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high pressure air going to the high pressure intake valves **16**-A, and in FIG. **2**-C, refrigerate the air going to the low pressure intake valve **16**-B. The latter chills the primary charge air for further improvements in reducing polluting emissions.

Alternatively, in the engine of FIG. **2**-C, the air or air/fuel (primary) charge first entering the cylinder **7** or **12** by intake valve **16**-B or ports **11** is compressed highly and passed through expansion valve **10'**, pressure-drop-distributor, **11'** and distributor tube (evaporator) **17***a*, at the beginning of the intake of valve **16**-B, which is then closed at BDC for Operational Designs 1 and 2 in which cam profiles are as normal. The intake valve **16**-B can close early or late in other designs in regard to the effective compression ratio desired. In this case, when greater power is needed (mode 2 or 3), the cool high pressure air or air/fuel charge is injected by intake valve **16**-A at any time during the compression stroke, or even during combustion, after intake valve **16**-B has closed in any case.

The expansion valves **10'** can alternatively have variable size openings and bypass systems R and X. They are controlled by the ECM-**27** to maintain optimum engine temperature and density in regards to polluting emissions and power requirements. Alternatively, the expansion valves may be combined with high-speed cylinder intake valves into one unit.

If the charge air entering expansion valve **10'** of engine of FIG. **2**-C was at 200 psi pressure, and the expansion valve **10'** dropped the pressure going to cylinder 7 to 70 psi, the chilling effect will be high and the pressure boost will be about five atmospheres for great power. If the primary air charge was compressed to 100 psi, it could be expanded by valve **10'** to say 15 psig for adequate cooling with a pressure boost of one atmosphere.

Fuel can be carbureted in any of the 4-stroke designs in one or both air inlet streams, with the exception of Design 4 of FIG. **1**, FIG. **2**, FIG. **2**-B, FIG. **2**-C and FIG. **18**-B where carburetion of fuel must of necessity be done in the high-pressure incoming stream only. Also, the 2-stroke designs should be carbureted by the high pressure inlet air stream only.

Fuel can also be injected in a central-body (not shown), or the fuel can be injected into one or both of the inlet streams of air, injected into a pre-combustion or pre-heater chamber, or injected directly through intake valves **16**-A, **16**-B (**16**-B only if **16**-B does not remain open past BDC and not at all in Design 4), or it may be injected directly into the combustion chamber at point x during the compression stroke (and during the intake stroke, only if intake valve **16**-B closes before or at BDC), or at the time after the piston **22** has reached point x in the compression stroke. The fuel can be injected along with compressed air, compressed cooled air, or with compression-expansion "chilled" accompanying air, the latter as depicted in FIG. **2**-B, FIG. **2**-C, FIG. **2**-D, FIG. **11**-B, FIG. **18**-B and FIG. **18**-C. The fuel can be injected with or without heated or cool accompanying air. In the case of diesel operation, fuel can be carbureted for spark ignition or for the HCCI system, as explained herein.

Alternatively, for modified or true HCCI operation of diesel fueled engines, the fuel can be carbureted, if during compression of the charge, the temperature is kept below the auto-ignition temperature of the fuel-air mixture. Compressing in stages with intercooling makes this system feasible. The air-fuel mixture is kept just below auto-ignition temperatures. The fuel can also be carbureted with the air charge before or after any stage of compression and cooling of charge. In either of these two systems, the charge can be ignited by spark or HCCI at near piston TDC. As an alternative to initial fuel carburetion, the primary air only charge can be compressed to temperatures higher than auto-ignition temperature. A small secondary air charge is then cooled and mixed (carburated) with the entire fuel charge and is injected 10–15 degrees before or at piston TDC for timely ignition. In either of these systems, the high-pressure secondary charge injection will assure homogenization and clean burning of the charge. After the temperature-and density-adjusting-air charge has been injected (mode 2 or 3), compression of the charge continues and with fuel present, is ignited at the opportune time, preferably 10–15° before TDC, for the expansion (3rd) stroke. The effective compression ratio is established by the displaced volume of the cylinder remaining after point x (the point where intake valve **16**-B closed whether before, at, or after BDC) has been reached on the compression stroke, being divided by the volume of the combustion chamber. Therefore, the compression ratio for Designs 1 and 2 is equal to the compression ratio, and for Design 4, it is zero. The expansion ratio is determined by dividing the cylinders total clearance volume by the volume of the combustion chamber.

Referring now to FIG. **1**-C, in engines having only one atmospheric intake conduit, but having different air paths and conduits, such as conduits **15**-A and **15**-C of FIG. **1**, a shunt conduit **202'** leading from the exhaust conduit **18** is divided into two shunt conduit portions **203***a*, **203***b*, each with a proportioning valve **209***a*, **209***b* operating so as to selectively admit exhausted gases to either or both of intake valve **16**-B (through conduit **9** and eventually conduit **15**-C) and/or to intake valve **16**-A (by way of conduit **8** and conduit **1**S-A). Each proportioning valve, **209***a*, **209***b* would allow either a portion or none of the exhausted gases to enter its respective port, meanwhile restricting entrance of fresh air if necessary. The exhausted gases can be cooled or heated by optionally arranging fins **202***a* on conduit **202'** and/or **203***a*, **203***b* and **203***c*, or by passing the exhaust through an optional intercooler or heater (not shown) before the gases are introduced into the air intake(s) of the engine. A take-off shunt conduit **203***d* and a proportioning valve **209***e* leading from shunt **202**, which is filled with exhaust gases, along with shunt **203***e* and proportioning valve **209***f*, leading from atmospheric air intake conduit **9**, with shunt conduit **203***d* and shunt **203***e* converging and becoming a single shunt conduit **203***f*, leading to a compressor **2'**, which has a conduit **203***g* leading to a bypass system **209***g*, **203***h* and an intercooler or heat exchanger **108**, which has a conduit **203***i*, leading to an outlet conduit **36**, which is connected to a preparation or pre-combustion chamber **38'** shown in FIG. **19** and FIG. **19**-B in combustion chamber of FIG. **19**-C and FIG. **19**-D.

With this arrangement, proportioning valves can direct undiluted exhaust gases or fresh air or any percentage of either, mixed through compressor **2** and optional cooler or heat exchanger **108** to inlet **36** of FIG. **19** and inlet **36**-B of FIG. **19**-B for the purpose of being used as a catalyst for ignition of the air-fuel charge in pre-combustion chamber **38'** or combustion chamber **38**.

Alternatively, as shown in phantom on FIG. 1-C, one shunt portion **203***a* is optionally diverted (shown as **203***c*) directly to conduit **15**-C and provided there with a proportioning valve **209***c*.

In the engine of FIG. **2** having dual atmospheric air intakes **8**, **9**, (**9** is in phantom) an arrangement similar to that shown in FIG. **1**-C is utilized, it being understood, however, that conduit **8** is open to the atmosphere.

In any engines having dual air intake conduits or dual air paths, a portion of exhausted gases can be introduced in any amount necessary, from one to three points and controlled preferably by an engine control module (ECM) for better management of combustion and emissions characteristics.

The Engine **100**^{2} of FIG. **2** Operating in Operational Designs 1–6

Referring now to FIG. **2**, there is shown a schematic drawing of a six-cylinder engine **100**^{2} operating optionally in three modes in a 4-stroke cycle. The engine is similar in structure and operation to the 4-stroke engine of FIG. **1** and shows alternative air induction systems, utilizing air intake **9** or air intake **8**. FIG. **2** also shows three intercoolers **10, 11** and **12** and dual manifolds **13** and **14** plus alternative intake manifold **14**-B. The need for dual atmospheric air intake (**8** and **9** in FIG. **2**) can be eliminated by providing air from port **8**-B of manifold **14**-B directly to air intake conduit **8**' shown schematically, in FIG. **2**.

Mode 1

One alternate air induction system shown in FIG. **2** supplies unpressurized charge-air to intake valve **16**-B of the engine of FIG. **1** and of FIG. **2**, by providing atmospheric pressure air to the intake runners **15***a*-C to **15***f*-C leading from manifold **14**-B in FIG. 1 and FIG. **2**, which receives atmospheric air through induction port **9**, and then, during an intake (1st) stroke of piston **22** distributes the unpressurized air to intake valves **16**-B of each power cylinder. Alternatively, the primary charge is boosted by compressor **1** and conduit **32**. Then compression (2nd) stroke occurs and the air-fuel charge is ignited near TDC for the power (3rd) stroke, which is followed by the scavenging (4th) stroke to complete a power cycle.

