-stroke engine is very similar to the basic 2-Stroke New Cycle Engine System of FIG. **8** and FIG. **9**, for greater torque, power, and durability with low fuel consumption and ultra low polluting emissions. The operation of this particular design is this:

Operation of the 2-Stroke New Cycle Engine

The operation of engine of FIG. **10** is the same as that of the engines of FIG. **8** and FIG. **9** for mode 1 operation, except that in mode 2 and 3 a difference is being able to inject the supplementary, secondary air charge through ports in the cylinder wall and ports **17**A and **17**B and alternatively to simultaneously inject cold supercharging air through an automatic valve **2'** or optionally directly through port **2** in cylinder head at valve **2'** with valve **2'** (shown in phantom) optionally being absent.

The supplementary, supercharging air charge for mode 2 and mode 3 in this design is compressed and cooled from conduits **113'** and **114'** of FIG. **2**-C or alternatively, compressed and chilled from conduit **27'***a*, as seen in FIG. **2**-B, is injected into the cylinder **12** by inlet valve **16**-A, (after cylinder scavenging and charging and ports **11** are closed by piston **22**), and by conduit **17**-A and inlet port(s) **17**-B, which optionally can be one or many, and located in cylinder wall **12** at any place deemed proper for best mixing of charge. (For Operational Design 4 operation, the cooling primary air charge is expelled and at piston near TDC, the entire working charge is injected through intake valve **16**-A.) If optional automatic inlet valve **2'** and accompanying opening (not shown) to inlet valve **16**-A is utilized, the air pressure from intake valve **16**-A, when open, would

depress valve **2'** to inject the high-pressure from the top and back-pressure on the incoming charge by valve **2'** would force a substantial part of the incoming charge to enter conduit **17** and **17-A** and pass into cylinder **12** through port(s) **17-B** for good air-fuel charge mixing. Besides aiding the mixing of the air-fuel charge, the cool high-pressure air from port(s) **17-B** will sweep out ring crevices and space between cylinder wall **12** and piston **22** to reduce HC and the formation of formaldehyde.

Optional automatic valve **2'**, if used, will also increase the velocity of the charge entering the cylinder from directly past valve **16-A** and that from lower port(s) **17-B**. The New Cycle Engine is inherently cooler operating, as a study of the working cycle shows. It can also be effectively chill-cooled by pumping cool, highly compressed air through port **4** in engine block or optionally, through a metering or expansion valve **4'** to inlet port **4** to conduits (the "evaporator") in cylinder head, walls and block, as described for the engines of FIG. **5**, FIG. **8** and FIG. **9**.

The efficiency of the engine is improved by, (a) compressing a large portion of the air charge outside of a hot firing cylinder during high power operation, by, (b) more complete combustion because of better mixing of the fuel/air charge by, (c) the thermodynamic improvements in greater density of the charge and by (d) the extended expansion process in Operational Designs 8(c) and 8(d).

Power is increased by, (a) the improved thermodynamics of a denser charge and which also allows more fuel to be utilized, by (b) more complete combustion and by (c) reduced compression work.

Emissions are less because of (a) low peak temperatures and pressures, by (b) more complete combustion and (c) a significant reduction of particulates (both smoke and nano-particles) in diesel fueled engines, resulting from more complete combustion, which in turn, is due to the pre-mixing (homogenization) of fuel/air charge, (in high-pressure supplementary, secondary charge only for 2-stroke engines), before ignition by spark or by HCCI. In this design, the secondary air charge is injected through port(s) **17-B** in the cylinder and optionally, through port at **2** or through automatic valve **2** in order to cool, mix, increase charge density and to clean out piston ring crevices where unburned fuel resides and to sweep out other narrow passages between piston and cylinder wall in order to reduce HC and formaldehyde emissions.

Durability is improved by the overall cooler working cycle and low peak temperatures and pressures and by lower RPM, the latter allowed by greater torque.

The operation of the engine of FIG. **10** is the TRIPLE MODE system described for engine of FIG. **8**, utilizing either of Operational Designs 8a–8d, with the preferred mode being mode 2. The advantage of mode 2 operation is that should compressors and coolers be damaged as in battle situations, the engine is switched to mode 1 operation and continues to operate and return home, still with the power of normal engines.

