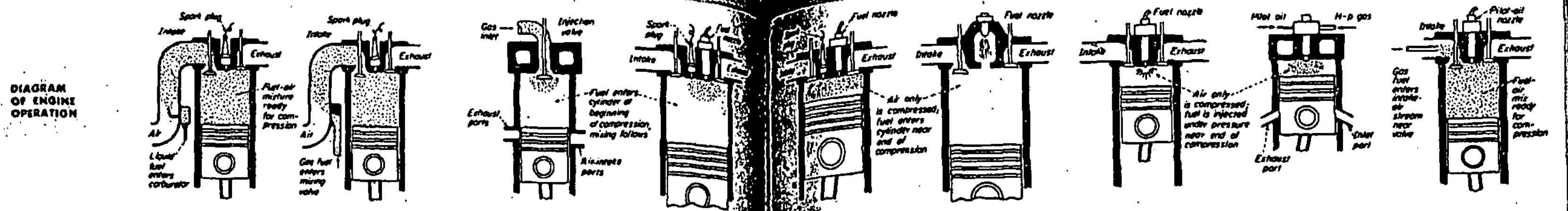
FUEL INTRODUCED BY:	CARBURETOR	MIXING VALVE	L-P INJECTION	HIGH-PRESSURE INJECTION					INDUCTION
WHEN AND WHERE FUEL AND AIR MIX:	OUTSIDE CYLINDER, BEFORE COMPRESSION		INSIDE CYLINDER, EARLY IN COMPRESSION			INSIDE CYLINDER, AT END OF COMPRESSION			OUTSIDE, BEFORE

DIAGRAM OF ENGINE OPERATION



COMPRESSION	LOW		LOW		LOW		HIGH		
IGNITION METHOD	SPARK		SPARK			HOT-SURFACE	COMPRESSION	COMPRESSION PLUS PILOT OIL	

OUTLINE OF ENGINE'S CYCLE OF EVENTS

GASOLINE ENGINE

1. Carburetor vaporizes fuel and mixes it with air in proper proportions
2. Suction stroke, with inlet valve open, fills cylinder with mixture
3. Compression stroke raises mixture pressure to 100-225 psi
4. Spark ignites mixture near end of compression stroke
5. The fired mixture expands, pushing piston down
6. Exhaust valve opens; rising piston clears cylinder of burned gas

GAS ENGINE

1. Mixing valve blends air and gas fuel in proper proportions
2. Suction stroke, with intake valve open, fills cylinder with mixture
3. Compression stroke raises mixture pressure to 75-300 psi
4. Spark ignites mixture near end of compression stroke
5. The fired mixture expands, pushing piston down
6. Exhaust valve opens; rising piston clears cylinder of burned gas

INJECTION GAS ENGINE

1. Air enters cylinder through inlet ports in cylinder wall
2. Piston closes inlet and exhaust; starts to compress
3. Gas fuel is injected at low-pressure early in compression stroke
4. Resulting mixture is compressed to 70-300 psi, depending on fuel
5. Spark ignites mixture near end of compression; fired mixture expands
6. Piston moves down on "working" stroke; uncovers exhaust ports near end

INJECTION GASOLINE ENGINE

1. Suction stroke, with inlet valve open, fills cylinder with air
2. Inlet valve closes; compression begins, fuel enters under high pressure
3. Fuel and air mix as compression stroke raises pressure to 100-225 psi
4. Spark ignites mixture near end of compression stroke
5. The fired mixture expands, pushing piston down
6. Exhaust valve opens; rising piston clears cylinder of burned gas.

HESSELMAN ENGINE

1. Suction stroke, with inlet valve open, fills cylinder with air
2. Compression stroke raises pressure to 115-135 psi
3. Fuel injection is completed before compression stroke end
4. Spark, just before compression ends, ignites fuel vaporized by compression and stored heat
5. Expansion pushes piston down
6. Exhaust valve opens, rising piston clears cylinder

VAPORIZING OIL ENGINE

1. Suction stroke, with inlet valve open, fills cylinder with air
2. Injected fuel vaporizes, mixes with burned gas, doesn't burn
3. Compression stroke (60-150 psi) forces air into vaporizer
4. Heated surface of vaporizer ignites mixture near compression end
5. Combustion is explosive, pushes piston down
6. Exhaust valve opens; rising piston clears cylinder

DIESEL ENGINE

1. Suction stroke, with inlet valve open, fills cylinder with air
2. Compression stroke raises pressure to about 500 psi
3. Fuel injection starts at or near end of compression stroke
4. High air temperature, caused by compression, ignites fuel
5. Burning mixture expands, pushing piston down on "working" stroke
6. Exhaust valve opens; rising piston clears cylinder

GAS-DIESEL ENGINE

1. Air enters cylinder through inlet ports
2. Piston closes inlet and exhaust; compresses air to about 500 psi
3. Near end of compression, fuel gas and pilot oil are injected
4. Heat of compression ignites fuel; pilot oil stabilizes combustion
5. Burning mixture expands, pushing piston down
6. Near end of stroke, piston uncovers exhaust and inlet ports

DUAL-FUEL ENGINE

1. Inlet valve opens; suction stroke fills cylinder with air and gas
2. Compression stroke raises pressure of mixture to about 500 psi
3. Near end of compression, pilot oil is injected to initiate combustion
4. Heat of compression ignites pilot oil, which causes mixture to burn
5. Resulting expansion pushes piston down
6. Exhaust valve closes; rising piston clears cylinder

How Diesel Engines Work

Like the familiar engine under the hood of your car, the diesel is an *internal-combustion engine*. The fuel-air mixture burns *inside* a cylinder and resulting expansion pushes directly on a piston which, through a connecting rod, turns the engine shaft and generates mechanical power.