Mode 2

The intake (1st) stroke has occurred and for more power for mode 2 or 3 operation, high-pressure, cooled air is injected through intake valve **16**-A at anytime after piston **22** reaches BDC on intake stroke, preferably during the compression stroke for Operational Designs 1 and 2 of FIG. **1** and FIG. **2** engine, and for Designs 3 (both methods), Designs 5 and 6, after piston **22** has reached point x during the compression stroke (the point in which intake valve **16**-B closes), and near TDC for Design 4. Alternatively, for Designs 3 (both methods) and Designs 5 and 6, intake valve **16**-A is opened at any point deemed appropriate in the intake stroke or compression stroke at or after the point at which intake valve **16**-B closes. Intake valve **16**-A then quickly closes, compression continues in Designs 1, 2, 3, 5 and 6 and fuel is added, if not present. The charge is ignited near (TDC) and the power (3rd) stroke occurs in all Design systems including Design 4 where the entire charge is introduced pre-compressed, near TDC of stroke **2** and ignited for the power (3rd) stroke, which is followed by the scavenging (4th) stroke.

Mode 3 (Steady-State)

Operational modes 1 and 2 are combined in this manner for a more simple operation: Piston **22** takes in air or air-fuel charge on the intake (1st) stroke according to the Operational Design chosen. A secondary high pressure air charge is injected by intake valve 16-A preferably during the compression stroke, either later or at the same time that the piston **22** reaches the point at which the intake valve **16**-B closes. Intake valve **16**-A then quickly closes, compression continues, with the exception Design 4, FIG. **1**, where piston **22** is near TDC when valve **16**-B closes and the high-pressure valve **16**-A charges the cylinder. Fuel is added, if not present and the charge is ignited at the appropriate place, preferably 10–15 degrees before TDC, for the power (3rd) stroke. This is followed by the scavenging (4th) stroke to complete the power cycle. (In Operational Design 4, intake valve, which is now outlet valve **16**-B, closes just far enough before TDC of piston **22** position to allow time for the injection of the entire air or air-fuel charge and its ignition near TDC.

In all operational modes, a third alternate and preferred air induction system shown in FIG. **2** supplies the primary air charge to intake valve **16**-B as follows: Charge-air which has been pressurized to a low pressure by compressor **1**, perhaps from 0.3 Bar to as much as 2 Bar or more, can selectively (and intermittently or continuously) be supplied to low pressure intake valves **16**-B of the engine of FIG. **1** or FIG. **2** by way of conduit **32**, leading from conduit **110** to the intake valves (**16***a*-B through **16***f*-B) which conduit receives charge-air at atmospheric pressure or which has been pressurized and has had its temperature optimized, all controlled by compressor **1** and intercooler **10** with the charge-air paths being controlled by ECM-**27** and valves **5** and **6** with the corresponding conduits. In this case the valve **33** is optional. The use of this system also eliminates the need for dual atmospheric air intakes.

A fourth alternate air induction system, shown in FIG. **2**, supplies the primary charge-air to the low pressure intake valves **16**-B by having charge-air coming selectively from intake system **9**, manifold **14**-B and intake runners **15**-C (shown in phantom) or from conduit **32**, which would direct air to power cylinder **7** at whatever level of pressure and temperature was needed at any particular time. With this arrangement, opening valve **33** at such a time that compressor **1** was compressing the charge passing through it, would have the effect of increasing the density of the primary charge-air, which in this case, has its temperature as well as its pressure adjusted by compressor **1** and control valves **5** and **6**. A one-way valve **34** would prevent the higher pressure air escaping through conduit **15**-C. When less power was needed, compressor **1** could be "waste gated" by opening, partially or completely, control valve **6** and closing shutter valve **5**. Alternatively, valve **33** could be closed by the engine control module (ECM-**27**) and the primary charge-air would be drawn into cylinder **7** at atmospheric pressure through intake duct **9**.

Operational Designs of Primary Air Charging and Setting of Compression Ratios for All Modes

Described below are six Operational Designs of the new-cycle engine **100**^{2} applicable also to operation of engines for FIG. **1**, FIG. **2**, FIG. **2B**, FIG. **2C**, FIG. **3**, FIG. **4**, FIG. **5** and FIG. **7**

Depending upon the power requirements of the engine (e.g., differing load requirements), either intake air at atmospheric pressure from inlet **9** or intake air that has been boosted in pressure by compressor 1, as shown in FIG. **2**, by conduit **32** and has had its temperature adjusted by bypass systems **5** and **6** and charge-air cooler **10**, is drawn into the cylinder **7** by intake stroke through air inlet **8** in FIG. **2** or **2**-B, the atmospheric air optionally through manifold **14**-B, intake conduits **15**-B, and either at atmospheric pressure or boosted, is received by intake valves **16***a*-B-**16***f*-B, by intake stroke of piston **22**. (Inlet port **8** in FIG. **2**-C admits air to

compressors **1** and **2**, intercoolers **10**, **11** and **12** and ultimately to both intake valves **16**-A and **16**-B, the latter by way of conduit **27'***a*, **27"***f* going to inlet valve **16**-B and conduits **113'** and **114'** going to inlet valve **16***a*-A–**16***f*-A.)

Operational Design 1. In this design, intake valving and combustion chambers are as in normal engines. On the primary air intake (1st) stroke, the intake valve is left open as normally done to receive as large a charge as possible and closed at the usual time, near (BDC) to capture a full air charge, which produces a normal compression ratio with the expansion ratio being equal to the compression ratio.

Operational Design 2. In Design 2, the primary air intake valving is as in normal engines to capture a full air charge, but the combustion chamber is larger-than-normal for a substandard compression ratio still with the expansion ratio being equal to the compression ratio.

Operational Design 3. There are two methods to this design. In the first method for the primary air intake, the intake valve **16**-B is closed early, during the intake stroke before the piston reaches BDC. The small trapped air charge provides a substandard or low effective compression ratio with the expansion ratio being greater than the compression ratio.

In the optional method of Design 3 of primary air charging after the intake stroke is complete, the intake valve **16**-B, which can be single or multiple, is left open for a period of time after the piston **22** has passed BDC and is then closed. This pumps part of the fresh air charge back into the intake manifold to again trap a smaller-than-normal air charge producing a substandard or low effective compression ratio with an extended expansion ratio.

Operational Design 4. Design 4 describes another system of primary air charging, which is to hold the intake valve **16**-B open on the intake (1st) stroke, through BDC to near piston (TDC). Valve **16**-B is then closed to trap very little primary air charge for an effective compression ratio of perhaps 2:1 or less with an extended expansion ratio. Optionally, intake valve **16**-B is closed at piston BDC and an ancillary valve (not shown) is opened to allow the primary air charge to be pumped through and out of the cylinder for cooling of the cylinder.

Operational Design 5. Design 5 describes an additional method of primary air charging an engine cylinder **7**, of engines of FIG. **1**, FIG. **2**, FIG. **2**-B, FIG. **2**-C, FIG. **3**, FIG. **4**, FIG. **5** and FIG. **7** with a smaller-than-normal charge is being captured in cylinder **7**, by intake valve **16**-B closing early in the intake stroke at piston BDC, or early in the compression stroke, optionally producing a substandard or normal compression ratio which alternatively produces an extended or a normal expansion ratio.

Operational Design 6. Design 6 describes still another alternative method of primary air or air-fuel-charging. In this system, valve **16**-B selectively closes early before BDC, or as late as BDC of piston **22**, optionally producing a substandard or normal compression ratio for optionally a variable expansion ratio.

General Operation of Operational Designs 1 Through 6

Mode 1

The intake (1st) stroke has occurred and the compression (2nd) stroke is now underway. Compression begins for a normal compression ratio in Design 1, and for a substandard compression ratio in Design 2, a substandard compression ratio for Design 3 and for a compression ratio of near zero in Design 4. Designs 5 and 6 can produce a normal compression ratio or a substandard compression ratio depending on the point that intake valve **16**-B closes. If the effective compression ratio is substandard in Operational Designs 3 through 6, the expansion ratio is extended.

With the substandard compression ratio of Design 2 and with the intake valve **16**-B closing early or late in Designs 3 and 4 and alternatively early or late in Designs 5 and 6, lessens the temperature rise of the primary air charge during the compression stroke. In Design 4, there is little or no heat-of-compression, only the cooling of the cylinder by the ejected primary air. At the end of the compressions (2nd) stroke fuel is added, if not present, the charge is ignited near TDC. Then, the expansion (3rd) stroke occurs, followed by the scavenging (4th) stroke. This produces an efficient low emissions operation with normal power, especially if the primary air is boosted in pressure.

Mode 2

Intake valve **16**-B has opened and closed for the induction of the primary air charge by piston **22** intake (1st) stroke. A secondary compressed, temperature-adjusted air charge is injected into the cylinder **7** by intake valve **16**-A, which opens and closes quickly after closure of valve **16**-B. This preferably happens during the compression stroke, or even during combustion in all Operational Designs. In all operational designs, the intake valve **16**-A will open only at or after reaching the point the intake valve **16**-B closes in the primary air charging process, which for Design 4 is near TDC, to inject the secondary air charge. In all cases, the engine of this invention can produce a more dense, homogenized temperature controlled charge in order to provide the torque and power desired of the engine. The later in the compression stroke the secondary air or air-fuel charge is injected, the less is the heat-of-compression for that portion of air also. This fact, coupled with the low heat-of-compression production of the first or primary air or air-fuel charge, assures a very cool compression process in total.