Results

1) Low peak temperatures and pressure
2) A homogeneous combustion charge
3) A denser charge
4) Greater efficiency
5) Greater engine durability

Advantages

1) Lower polluting emissions
2) Greater power
3) Greater torque
4) Increased vehicle range
5) Longer engine life
6) Multi-fuel capability
7) Greater reliability

The ability to auxiliary-cool the engine on demand and to continue to operate in mode 1 if the compression system is damaged, coupled with multi-fuel capabilities and increased vehicle range, greatly reduces logistics problems for the military on both land and sea.

Dual Air Pressure Levels Supplied by Pressure Amplifier

Referring now to FIG. **11**, (System A), there is shown a schematic view of a six cylinder engine, 4-stroke or 2 stroke, having both low and high-pressure charge air supplied by one or two initial stages of compression. The pressure in one line, **9'** is being amplified by a pressure amplifier and illustrates how one compressor **5** and a pressure amplifier **2** can supply either low or low boosted, and high-pressure air for operation of the new cycle engine or a constant speed engine, such as for power generation, pumping, etc. This pressure amplifier system may be used for any other appropriate need for high pressure gas or other fluids. The compressor-cooler system of the present invention is not limited to any particular type of compressor and cooler system.

The 4-stroke and 2-stroke engines of this invention require a supply of air or air-fuel charge presented to the engine **1'** at two different pressure levels and generally at different temperatures. This pressure amplifier system offers an advantage to both 4-stroke and 2-stroke designs.

Supplying and utilizing the pressure amplifier system is using one compressor **5** with proper conduits, valving, intercoolers and high-pressure distributing manifold **12**, and a second manifold **13** for distribution of the low pressure (primary) air charge for both 4-stroke and 2-stroke engines. Manifold **12** and **13** have optional pressure regulators indicated by numbers **14'** and **15'** (shown in phantom). These optional pressure regulators, if desired, or additional pressure regulations, could be placed on conduits **14"** and **15"** (shown in phantom) between manifolds **12** and **13** and inlet valves **16-B** and **16-A**, respectively.

An ancillary compressor **1** (in phantom) receives atmospheric air at port **8** which it compresses and sends either through air cooler **11** or, in whole or part, by-passes the air cooler **11** and conducts it to compressor **5** where the charge is compressed and passed through intercooler **6**, or cooler **6** is bypassed, in whole or part, by conduit **3'** and valve **2'**. The air is then divided into two streams at point **2"**, with part of the compressed air going through the low-pressure side of a pressure amplifier **2**, by way of valve **14**, and exits at valve **33**. The second part of the charge passes through the high-pressure end of the amplifier **2**, entering by way of valve **4** and exiting by valve **10**, where the high-pressure charge passes through intercooler **9** or, in whole or part, bypass systems **34** and **35** or partly through both cooler **9** and bypass conduit **34**, with the system being regulated by valve **35** and optionally controlled by ECM-**27'** of FIG. **2**.

In the amplifier **2**, the larger piston **7** with the greater piston face surface is depressed by the expanding air entering valve **14** from compressor **5**. Now, a second portion of the compressed air enters valve **4** to the smaller piston, which further compresses by pressure exerted by larger face **7** of piston **2**, and expels the second high-pressure part of the charge through valve **10** into conduit and cooler **9** or, wholly or partly, through bypass **34** and valve **35**, or partly through

each, where the temperature is adjusted to needed temperature for the manifold **12** to supply high-pressure air inlet valve **16**-A of engine of FIG. **11**. The low-pressure air charge also passes through a cooler or heater **11'** or, in whole or part, bypass system **34'** and **35'** and to manifold **13** and then to low pressure inlet valves **16**-B of engine of FIG. **11** or alternatively, to ports **11** of 2-stroke engine of FIG. **8**. Means for regulating pressure in manifold **12** and **13** are depicted as items **14** and **15**. Thus, pressure amplifier FIG. **11** is supplying high and low-pressure air at different temperatures and should be of value in other industrial functions.