Family Characteristics. The fact that the fuel burns within the engine itself sets these units apart from steam engines and turbines, the other commonly used prime movers. As you would expect, all internal-combustion engines bear a strong family resemblance. All have these basic mechanical features: a *cylinder* in which fuel is fired, a *piston* to receive expansive force of burning fuel and convert it into mechanical motion, a *connecting rod* and *crankshaft* (or their equivalent) to turn up-and-down motion of pistons to rotating motion suitable for driving electric generators, turning machinery or spinning propellers. In addition, suitable *valves* must control flow of air, fuel and exhaust gas, and there must be reliable means for igniting fuel.

All internal-combustion engines operate in the same general way. Each *cycle*, or series of events taking place in the cylinder, involves four steps: (1) cylinder is charged (2) charge is compressed and ignited (3) burning charge expands, pushing on piston, and (4) burned gas is exhausted so cylinder can be recharged.

Nine Basic Types. Although alike in major respects, there are nine basic kinds of internal-combustion engines. They differ mainly in the fuels they handle, when and where the fuel and oil mix, how much the charge is compressed and how it is ignited. These differences account for differences in efficiency, performance and cost, and hence in application. A quick look at these types, as compared above, yields a better appreciation of the diesel principle and its *relation* to the others.

When fuel and air mix is perhaps the most important consideration; the nine types divide into two groups on this point—those in which mixing occurs *before* compression and those in which it occurs *near the end*. They likewise divide into two groups with respect to compression pressure, which is related to when and where fuel and air mix. The key importance of these two matters can best be seen by looking closely at an example of each—the gas engine and the diesel.

Gas-Engine Operation. A *mixing valve* proportions and brings together the fuel, already in gaseous form, and the air. The mixture flows into the cylinder and is compressed. Near the end of compression, an electric spark ignites the inflammable mixture, which burns explosively. Cylinder pressure rises rapidly and acts on the piston to move it downward on its *power stroke*.

The familiar fact that compressing a gas raises its temperature works against us in *this case*, just as we'll see later that it works for us in the diesel. Compressing the fuel-air mixture may make it hot enough to *self-ignite* before end of the stroke. Such *preignition* (and the *detonation*, or "knocking" familiar to the motorist, which also results from too-high *compression pressure*) causes loss of power. It can be seen that compression pressure must be limited in this type of engine. Is that good or bad? Let's take a look at the business of *compression ratio* and see.

Compression ratio is the volume of the cylinder at the beginning of the stroke divided by the volume at the end, as shown in the diagram on the next page. Pressure at end of compression is roughly proportional to compression ratio. It is important for two major reasons: (1) theoretically, the higher the compression ratio, the more efficient the engine, and (2) in general, the higher the compression ratio, the stronger and heavier must be the engine.

Thus, although it is desirable to raise compression ratio, in engines where fuel and air mix before compression the nature of the fuel imposes a limit. This explains the intensive effort given to developing high-octane or anti-knock gasolines. These finer fuels permit higher compression ratios—up to 9 to 1 for 100-octane aviation gasoline as against 6 or 7 to 1 for ordinary motor fuels. (See POWER, June 1945, pp 79-83 for a more complete discussion of compression ratio and anti-knock fuels.)

Diesel Principle. In contrast to engines in which fuel and air mix before compression stand those in which only air is compressed and fuel enters it near end of compression. In the diesel, prime example of this class, heat of compression is used to ignite the fuel.

In a typical diesel, air is compressed to about 450 psi, which brings it up to about 1000 F. When finely atomized oil is sprayed into this "red-hot" air, it ignites and burns. Thus, in the diesel, the high compression ratio needed for reliable ignition means inherently high efficiency.

How Much Compression? Because, in practice, compression ratios above those needed for ignition return little or no gain in efficiency, it is customary to go no higher. The pressure and temperature resulting from a given compression ratio depend on engine speed, cylinder size and other design factors. Typical compression pressures in diesels range from about 450 to 600 psi, with small high-speed engines generally having higher compression pressures than large low-speed engines.

In engines with combustion chambers of special design, compression pressure may run *as low as 350 psi. If* a heating device for cold starting is provided, compression pressure can be brought down to about 250 psi. After a brief warmup, such an engine will operate by self-ignition. Where ignition devices of one kind or another are used during operation, compression pressure can be still lower. Surface-ignition engines usually show compression pressures ranging from 60 to 150 psi. The Hesselman engine, featuring *fuel injection and spark ignition*, operates at compression pressures of about 125 psi.

Thus in engines where air alone is compressed, pressure depends largely on ignition method, being necessarily higher for compression-ignition engines than *for* those with ignition devices. Both types offer advantages.

Diesels, with high compression