For Operational Design 4, the secondary charge produces virtually no heat-of-compression for the coolest working cycle of all Designs.

Mode 3 (Steady-State)

The engines of the present invention can be simply and efficiently operated in a single mode, mode 3, by combining the operations of mode 1 and mode 2, whereby the secondary air or air-fuel of mode 2 is added in mode 3 without interruption at the same point it would be injected in mode 2, according to the Operational Design of 1 through 6 that is chosen for the particular engine design and duty cycle selected.

Discussion of Various Operating Parameters

In Design 4, after inducting the primary air charge by the intake (1st) stroke of piston **22**, little air charge is retained on the compression stroke and cylinder **7** is empty, or almost so and near TDC as intake valve **16**-B closes after ejecting almost all of its fresh air charge back into the intake system. Close to the end of the 2nd stroke and near TDC high pressure "conditioned" air intake valve **16**-A opens to inject nearly, or virtually all of the required air or air/fuel charge. (In this system, the primary air charge is pumped in and out of the cylinder, mostly to cool cylinder **7** before the "loading" and firing at TDC for the power (3rd) stroke of piston **22**. Alternatively, an ancillary exhaust valve **16**-C (indicated in FIG. **2**, FIG. **2**-B and FIG. **2**-C, but not shown) or exhaust

valve **17** would be opened at the beginning of compression (2nd)stroke of piston **22** and closed near piston TDC rather than keeping intake valve **16**-B open to near end of compression stroke. This is in order to vent the unused air of the non-compressing (2nd) stroke to the exhaust manifold, to be used to cool compressor or engine cylinders or expelled to the atmosphere or for other use.) As soon as the air charge is injected near TDC, fuel is added, if not present. The charge is ignited for a very cool, dense combustion expansion process in the expansion (3rd) stroke followed by the scavenging (4th) stroke. This completes one power cycle. In this Operational Design, the fuel charge is injected near piston TDC, but early enough that the charge can be placed, the valve **16**-B closed and the charge ignited, the latter preferably 10–15 degrees BTDC.

For Design 4, among the various choices available, the engine of either FIG. **2**-B or FIG. **2**-C could be utilized, offering a choice of thermodynamically chilling either the primary air charge, which only cools the cylinder, or chilling the secondary air charge or chilling both charges with the primary air charge being used to cool the cylinder **7** and its combustion chamber with the secondary charge being a chilled working charge. The primary charge is expelled either back through intake valve **16**-B or through an ancillary valve **16**-C (not shown) or through exhaust valve **17**, FIG. **1** which is again opened at BDC and left open to near TDC.

Operating in mode 2 or steady-state mode 3 when even greater power is required using either of the Operational Designs, the secondary air charge can be increased in density and weight by causing shutter valves **5** and **3** and by-pass valves **4** and **6** to direct all or a greater part of the air charge through compressors **2** and **1** and through coolers **10**, 11 and **12** to increase the charge density and/or by increasing compressor speed or by cutting in a third stage of auxiliary compression, thus enabling more air to be pumped in on the backside. Alternatively, the secondary air or air-fuel charge can be compression-expansion chilled by the system shown in FIG. **2**-B, FIG. **11**-B, FIG. **18**-B and items **10'**, **11"**, **12**, **17***a*, **27***'a*, **27***'f* and **16***a*-A and **16***f*-A. In the engine of FIG. **2**-C, the primary air charge through intake valve **16**-B is compression-expansion chilled with intake valve **16**-A, when operating in mode 2 or mode 3, receiving the dense, non-expanded air charge as in engine of FIG. **2**-C. The timing of the closing of intake valve **16**-B can be optionally altered in Designs 3, 4, 5 or 6, perhaps temporarily, to retain a smaller, or a larger charge.

In all Designs for modes 1, 2 and steady-state mode 3, near the end of the compression stroke, fuel is added, if not present, the charge is ignited by spark, compression, modified HCCI or by HCCI, and combustion produces a large expansion of the combusted gases against the piston **22** for the power (3rd) stroke producing great energy in either mode 1, mode 2 or mode 3 for Designs 1, 2, 3, 5 or 6 (Design 4 operates only in mode 3). This energy is absorbed and turned into high torque and power.

Near piston BDC, for modes 1, 2 and 3, the exhaust valves **17***a*–**17***f*, **17***a'*–**17***f'* open and the cylinder **7** is efficiently scavenged by the (4th) stroke of piston **22**, after which valve(s) **17** close (seen in FIG. **1**).

Shown in FIG. **2** is a suggested engine control system consisting of an engine control module (ECM) **27**, two shutter valves **3** and **5**, two air bypass valves **4** and **6**, the optional pressure reducing valves **25** (**25***a*–**25***f*) on air conduits **15**-B (**15***a*-B–**15***f*-B) There is also a scheme of controlling the pressure, temperature and density separately by controlling air bypass valves **4** and **6** and shutter valves **3** and **5**. As illustrated, air bypass valve **4** is closed to allow compressor **2** to fully compress the charge and shutter valve **3** is slightly open, allowing part of the air to flow uncooled (hollow arrows) and some of the air cooled (solid arrows) to the manifolds **13** and **14**, all of which could be controlled by the ECM-**27** in order to provide an air charge at optimum density, temperature and pressure. The hollow arrow **4**-A in conduit **120** shows how ABV **4** can be partially opened to allow some of the air to bypass and return to compressor **2** in order to finely adjust the pressure of the secondary air charge that is injected during mode 2 operation to adjust the charge density, turbulence and temperature. Part or all of the air charge can be directed through the intercoolers **10**, **11** and **12** (except that going through conduit **32** to intercooler **10** on the way to intake valve **16**-B) or through bypass conduits **121** and **122**, to the manifolds **13** and **14**. In addition, the temperature and density in cylinder(s) **7** can be controlled over a greater range by utilizing the compression-expansion charge chilling feature depicted and described in FIG. **2**-B, FIG. **2**-C, FIG. **2**-D, FIG. **11**-B and **18**-B, with the expansion valve opening size and the bypass system alternatively, also being controlled preferably by ECM-**27**.

In any of the engines of this invention, the problem common to normal engines of incomplete mixing of fuel, air and residual gas, with consequent variation in conditions at the ignition point is minimized and, in some cases, eliminated by the turbulent air charge injection at high pressure and/or by carburetion of fuel-air. This problem, hereby addressed by the present invention, is extreme in current engines when gaseous fuel is injected directly into the cylinder where the spark may occur in mixtures of varying air-fuel ratios, hence with various rates of flame development.

The turbulence produced in mode 2 and steady-state mode 3 by high pressure charge injection during the compression stroke, or later, is not dampened by the compression stroke. In Operational Design 2 through 6, the subnormal compression ratios lessen the heat-of-compression for the first portion of air charge. The later the supplementary, secondary charge is injected, the smaller the volume of charge is required to produce the desired turbulence and less the heat-of-compression development for that portion of charge, also. In any reciprocating internal combustion engine, operating in accordance with the method of the present invention, a very high pressure, temperature-controlled air charge can, selectively, be injected very late in the compression stroke, (and in Operational Design 4 for FIG. **1**–FIG. **7** engines, the charge is injected in just far enough before TDC to allow proper charging and ignition.

The use of this system will result in lower maximum cylinder pressures and temperatures. Efficiency should be greater and the detonation limit higher, thus allowing an appreciable increase in efficiency and mean effective cylinder pressure with a given fuel. All of the engines of this invention can, with the exception of Operational Designs 1 and 2, operate with a more complete expansion process, as compared to the typical prior art engines, to provide even further improvements in efficiency and emissions characteristics. In Designs 1 and 2, the compression and expansion ratios are equal.

The fuel can be injected with part, or all, of the air charge in either mode 1, 2 or 3 with the exception of Design 4 which operates only in mode 3. The fuel can also be injected later and, in the case of conventional diesel operation, can be injected into the combustion chamber at the usual point for diesel oil injection, perhaps into a pre-combustion chamber

or directly onto a glow plug. In mode 2 or 3, after the temperature-and-density-adjusting-air charge has been injected, if used, compression of the charge continues except, in Design 4 of FIG. **1** engine, where piston is near TDC, and with fuel present, is ignited at the opportune time for the expansion stroke. Now, in all modes, the air-fuel charge has been ignited and the power stroke of piston **22** takes place as the combusted gases expand. Near BDC of the power stroke, the exhaust valve(s) **17** opens and the cylinder **7** is efficiently scavenged by piston stroke **4**. If Design 4 of FIG. **1** or FIG. **2** engine is utilized, an outlet valve **16**-C (not shown) or exhaust valve **17**, FIG. **1** expels almost the entire primary charge, using it only to cool cylinder **7**, with a heavier secondary air charge being injected into cylinder **7** by valve **16**-A and ignited at or near TDC. Alternatively, intake valve **16**-B may be left open through most of the compression stroke for Design 4 in order to express the primary charge back through valve **16**-B.