Dual Chilled High-Pressure Air and Low Pressure Air Supply

Referring now to FIG. **11**-B, (System B) there is shown a schematic view of a six cylinder engine, 4-stroke or 2-stroke, having both low and high-pressure charge air supplied by one or two stages of pre-compression. The pressure to one line **9'** is being amplified by a pressure amplifier **2** and illustrates how one compressor **5** and a pressure amplifier **2** can supply either low or low boosted, and high pressure air, for operation of a constant speed engine of this invention such as for power generation, pumping, etc. The compressor-cooler system of the present engine invention is not limited to any particular type of compressor or cooler system.

The 4-stroke and 2-stroke engines of this invention require a supply of air or air-fuel charge presented to the engine **1'** of FIG. **11** or FIG. **11**-B or alternatively, to 2-stroke engine of FIG. **8**, at two different pressure levels and generally at different temperatures, with the capability of expansion chilling the high pressure charge air. One means of providing such is by use of one compressor **5** with proper conduits, valving, intercoolers and optional high-pressure surge tank **12**, expansion valve **10'** and pressure drop distributor **11"** on the high pressure conduit **9'**, leading to conduit **27'** and intake valve **16**-A of engine of FIG. **11**-B or FIG. **8**, and a manifold **13** for distribution of the low pressure (primary) air charge from valve **33** on low side of pressure amplifier **2**, as depicted in FIG. **11**-B. (Surge tank **12** and manifold **13** have optional pressure regulators, if needed, indicated by numbers **14"***a* and **15"***f* (shown in phantom)). The low pressure air is fed by the low pressure valve **33** on pressure amplifier **2** to cooler or bypass system **11**, **34** and **35** to optional manifold **13** and conduit **26**, leading to low pressure inlet valve **16**-B of engine of FIG. **11**-B or alternatively, to low pressure inlet ports **11** of engine of FIG. **8**, FIG. **9** or FIG. **10**.

Distributor tube **17***a* receives chilled air from expansion valve **10'** and delivers it in equal quantities to distributor tubes **27'***a* and **27'***f* to intake valves **16***a*.-A and **16**f-A of engine of FIG. **11**-B or alternatively, FIG. **8**, FIG. **9** or FIG. **10**.

2-Stroke Engines

For the designs of 2-stroke engines FIG. **8**, FIG. **9** and FIG. **10**, the pressure amplifier system of FIG. **11** and FIG. **11**-B will provide similar improvements for these designs by using high-pressure, cooled or chilled charge air going to cylinder input valves **16**-A in each design and low-pressure, cooled charge going to cylinder inlet ports **11**.

Otto and Diesel Cycle Engines

For FIG. **2**-D, current technology 2-stroke and 4-stroke Otto and Diesel Cycle engines, the high-pressure cooled or chilled dense air or air-fuel input to intake valves **16**-A would be utilized for performance improvements. The low-pressure output of the pressure amplifier could be returned to suction side of compressor **1** or compressor **2** and would be mandatory if fuel is premixed with the air.

Referring now to FIG. **12**, there is shown a pressure-volume diagram (which is a compilation of 4 diagrams) for a high-speed Diesel engine, compared to the engines of this invention, showing three stages intercooled compression and a fourth stage of uncooled compression, which arrangement is suggested for optimum power and efficiency for the engine of this invention.

Note 1—In FIG. **12**, the travel distance of the line for engine B on the horizontal coordinate, indicates the theoretical volume at the greater density. The density is kept at that level at the actual combustion chamber volume (as shown by dashed line V) regardless of the density, by pumping in more charge at the backside.