The Engine $100^{2\text{-}B}$ of FIG. 2-B Operating in Operational Designs 1–6

Referring now to FIG. **2**-B, there is shown a six cylinder reciprocating internal combustion engine $100^{2\text{-}B}$ having one atmospheric air intake **9** and is so constructed and arranged that a compressor **1** and **2** receives charge air from manifold **14**-B through openings **8**-B (shown in FIG. **2**) and conduit **8'** which air enters through common air intake duct **9** or by way of inlet port **8**. Intake conduits **15***a*-C to **15***f*-C or **32**, the latter optionally boosted in pressure, distributes the low pressure air to the intake valves **16**-B of each power cylinder. This arrangement allows the provision of air to intake valves **16**-A and **16**-B at different pressure levels since the charge air from conduit **27***a*–**27***f* are selectively pressurized by compressor **2** and alternatively, by compressor **1** which also receives the total air charge through intake duct **8**. Intake conduits **27***a*–**27***f* and **15***f*-C, in which all of the cylinders (only two (**7**) of which are shown in a sectional view) **7***a*–**7***f* and associated pistons **22***a*–**22***f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. A compressor **2**, in this figure, a Lysholm type rotary compressor, is shown, which with air conduits, as shown, selectively supplies pressurized air to one or more cylinder intake valves **16**-A. An air inlet conduit **8'** receives atmospheric air from a low-pressure manifold **14**-B, which receives atmospheric air through inlet **9**. Inlet conduits **15**-C, **27***a*–**27***f* or **32** separately supply air charge at atmospheric pressure, or optionally boosted slightly if by conduit **32**, and air which has been compressed to a higher pressure to separate intake valves **16**-A (high pressure) and **16**-B (low pressure) opening to the same cylinder (shown here opening to cylinder **7***a* and **7***f*). Intercoolers **10**, **11** and **12** and control valves **3**, **4**, **5** and **6** are used, controlled by ECM-**27**, in the preferred embodiments, to control the air charge density, weight, temperature and pressure. The intake valves **16***a*-B–**16***f*-B, which receive air through manifold **14**-B, or inlet port **8** and intake conduits **15***a*-C to **15***f*-C or **32** (in Designs 3 through 6), are timed to control the "effective" compression ratio of the engine $100^{2\text{-}B}$ according to the Operational Design 1–6 chosen for the engine. Engines operating in Operational Designs 1 and 2 have compression and expansion ratios that are equal, although Design 2 has a substandard compression ratio set by an oversized combustion chamber. Also, the engine, shown in FIG. **2**, is characterized by the ability to provide an extended expansion ratio, and a low "effective" compression ratio in Operational Designs 3 through 6, and all are capable of producing a combustion charge varying in weight from substandard to heavier-than-normal. It is also characterized by being capable of selectively providing a mean effective cylinder pressure higher than can the conventional arrangement in normal engines with lower maximum cylinder pressure and temperature in comparison to conventional engines. Engine Control Module (ECM) **27** and variable valves **3**, **4**, **5**, and **6** on conduits, as shown, provide a system for controlling the charge pressure, density, temperature, and mean and peak pressure within the cylinder, which allows greater fuel economy, production of greater power and torque, with low polluting emissions for spark ignited, compression ignited, modified HCCI, or true HCCI engines.

In alternate embodiments, a variable valve timing system, with the ECM-**27**, can also control the time of opening and closing of the intake valves **16**-A and/or **16**-B and the opening size of expansion valve **10'** and/or bypass valve R. This system can further provide an improved management of conditions in the combustion chambers to allow for a flatter torque curve and higher power, with low levels of both fuel consumption and polluting emissions. As shown in FIG. **2**-B, FIG. **2**-C, FIG. **11**-B and FIG. **18**-B, the engines of this invention and any current technology Otto or Diesel Cycle engine (FIG. **2**-D) or any other internal combustion engine, can utilize compression-expansion chilled charge air or air/fuel mixture for greater power and efficiency and to lessen polluting emissions. As depicted in FIG. **2**-B, a high pressure charge air or air-fuel mix is expansion chilled by conduits **114** and **113**, receiving highly compressed and cooled air. The air is compressed by one or several stages of compression with intercooling, while conduits **114** and **113** convey the cool, dense air or air-fuel charge to and through optional surge tanks below C and B (shown in phantom), to optional bypass system R and X and/or to expansion valves **10'** and **10"**, pressure-drop-distributors **11'** and **11"**. It is here where the effluent is divided into distributor tubes (evaporator tubes), tube **17***a* and **17'***a*, conveying the effluent to conduits **27***a* and **27***f* and to intake valves **16***a*-A and **16***f*-A respectively, which open selectively into cylinders **7***a* and **7***f*. These evaporator tubes **17** would of necessity be short or combined with the intake valves **16**-A, eliminating conduits **27***a* and **27***f*. The low pressure primary charge intake valves **16***a*-B–**16***f*-B may optionally receive "chilled" charge air also on the intake stroke by way of conduits **15***a*-B–**15***f*-B and optional pressure control **25***a* leading from conduits **27'***a*–**27'***f*.

The air or air-fuel charge can be composed of air and such fuels as gasoline, alcohols, diesel oils, diethyl ether, propane, natural gas, hydrogen, etc. Due to their high density charge and low operating temperature, the Entec Cycle Engine Designs become the most feasible engine for hydrogen fuel operation and for HCCI operations, the only engine for diesel fuel operation.

Brief Description of the Engine $100^{2\text{-}B}$ Shown in FIG. 2-B

The new cycle engine $100^{2\text{-}B}$ of FIG. **2**-B is a high efficiency engine that attains both high power and torque, with low fuel consumption and low polluting emissions. The new cycle is an external compression type combustion cycle. In this cycle, part of the intake air (all of which is compressed in the power cylinders in conventional engines) is selectively compressed by an ancillary compressor **2**. The temperature rise at the end of compression is suppressed by subnormal compression ratios (except in Designs 1) and by use of air coolers **10**, **11** and **12**, which cool the intake air and by the late cylinder injection of temperature-adjusted sec-

ondary air charge and alternatively, by expansion chilling the charge air injected at any point deemed desirable, preferably during the compression stroke, after reaching or passing the point intake valve **16**-B has closed.

Operation

The operation of engine of FIG. **2**-B is the same as that described for the engine of FIG. **1** and FIG. **2**, operating optionally and selectively in one to three modes and where the operating parameters are fully explained. The preferred system is mode 3 operation as described for the engines of FIG. **1** and FIG. **2** in which modes 1 and 2 are combined to produce mode 3, providing somewhat simpler controls, always operating with a supplementary, secondary air injection.

Primary air charging is the same as the various Operational Designs 1–6 described for engines of FIG. **1** and FIG. **2**. The chief difference between engine systems of FIG. 1, FIG. **2** and FIG. **3** is that the secondary air charge added in mode 2 and mode 3 is compression-expansion chilled for greater charge densities and cooler working cycle. This provides greater power and durability along with reduced fuel consumption and lower polluting emissions. Optionally, the primary air charge may also be compression chilled by way of conduit **15**-B receiving charge air from conduit **27**'*a*.

Engine **100**$^{2-C}$ of FIG. **2**-C Operating in Operational Design 1–6

Referring now to FIG. **2**-C, there is shown a six cylinder reciprocating internal combustion engine **100**$^{2-C}$ so constructed and arranged that a compressor **1** receives and selectively compresses charge air which enters through common air intake duct **8**. All of the cylinders (only two (**7**) of which is shown in a sectional view), **7***a*–**7***f* and associated pistons **22***a*–**22***f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. The charge air is alternatively mixed with fuel in carburetor **56** and then bypassed or passed partly or wholly through conduit **102** to bypass or pass partly or wholly through bypass valve **6** or to bypass or to push partly or wholly through conduit **105** to intercooler **10** and through conduits **106** and **110** to compressor **2**. The compressor **2**, in this figure, a Lysholm type rotary compressor, shown with air conduits, selectively, supplies pressurized air to one or more cylinder intake valves **16**-A and **16**-B at different pressure levels to the same cylinder **7***a*–**7***f* (for example, shown here opening to cylinder **7***a* and **7***f*). Intercoolers **10**, **11** and **12** and control valves **3**, **4**, **5** and **6** are used, in the preferred embodiments, to control the air charge density, weight, temperature and pressure. The intake valves **16***a*-B–**16***f*-B receive charge air or air-fuel mix through expansion valve **10'**, pressure-drop-distributor **11'** and distributor tube **17***a* leading from high-pressure conduits **114** and **113** and are timed to control the compression ratio of the engine **100**$^{2-C}$ according to which of the Operational Designs 3–6 is selected. Designs 1 and 2 have fixed compression ratios that are equal to their expansion ratios. Alternatively, the charge density is controlled by either bypass system R and X and/or, by varying the nozzle opening of expansion valve **10'**, and hence, controlling the density and temperature of the incoming charge to valve **16**-B. (Because of noticeable similarities between the engine **100**^{2} of FIG. **2** and that of FIG. **2**-C, reference will be made as deemed helpful to FIG. **2** for certain common components).

The engine **100**$^{2-C}$ shown in FIG. **2**-C is characterized by the ability to provide equal compression and expansion ratios in Operational Designs 1 or 2 and an extended expansion ratio and a low "effective" compression ratio in Designs 3, 4, 5 and 6, all capable of producing a combustion charge varying in weight from substandard to heavier-than-normal and capable of selectively providing a mean effective cylinder pressure (MEP) higher than can the conventional arrangement in normal engines with lower maximum cylinder temperature in comparison to conventional engines. Engine Control Module (ECM) **27** and variable valves **3**, **4**, **5**, and **6** on conduits, as shown, provide a system for controlling the charge pressure, density, temperature, and mean and peak pressure within the cylinder which allows greater fuel economy, production of greater power and torque, with low polluting emissions for spark ignited, compression ignited, modified HCCI, or true HCCI engines. In alternate embodiments, a variable valve timing system with the ECM-**27** can also control the time of opening and closing of intake valves **16**-A and/or **16**-B and the size of the opening in expansion valve **10'**, and/or opening and varying passage through bypass system R and X. This further provides an improved management of conditions in the combustion chambers which allows for a flatter torque curve and higher power, with low levels of both fuel consumption and polluting emissions. As shown in FIG. **2**-B, FIG. **2**-C, FIG. **2**-D, FIG. **11**-B and FIG. **18**-B, the engines of this invention and any current technology Otto or Diesel Cycle engine, or any other internal combustion engine, can utilize compression-expansion chilled charge air for greater efficiency and power and to lessen polluting emissions. As depicted in FIG. **2**-C, the low pressure primary charge air, or air-fuel mix to intake valve **16**-B, is expansion chilled by conduits **114** and **113**, receiving highly compressed and cooled air, compressed by one or several stages of compression with intercooling and conveying the cool dense air or air-fuel charge to expansion valves **10'** and **10"**, pressure-drop-distributors **11'** and **11"**. It is here where the effluent is divided into distributor tubes, tube **17***a* and tube **17***f*, conveying the effluent to intake valves **16***a*-B and **16***f*-B, respectively by way of evaporator tubes **27**'*a* and **27***f*, which open selectively into cylinders **7***a* and **7***f* respectively. Conduits **113'** and **114'** separate, as in conduits **113** and **114**, to convey the same highly compressed density and temperature adjusted charge from conduit **113** and **114** and bypasses expansion valve **10'** and its associated components, and the very dense, cool effluent is directed, without being expanded, to high pressure intake valve **16***a*-A, **16***f*-A, and to the same cylinders **7***a* to **7***f* respectively, for producing great density and steady-state power. Conduits **113'** and **114'** may optionally be fitted with pressure regulators D and E as shown in phantom.

The air or air-fuel charge can be composed of air and such fuels as gasoline, alcohols, diesel oils, diethyl ether, propane, natural gas, hydrogen, etc. Due to its high density charge potential and low operating temperature, the Entec Cycle Engine becomes the best reciprocating engine for hydrogen fuel operation and for HCCI operation, the only engine for diesel fuel.

Brief Description of Operation of the Engine **100**$^{2-C}$ Shown in FIG. **2**-C

The new cycle engine **100**$^{2-C}$ of FIG. **2**-C is a high efficiency engine that attains both high power and torque, with low fuel consumption and low polluting emissions. In this cycle, the intake air is selectively compressed by ancillary compressor **2** and alternatively also by compressor **1**. The temperature rise at the end of compression stroke is restrained by a substandard compression ratio in all designs

except Operational Design **1** (see engine of FIG. **2**) and by use of air coolers **10, 11** and **12**, which cool the intake air and optionally by using chilled primary charge air and selectively by the late cylinder injection during the compression stroke of cool, temperature-adjusted, dense supplementary, secondary air charge.

Operation

The entire air charge is received through inlet port **8** leading to compressor **1**. The air is compressed, cooled and directed to compressor **2** where it is further compressed and has the charge temperature adjusted by intercoolers and bypass system and the high pressure charge is conveyed to conduits **113** and **114**. The charge is then divided and one part conveyed through expansion chillers (items **10'**, **11'**, **17***a* and optionally, R and X) to primary air intake valve **16**-B while another portion of charge is conveyed to secondary intake valve **16**-A optionally, without any expansion of charge, but alternatively, with the pressure regulated by regulators D and E on high pressure conduits **114'** and **113'**.

Mode 1

During operation, a primary air charge is supplied during the intake (1st) stroke to the cylinder **7** through intake valve **16**-B, which air or air/fuel has been highly compressed, cooled and expanded through expansion valve **10'**, pressure-drop-distributor **11'** and distributor tube **17***a*, and conduits **27'***a* and which is preferably mixed with fuel and carbureted. During the intake stroke, intake valve **16**-B closes, specified for either Operational Design 1, 2, 3 or 4, as described for engine of FIG. **2**. At BDC of piston **22**, intake valve **16**-B closes, or is already closed, and the charge is then compressed in the cylinder **7** by piston (2nd) stroke. Fuel is added, if not present, and ignited at the appropriate point near piston TDC for the power (3rd) stroke, the piston expanding to BDC, after which the exhaust (4th) stroke occurs. (The charge density can be from subnormal to as much as 6–7 atmospheres pressure with some designs having an extended expansion ratio, according to the Operational Design selected. All Designs provide high fuel economy and low polluting emissions.) This completes one power cycle in mode 1 and the piston now turns around to begin another cycle. The engine performs with power and low fuel consumption and emissions in this operation mode. The chilled air or air-fuel charge plus the substandard compression ratio of all Operational Designs, except Design **1**, assures very low heat-of-compression for this first portion of charge.

Mode 2

The intake valve **16**-B has opened and closed on the intake (1st) stroke, according to the Operational Design chosen, receiving a chilled primary charge. The piston **22** turns around and begins the power stroke, a secondary (non-expanded) high pressure, dense, cool temperature-adjusted air charge originating from air conduits **113** and **114**, by way of conduits **113'** and **114'**, from just below B and C, is introduced, optionally pressure regulated, into the power cylinder **7**. This occurs preferably during the compression (2nd) stroke of piston **22**, even as late as near TDC, by a second intake valve **16**-A. This intake valve introduces the cool, high pressure supplementary air charge, at any time after the first intake valve **16**-B has closed in order to adjust the temperature and to increase charge density and turbulence of the charge. After the supplementary air charge has been injected, intake valve **16**-A, which can be operated hydraulically or electrically or, in some designs, by cam, quickly closes and the compression (2nd) stroke continues. (The temperature, pressure, amount and point of injection of the supplementary charge, after piston **22** begins the compression stroke, is adjusted to produce the desired results. The later the secondary charge is injected, the lower will be the compression ratio and the heat-of-compression for that portion of the charge also.)

Near the end of the compression (2nd) stroke, fuel is added if not present, the charge is ignited by spark, compression, modified HCCI or HCCI, and combustion produces a large expansion of the combusted gases against the piston **22** for the power (3rd) stroke, producing great energy in any of the Operational Designs 1, 2, 3, 4, 5 or 6. This energy is absorbed and turned into high torque and power.

Near BDC of the piston, exhaust valves **17***a*–**17***f*, **17***a'*–**17***f* (see FIG. 1) open and the cylinder **7** is efficiently scavenged by the (4th) stroke of piston **22**, after which valve(s) **17** close, completing a power cycle.

The air pressure supplied to intake runner-conduit **113'**-**114'**, running between conduits **113** and **114** and intake valves **16***a*-A and **16***f*-A (FIG. **2**-C), is produced at a high level. Not being expanded, as is the primary charge, it remains very dense and cool and may alternatively be pressure regulated. In alternate embodiments, intake valve **16**-A is replaced by a fast-acting, more controllable valve such as, but not limited to, a high speed valve (**21'** of FIG. **4**), which performs either mechanically, hydraulically, electrically, Piezo or vacuum operated under the control of an engine control module (ECM)-**27**. In mode 2 or mode 3, a denser, temperature-adjusted, high-pressure charge, with or without accompanying fuel, can, selectively, be injected, at any time during the compression stroke, or even during the combustion process, in order to adjust the charge temperature and increase charge density, to reduce peak and overall combustion temperatures, and to complete the desired charge mixing before combustion.