There are several features that improve the thermal efficiency of the engine of this invention. Greater power to weight ratios will provide a smaller engine with less frictional losses. Increased torque allows much lower RPM, again reducing frictional loses. The extended expansion ratio results in higher thermodynamic efficiency cycle, which is shown in theoretical considerations. There are also definite efficiency gains in a "staged" compression process, even with external compressors with associated piping, intercoolers and aftercoolers, etc. There is a very significant energy savings when air is compressed in intercooled stages. Less energy is used in compressing a charge to 500 psi in 2, 3 or 4 intercooled stages than is used to compress the hot charge to the same 500 psi in a conventional engine. A normal engine uses approximately 20% of its own energy produced to compress its own air charge. Calculations show a significant energy savings in an engine, if the air is compressed in aftercooled stages. Compressing a charge in only two stages to 531 psi (a 13:1 compression ratio) reduces the energy used by 15.8% over compressing to the same 531 psi level in a single stage, as does the Otto and the Diesel Cycle engines. Three stages of intercooled compression raises the savings to 18%. This is the ideal. Degradation from the ideal should not exceed 25%, which leaves a 13.5% energy savings. This 13.5% energy savings times the 20% of a normal engine's power used for compressing its own charge, is a 2.7% net efficiency improvement by the compression process alone. This is one of the advantages of the engine of this invention, which adds to the other thermal efficiency improvements. The dense charge, along with the large expansion ratio (the latter is several designs) provide improvements in fuel efficiency, greater torque, power and durability, while lowering polluting emissions.

Air Bypass Valve (ABV) Control Operation

An engine control module (ECM) **27** controls the air cooler bypass valves **3** and **5**. The bypass valves may be a shutter type valve as illustrated to pass part, all or none of the air charge in either direction, or valves **3** and **5** may be of a helical solenoid or other type of valve which can pass part or all of the air charge through bypass conduits **121** and **122** and part or all through air coolers **10**, **11** and **12** for fine control of the temperature and density of the air charge. The ECM receives signals from sensors, such as an engine coolant sensor, a crankshaft position sensor, camshaft position sensor, a manifold absolute pressure sensor, a heated oxygen sensor and pressure and temperature sensors, the latter two preferably placed in the combustion chamber.

To provide optimum air charging pressure for differing engine operating conditions, the ECM-**27** sends signals to

control air bypass valves **4** and **6**. These valves could be on-off solenoid valves, possibly vacuum operated, or they could be helical solenoids or other type of valve, which could remain closed or open part way or all the way in order to optionally re-circulate, part or all, of the air charge back through the inlets **110** and **8** of compressors **1** and **2** in order to optionally reduce or eliminate entirely the pumping pressure of either compressor **1** or compressor **2**, or both. Similar arrangements of air pressure control could be used for additional stages of air compression, if additional stages are used.

The operation is thus: The ABV valves **4** and **6** is controlled by signals from the ECM-**27** to control the angle of valves **4** and **6** to provide the optimum air charging pressures for various engine loads and duty cycles. When ABV **6** is opened partially, some of the air pumped through compressor **2** is passed back into the intake **8** of compressor **2** to reduce compression pressure. When ABV **6** is opened fully, all of the charge of compressor **2** is passed back through compressor **2**. Thus, compressor **2**, valves **3** and **4** and ECM-**27** can exert fine control of charge air density.

With this arrangement, combined with the arrangement of ECM-**27**, control of charge-air cooler bypass system for variable valves **3** and **5**, and in the optional design of **11**-B, the variable expansion valve **10'**, the temperature, density, pressure and turbulence of the charge-air can be managed to produce the desired power and torque levels and emissions characteristics in the power cylinder of the engine.

Engine conditions that could be monitored by ECM-**27** in order to affect proper engine conditions, in regard to control of ABV valves **4** and **6**, could include a fuel injection activity sensor, air temperature sensor at various points, manifold absolute pressure sensor, a heated oxygen sensor and/or other sensory inputs known to be used in internal combustion engines. The ECM-**27** controls both the shutter valves **3** and **5** and the air bypass valves **4** and **6** in order to maintain the optimum air charging density pressure and temperature at all engine operating duty cycles.

Alternate Combustion Systems

Referring now to FIG. **13**, there is shown a schematic transverse view of a pre-combustion chamber **38'**, a combustion chamber **38**, a piston **22** and associated fuel inlet **36**, a sparking or glow plug **37**, an air or air/fuel mixture inlet duct **8'** intake valve **20**, an exhaust duct **18'** an exhaust valve **17**, suggested for liquid or gaseous fuel operation for the engines of this invention or for any other internal combustion engine.

There are many choices of systems for compression or spark ignition for the engine of this invention, as described in FIG. **1** and FIG. **2**. Every fuel from gasoline to heavy diesel fuels, including the alcohols and gaseous fuels can be spark ignited or compression ignited (CI) in this engine, as well as by HCCI. One good system would be similar to the system shown in FIG. **13** or FIG. **19** for compressed natural gas, propane, hydrogen, gasoline, alcohols or diesel fuel. In this system, an extremely fuel rich mixture constituting the entire fuel charge is, preferably, injected into the pre-combustion chamber **38'**. The fuel could be injected through fuel duct **36** with or without accompanying heated or cool re-circulated exhaust gases or air. The air charge, some of which can accompany the fuel charge, would be compressed into the pre-combustion chamber **38'** by piston **22** during the compression stroke. Additional air, with or without additional fuel, could be introduced into the cylinder proper on the compression stroke through intake conduit **8'**. In either case, the second combustion stage in the cylinder proper would be with a lean mixture. The two-stage combustion system shown in FIG. **13** will operate in this manner

Pre-Combustion (First Stage)

Pre-combustion occurs in the pre-combustion chamber **38'** when fuel, in an amount much in excess of the amount of oxygen present, is injected through conduit **36** and ignited (injector not shown). This oxygen deficiency, along with the cooler, turbulent charge and lower peak temperatures and pressures, greatly reduces the formation of oxides of nitrogen. The combination of the hot pre-combustion chamber wall and intense turbulence promotes more complete combustion.

Post-Combustion (Second Stage

Post-combustion takes place at lower pressure and relatively low temperature conditions in the space above the piston in the cylinder as the gases expand from the first stage pre-combustion chamber into the cylinder proper. If there is additional fuel in the cylinder proper, the leaner mixture is ignited by this plasma-like blast from the pre-combustion chamber. The low temperature and the admixture of burned gases prevent any further formation of oxides of nitrogen. Excess air, a strong turbulent action, and the extended expansion process assure more complete combustion of carbon monoxide, hydrocarbons, and carbon.

The results of the engine of this invention, using the pre-combustion chamber **38'** of FIG. **13**, are: higher thermal efficiencies due to the greater expansion and a denser charge, along with a cooler exhaust and a lower level of polluting emissions, including oxides of nitrogen, and in addition, lower aromatics and particulates for diesel fuels.

Variable Compression Ratio and Double Power Designs

In following arrangements, there is shown schematic transverse sectional views of two optional cylinder designs of the engine of this invention which will convert the 2-stroke engine of FIG. **8** through FIG. **10** or any other 2-stroke engine to a one power stroke per piston stroke engine, and will convert the 4-stroke engines of FIG. **1** to FIG. **5** and FIG. **7** or any other 4-stroke engine to operate as a 1 power stroke per cycle engine.

By building any 2-stroke engine with all power cylinders double acting, the power to weight ratio can be doubled over the basic engine. One end of the cylinder fires and the other end is scavenged and charged on each piston stroke for a "nominal" one power stroke for each piston stroke (or two power strokes for each shaft rotation) of the engines of FIG. **8** through FIG. **10**. Use of double-acting power cylinders in the 4-stroke engine of FIGS. **1–5** and FIG. **7** converts the engine to a 1 power stroke per shaft rotation engine because two of the functions of a 4-stroke cycle engine are accomplished on each stroke of the piston.

Referring now to FIG. **14**, there is shown a double-acting cylinder with a means of varying beam **39** length to vary the compression ratio, which is accomplished by the beam end forming a scotch yoke **40** and fitting over the wrist pin **41** of the piston.

The double-ended piston **22"** can be linked to the end of a vertical beam **39** that pivots at the lower end **42**. A connecting rod **19'** is joined between the midpoint of the beam and the crankshaft **20'**.

Since the crankshaft **20'** does no more than transmit torque, its main bearings will be very lightly loaded. As a