In the engine of FIG. **2**-C the primary air or air/fuel charge to valve **16**-B is chilled in all modes by expansion valve **10'** (optionally, some or all of the charge is bypassed by use of R and X) and associated apparatus to cool cylinder and charge and which along with a low compression ratio for that supplementary portion of charge also means low heat-of-compression for both charge portions.

The high pressure cool supplementary charge, entering valve **16**-A after valve **16**-B has closed, is kept dense in order to produce great power.

The expansion valves **10'** can alternatively have variable openings (nozzle(s)), preferably controlled by the ECM-**27** to maintain optimum engine temperature and density in regards to polluting emissions and power requirements. For greater power in either mode, expansion valve **10'** effluent passage may be further or fully opened to direct a more dense charge into valve **16**-B during air intake or, alternatively, valve R may be opened, allowing some or all of the high pressure effluent to bypass expansion valve **10'** by way of conduit X, bringing a denser air-fuel charge into intake valve **16**-B. Either of these system, or the two systems in conjunction, preferably controlled by ECM-**27**, which receives command signals from sensors in the combustion chamber of cylinder **7** and perhaps other locations. In this case, intake valve **16**-B preferably allows piston **22** to go to BDC in the intake stroke before closing, as either valving system of Designs 1 to **6** of FIG. **2** engine can be employed.

Mode 3

The operation of FIG. **2**-C is simplified by combining the operations of mode 1 and mode 2to operate in a single mode,

mode 3, whereby the supplementary, secondary air or air-fuel charge is injected in mode 3 at the same point it would be injected in mode 2 operation, according to the Operational Design of 1 through 6 that is chosen for the particular engine design and duty cycle selected. Thereafter, the engine operates the same as that of mode 2 operation as explained for mode 3 operation in description of FIG. **2** engine. In other words, modes 1 and 2 are not used intermittently. Hence, the engine is operating in the simpler mode 3 continually.

Refrigerated Air Supercharged OTTO and Diesel Cycle Engines Operating in Operational Design 7 4-Stroke Cycle

Referring now to FIG. **2**-D, there is shown a six cylinder reciprocating internal combustion engine **100**$^{2\text{-}D}$ having one atmospheric air intake **8**. It is so constructed and arranged that a compressor **2** receives charge air optionally from air inlet **8** and optionally, compressor **1**. All cylinders **7***a*–**7***f* and associated pistons **22***a*–**22***f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. A compressor **2** in this figure, a Lysholm type rotary compressor and optional compressor **1** are shown, which with air conduits as shown selectively, supplies pressurized thermodynamically chilled air to cylinder intake valves **16***a*-A–**16***f*-A. Intercoolers **10**, **11** and **12** and control valves **3**, **4**, **5** and **6** are used, in the preferred embodiments, to control the air charge density, weight, temperature and pressure before reaching expansion valves **10'** and **10"** or valve bypass system R and X. The intake valves **16***a*-A–**16***f*-A, which receive air through conduits **17***a* and **17'***a*, by way of conduits or evaporator tubes **27'***a*–**27'***f*, are timed to receive and capture all of the air or air-fuel volume possible, with the compression ratio being equal to the expansion ratio as normal, or alternatively, the compression ratio may be varied or may be variable with expansion ratios being inversely varied. Passages of expansion valves **10'** and **10"** are preferably variable in order to also control the temperature and density of the air charge to the engine. The combustion chambers are sized to establish the compression ratio of the engine which is preferably equal to the expansion ratio. Because of noticeable similarities between the engine **100**^{2} of FIG. **2** and that of FIG. **2**-D, reference will be made as deemed helpful to FIG. **2**-D for certain common components.

The engine **100**$_{2\text{-}D}$ shown in FIG. **2**-D, optionally may cause the air intake valve **16**-A to close early or late in order to provide alternatively equal compression and expansion ratios or to provide an extended expansion ratio with a substandard "effective" compression ratio. It is optionally capable of producing a combustion charge, varying in weight from substandard to heavier-than-normal, and is optionally capable of selectively providing a mean effective cylinder pressure (MEP), higher than can the conventional arrangement in normal engines with lower maximum cylinder pressure and with lower maximum temperature in comparison to conventional engines. Engine Control Module (ECM) **27** and variable valves **3**, **4**, **5**, and **6** on conduits, as shown, provide a system for controlling the charge pressure, density, temperature and mean and peak pressure within the cylinder which allows greater fuel economy, production of greater power and torque, with low polluting emissions for spark ignited, compression ignited, modified HCCI, or true HCCI engines. (For HCCI operation, Method F of FIG. **19**-C or Method G of FIG. **19**-D is suggested for combustion chamber temperature control).

In alternate embodiments, optional variable opening expansion valves **10'** and **10"** along with pressure-drop-distributor **11** and expansion tubes **17***a*–**17'***a* along with conduits **27'***a*–**27***f* in conjunction with bypass control valve R and conduit X, provide an additional means of controlling charge density to further provide an improved management of conditions in the combustion chambers to allow for a flatter torque curve and higher power with low levels of both fuel consumption and polluting emissions.

As shown in FIG. **2**-D, the engines of this invention and any current technology, Otto or Diesel Cycle engine, or any other internal combustion engine or turbine can utilize compression-expansion chilled charge air for greater power and efficiency and engine durability and to lower polluting emissions. As depicted in FIG. **2**-D, the high pressure charge air or air-fuel is chilled by conduits **113** and **114**, receiving highly compressed and cooled air, compressed by one or several stages of compression with intercooling. Then, conduits **113** and **114** convey the cool dense air or air-fuel charge to and through optional surge tanks below C and B (not shown) to expansion valves **10'** and **10"** (with optional variable openings), pressure-drop-distributors **11'** and **11"**. The latter divides the effluent into distributor (evaporator) tubes, tube **17***a* and tube **17***f*, conveying the effluent by way of conduits or evaporator tubes **27'***a*–**27'***f* to intake valves **16***a*-A and **16***f*-A, which open selectively into cylinders **7***a* and **7***f* respectively. A bypass system composed of control valve R and conduit X, perhaps in conjunction with variable valves **10'**-**10"**, permits fine-tuning of the charge density and temperature by allowing the charge to go to intake valves **16**-A at different degrees of expansion (perhaps from no expansion to 70 psig), the latter still being a five atmosphere pressure boost in order to control power level and emissions characteristics of engine. These two systems working together alternatively adjust the density and the temperature in order to fine-tune control of the air or air-fuel charge of the engine.

The air or air-fuel charge can be composed of air and such fuels as gasoline, alcohol, diesel oil, diethyl ether, propane, natural gas or hydrogen, etc. Due to its high density charge and low operating temperature, the engine also becomes a superior engine for hydrogen or diesel fuel operation.

If the cooled air or air fuel charge in conduits **114** and **113** was at a level of, say 200 psi, it could be expanded to a very cold 70 psig working charge, which is about a 5 atmospheric pressure boost. If the initial cold charge was 100 psi, it could be expanded to 15 psi gage for a one atmosphere boost, or it could be expanded to a cold charge of less than atmospheric pressure for an extended expansion combustion process.

Brief Description of Operation of the Engine **100**^{2D} Shown in FIG. 2-D

The new engine **100**$^{2\text{-}D}$ of FIG. **2**-D is a high efficiency engine that attains both high power and torque, with low fuel consumption and low polluting emissions. In this engine design, the entire intake air charge is selectively highly pre-compressed by an ancillary compressor **2** and optional compressor **1**. The temperature rise at the end of compression is reduced by use of air coolers **10**, **11** and **12**, which cool the charge air. The air charge is then compression-expansion chilled and injected into the power cylinders which temporarily become "evaporators.".

During operation, an air charge, originating from air conduit **8**, by conduits **110** and **109**, intercoolers **10**, **11** and **12**, compressors **1** and **2**, conduits **113**-**114**, expansion valve

10', 10", pressure-drop-distributor 11' and 11", and distributor tubes 17*a* and 17'*a* in FIG. 2-D, is introduced into the power cylinder 7 by way of conduits 27'*a*–27'*f* during the intake stroke by intake valve 16-A, which introduces the expanded chilled air charge in order to adjust the temperature, turbulence and charge density. After the air charge has been injected, intake valve 16-A, which can be operated hydraulically of electrically, or in some designs, by cam, closes at the BDC. The initial air charge may be boosted to a higher pressure by cutting in an optional second ancillary compressor, in series with compressor 2 (see for example, compressor 1 in FIG. 2-D). The main compressor to be used in the engine of FIG. 2-D is the compressor 2, shown in FIG. 2-D, for example as, but not limited to a Lysholm rotary type, between air inlet 8 and conduits 113, 114 with the air being intercooled and optionally expansion chilled.

Alternatively, the air bypass valve (ABV) 6 can be opened to re-circulate charge air back through the compressor 1 in order to relieve the compressor of compression of some of its work during light-load operation. Additionally, compressor 2 work can be decreased or increased by control valve 4 as needed.

Alternately, inlet ports 17-A and 17-B of FIGS. 3, 4, 7 and 10 are placed in the cylinder wall and a portion of the compressed air is directed to inlet ports 17-A, as shown in these figures, and injects air between cylinder 7 wall and piston 22. This will provide cooling for the engine and sweep the area and crevices clean of unburned hydrocarbons and also prevent the formation of formaldehyde. In any of the engines of the present invention, the cooling system in, and described for, FIG. 6 may be used to help control the temperatures perhaps most importantly in military and/or HCCI operation.

The expansion valves 10' can alternatively have variable size nozzles and bypass system, valve R and conduit X, controlled by the ECM-27 to maintain optimum engine temperature and density in regards to polluting emissions and power requirements. Again, alternatively, the expansion valves may be combined with high-speed cylinder intake valves into one unit.

Operation

Atmospheric air is received by duct 8, compressed by compressor 1 where optional carburetor 56 mixes air and fuel and optionally directs charge through intercooler 10. The air is then directed to compressor 2 and bypass valves 3 and 4 where part, or all, of the charge is compressed and directed to intercoolers 11 and 12. This is where part, or all, of the charge is cooled and directed to conduits 113 and 114, leading to expansion valves 10' and 10", pressure-drop-distributors 11' and 11" and distributor tubes 17*a* and 17'*a* which distribute the charge, by way of conduits 27'*a*–27'*f*, to intake valves 16*a*-A to 16*f*-A which receive the cold charge air into cylinders 7*a* to 7*f*. Valves 16*a*-B to 16*f*-B are exhaust valves leading to exhaust pipes 18 which lead to turbine of optional turbo-charger compressor 1 and to the atmosphere at turbo-charger outlet 18. The engine operates in the conventional manner. Atmospheric air is received through inlet duct 8, compressed by compressor 1, cooled, passed to compressor 2 where it is further compressed, and cooled by intercoolers 11, 12. and sent to expansion chiller system 10', 11' and 17' where the air or air/fuel charge is expanded and ducted to cylinder 7 intake valves 16*a*-A–16*f*-A by way of conduits 27'*a*–27'*f*. Alternatively, pressure-drop expansion is regulated and perhaps reduced by variable expansion valves 10' and/or partly or wholly bypassed through R-X system and the charge goes to inlet valves at the temperature and density required at any particular time preferably controlled by ECM-27, FIG. 2.

Action

Intake valve 16-A opens and piston begins intake (1st) stroke. The expanding charge enters intake valve 16*a*-A–16*f*-A of cylinder 7, chilling aided by the low pressure in cylinder. Near or at BDC of piston 22, intake valve closes, piston reverses and (2nd stroke) compresses the cold charge to perhaps 10–15 degrees before, or at TDC, where the charge, fuel being present, or now injected, is ignited, driving the piston in the power (3rd) stroke. Near BDC, exhaust valves (17 in FIG. 1) open and piston 22 performs the scavenging (4th) stroke. Near TDC, exhaust valves close and intake valve 16-A opens to begin the next cycle.

A single rank of cooler 9, conduit 9', manifold (C and B, not shown), expansion valve 10', pressure-drop-distributor 11' and evaporator tubes 17*a* and 27*a* of the air chilling system may be employed for cylinder charging, as shown in FIG. 11-B, rather than the dual systems illustrated for the engine of FIG. 2-D.

Advantages

(1) In general, a cold air charge gives greater steady-state power with lower peak temperatures and pressures for lower polluting emissions.

(2) The expanded charge intake valve 16-A can be closed early, or at BDC and the compression (2nd) stroke begins for a normal or a substandard compression ratio, the latter providing an extended expansion ratio, for even lower peak pressures and temperatures and higher efficiency.

(3) When using the charge expanded, the charge pressure can be from 5–7 atmospheres more or less or can be expanded to less than one atmosphere for an extended expansion ratio.

(4) Power can be adjusted for power or cruising by adjusting the density and pressure of the initial charge and by adjusting expansion valve 10' nozzle to control chilling versus power and/or alternatively, bypassing part or all of the charge through bypass system, valve R and conduit X. (If all, or most of the charge bypasses expansion valve 10', the pressure of the charge entering cylinder 7, can be regulated by optional pressure control valves D and E).

(5) If the compressed air charge is expanded until it is much colder, but less dense than in normal engines, a larger displacement engine will provide greater power in an even cooler working cycle, with low polluting emissions and much longer engine life—ideal for power generation, pumping, etc.

(6) In any engine designs using compression-expansion air charge-chilling, the pressure of the charge can be adjusted so that after intercooling and expanding, the charge entering the cylinder can be much denser and cooler than in current engines. This produces much greater steady-state power and durability with lower emissions than that of normal engines.

(7) Increased turbulence and cooler charge results in much lower polluting emissions, especially HC, NO_X and particulates.

(Refrigerated air charge 2-stroke engines are described hereafter for FIGS. 8, 9 and 10).

4-Stroke Engine Operating in Operational Design 1–6

Referring now to FIG. 3, there is shown a part sectional view through one power cylinder of the 4-stroke engine of

FIG. **3**, at the two intake valves, showing an alternative method (adaptable to other embodiments of the present invention) of high-pressure air charging and showing a means of mixing fuel and air and of passing air between cylinder wall and piston. This is in order to prevent formation of formaldehyde, CO and unburned hydrocarbons (HC), and of closing bottom inlet port(s) **17**-B while popette valve **16**-A is closing high-pressure inlet from conduit **15**-A and top inlet to conduit **17**.

The charge air or air-fuel may be compressed and cooled for any of Operational Designs 1 through 6, as described and illustrated for FIG. **1**, FIG. **2**, FIG. **2**-B and FIG. **2**-C engines. Additionally and alternatively, compression-expansion chilling may be employed before induction into cylinder **12**, the latter system by employing the compression chiller system shown in, and described for FIG. **2**-B, FIG. **2**-C, FIG. **2**-D, FIG. **11**-B and FIG. **18**-B, items **10'**, **11'**, **12**, **17***a* and **27'***a*, supplying chilled, high-pressure air through intake valve **16**-A by one or more compressors, with the engine operation being the same as that described for engine of FIG. **2**. Alternatively, the high-pressure conduit can divide, as in FIG. **2**-C, and supply air to both inlets **16**-B and **16**-A, with valve **16**-B receiving the compression-expansion chilled primary charge and intake valve **16**-A receiving the dense and cooled high-pressure air charge, with the engine operation being the same as that of FIG. **2**-C with optional pressure regulator on the secondary air charge inlet conduit **16**-A.

Mode 1

The operation of this engine is similar to the operation of the engine of FIG. **2** or FIG. **2**-C, operating in either system of Design 1 through Design 6, as described for engine of FIG. **2**, with low-pressure air, or alternatively expansion chilled air or air-fuel entering cylinder **12** through intake valve **16**-B on the intake (1st) stroke in which alternatively, intake valve **16**-B may be closed before, at or after BDC to capture either a normal or small air charge, (Designs 1 through Design 4 in FIG. **2**). (In closing after BDC, the intake valve may be left open to near TDC on the compression (2nd) piston stroke. Therefore, the primary charge would be expelled after cooling cylinder **12** (Design 4 of FIG. **2** engine). At the end of the intake stroke, compression (2nd) stroke begins and near TDC of piston, the fuel-air charge is ignited for the power (3rd) stroke. Then the scavenging (4th) stroke occurs and a new power cycle begins. This produces normal power with low fuel consumption and low polluting emissions.

Optional Mode 2

When more power is needed, intake valve **16**-B opens and receives the primary air charge by the intake (1st) piston stroke. Then a high density, supplementary air charge is injected as follows: Preferably during the compression (2nd) stroke to as far as TDC, high-pressure intake valve **16**-A opens (always after valve **16**-B closes) and closes quickly, injecting temperature adjusted, high-pressure air from conduit **15**-A as described for engines of FIG. **1** or FIG. **2**. (The compression ratio and, hence, the amount of heat produced for this second portion of air depends on the point in the compression stroke that the second portion of air is injected). Inlet valve **16**-A is preferably activated by valve mechanism represented by **21'**, which can open and close within 40° crank angle. The valve **16**-A can be of any fast-acting type. The incoming air streams **15**-A and **15**-C can be both carbureted (except for Design 4) or alternatively, singularly carbureted, or fuel can be added at any point including cylinder injection for a homogenized air/fuel mixture.

During or at the end of the compression stroke, as inlet valve **16**-A opens, part of the inlet air passes into cylinder **12** directly and part of the compressed charge travels past the now open valve **16**-A (which can be structured in various ways) into conduit **17** to common air rail (in phantom) **17**-A. Here, the charge is directed to inlet port(s) **17**-B (which can be singular with air rail **17**-A being eliminated).

The high-pressure air or air and fuel enters high pressure cylinder valve **16**-A for excellent turbulent mixing of the charge. The compression (2nd) stroke continues, piston **22** covers port(s) **17**-B and valve **16**-A closes, earlier or later, covering both port from conduit **15**-A and top open port to conduit **17**. The place in the cylinder wall best suited for mixing, cooling, etc. should be chosen for placing inlet port(s) **17**-B by experimentation and calculations. The secondary high-pressure air charge mixes any charge in the cylinder, adjusts temperature and adds density to produce greater power, fuel economy and low polluting emissions, with low peak temperatures and pressures, further reducing polluting emissions and providing longer engine life. As the piston **22** continues to rise in the compression (2nd) stroke, less heat of compression, and no heat of compression for Design 4 of FIG. **2** engine, reduces NO_X and CO formation. Also, the heat of compression for the secondary air charge is low and the compression ratio of that portion is set by the point in the stroke this air was injected. Particulates are also greatly reduced because of the homogenizing of the charge for more complete combustion. Unburned hydrocarbons (HC) are reduced greatly because of better mixing of fuel and oxygen and, in addition, the gentle air injection between cylinder wall **12** and piston **22** as the piston passes open ports **17**-B cleans out piston ring crevices where unburned fuel hides. This also vents and cools space between piston **22** and cylinder **12** walls above the first piston ring where most formaldehyde forms. At near TDC the charge is ignited by spark, compression (glow plug), modified HCCI or HCCI. During the power (3rd) stroke, the pressurized air, which is trapped in conduit **17**, is released as piston uncovers inlet port(s) **17**-B, the trapped compressed air in conduit **17** rushes out **17**-B, again cleaning crevices and space between cylinder wall **12** and piston **22** for more complete combustion. The piston **22** now rises in the scavenging (4th) stroke and a new cycle begins. (If Design 4 of the engine of FIG. **2** is utilized, an outlet valve **16**-C (not shown) or intake valve **16**-B stays open until near TDC on the compression stroke and expels the full or almost complete primary charge near TDC using it only to cool cylinder **12** with the supplementary supercharge supplying all charge needed, being injected by valve **16**-A near TDC.)

Mode 3

Mode 3 operation constitutes a method of operating the engine of FIG. **3** in a single mode with full power and efficiency by combining mode 1 and mode 2 operations as described for engine FIG. **2**, and operating alternatively in any of the Operational Designs described. This mode is simplified by eliminating valving, etc., which are required to operate modes 1 and 2 intermittently.

4-Stroke Engine Operating in Operational Design 1–6

Referring now to FIG. **4**, there is shown a part sectional view through one power cylinder similar to the 4-stroke engine of FIG. **1**, FIG. **2**, FIG. **2**-C, and FIG. **3** at the two

intake valves, operating in any system of Operational Design 1 through Design 6, as described for engine of FIG. **2**. This shows an alternative method (adaptable to other embodiments of the present invention) of supplementary high pressure air charging after the primary air has been induced by the intake (1st) stroke. This is a means of increasing charge density and of mixing fuel and air and of passing air (somewhat differently from that of FIG. **2**, FIG. **2**-C and FIG. **3**) between cylinder wall **12** and piston **22** and of cleaning out piston ring crevices in order to prevent formation of formaldehyde, CO, unburned hydrocarbons (HC) and of closing inlet port(s) **17**-B while inlet valve **16**-A is closing. Low peak temperatures and high turbulence greatly reduce NO_x emissions and particulates.

Mode 1

The operation of the engine of FIG. **4** is similar to that of FIG. **2**, FIG. **2**-B, FIG. **2**-C and FIG. **3**, with the primary air charge in all designs except Operational Design 1 of FIG. **2** engine, alternatively having a low compression ratio with cool or chilled, low pressure primary air, or air-fuel charge coming in on the intake (1st) stroke of piston **22**, which is then compressed (2nd stroke) and, with fuel present, is fired for normal power (3rd stroke) such as cruising with low polluting emissions. The scavenging (4th) stroke follows. This completes one power cycle.

Mode 2

When greater power is needed. the operation is thus: following the intake (1st) stroke of piston **22**, a supplementary, secondary high-pressure air or air-fuel charge is injected during or at the end of the compression (2nd) stroke, by intake valve **16**-A. The supplementary air entering cylinder **12** is solely from conduit **17**, through common air-rail **17**-A and inlet port(s) **17**-B. This is another means of homogenization, increasing density and adjusting the density and temperature of the charge. (Common air-rail **17**-A and all but one of inlet ports **17**-B may be eliminated.)

Alternatively, the primary or supplementary charge air or air-fuel charge can be compression-expansion chilled before intake into cylinder **12** through valve **16**-B or **16**-A respectively by utilizing the expansion valve chiller system depicted in and described for FIG. **2**, FIG. **2**-C and FIG. **3**.

Detailed Operation of Mode 3 (Single Mode Operation)

Intake valve **16**-B opens, piston **22** descends in intake (1st) stroke to admit atmospheric pressure air or air boosted in pressure, which is alternatively cooled or chilled. The primary charge intake system is either of the Methods of Primary Air Charging of Operational Designs 1 through Design 6, as described for engine of FIG. **2**. After the primary charge has been received and intake valve **16**-B has closed, the piston **22** reaches BDC and the compression (2nd) stroke begins. During the compression stroke of each cycle, intake valve **16**-A opens and injects a supplementary, secondary cool or chilled, dense air charge into port **17** and through port **17**A or ports **17**-B. After port(s) **17**-B, which can be of any number or place deemed appropriate within cylinder **12** wall are closed, compression continues and at, or near TDC of piston **22**. Ignition then takes place for the power (3rd) stroke, followed by the 4th or exhaust stroke. In the engine of FIG. **4**, compressed air sweeps out ring crevices and space above top piston ring between piston and cylinder wall and some of the compressed air is trapped in conduit **17** during the compression stroke. As piston **22** expands in the power stroke, the residual compressed air in conduit **17** expands against piston **22**, again cleaning out crevices and other spaces and then expands into the cylinder, further mixing oxygen and fuel for more complete combustion. Operation is the same as that of Operational Designs 1–6 of FIG. **2**, FIG. **2**-B. FIG. **2**-C and FIG. **3** engines.

Military Model 4-Stroke Air-Cooled Engine Operating in Operational Designs 1–6

Referring now to FIG. **5**, 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 4-stroke cycle, operating in either system of Design 1 through Design 6, as described for engine of FIG. **2**, FIG. **2**-B and FIG. **2**-C and representing a preferred embodiment of the apparatus of the present invention, from which a first method of operation can be performed and will be described. Among its other components, this embodiment is seen as having an auxiliary cooling system to provide engine cooling during such time as the liquid cooling system should be damaged. Due to the overall cooler working cycle of the engine of this invention air-cooling becomes simple and efficient.

The operation of the engine is the same as the operation of the engine of FIG. **2** with a first mode and optional second and preferred third modes of operation, as described for engine of FIG. **2**, FIG. **2**-C, FIG. **3** and FIG. **4** with the following alternative arrangements:

The engine of FIG. **5** is fitted with a high performance air compressor, which could be a dedicated compressor (not shown), or the compressor **2** of FIG. **2** or FIG. **2**-C and could be fitted with branching conduits, one of which would be fitted with control valve(s) and lead from fittings C and B, FIG. **2**-C leading from intercooler(s) **11** and/or **12** of FIG. **2**-C, and would be attached to an inlet port in the engine head or engine block, in this case, engine head at port **4**. Engine port **4**, alternatively, is fitted with an expansion valve **4'**. Thus, expanding cool, highly compressed air is sent through ports and passages in engine or alternatively pumped through port **4** and expansion valve **4'**, sending the expanding air chilled through passages which now become evaporator tubes within the engine head and block. In addition, the compressed cool and chilled air can be directed through cooling channel(s) **6** of FIG. **6** in walls of cylinder sleeve **12** of FIG. **6**.

The system for supplying compression-expansion chilled air, which can alternatively be used for both engine operating charge air and engine cooling air is described for engine of FIG. **2**-C, FIG. **3** and FIG. **4**, in which system any type of efficient compressor system may be employed.

Military Model 4-Stroke New Cycle Engine

Since about fifty percent of combat vehicle engine failures during battle conditions are historically due to loss of the cooling system, the ability to switch to auxiliary cooling will be a boon to the military, allowing the vehicle to continue in its duty and to return home. When running on auxiliary cooling, the engine uses about twice the amount of compressed air as when liquid cooled. For this reason, when switched to air-cooling, fuel economy is slightly compromised, but for the military, under battle conditions, this will be happily tolerated.

There are several designs of the New Cycle Engine that are capable of providing efficient auxiliary cooling at such a time that the liquid cooling system should fail. Described here are only two such designs for a 4-stroke engine and three such designs for a 2-stroke engine.