A LOOK AT THE DIESEL SITUATION

By O. FRANKLIN ZAHN, JR., '30

"The amazingly rapid development of the light, high-speed engine is the most outstanding single achievement in the development of the internal combustion engine" . . . this from a celebrated British mechanical engineer. However far we go in agreeing with this statement, we must admit that this progress "is a development . . . almost of the last ten years."

For a comparatively long period, from 1897 when a diesel first ran in one piece, until 1925, the diesel was a purely capital goods product, and applied as a large, heavy, slow speed unit to motorships, oil pumping stations, generating plants, submarines, and a few switching engines, etc. Then about ten years ago a small, lightweight, high speed diesel appeared in large quantities in Germany and England, and showed its face elsewhere, including this country.

Diesels were being applied to automotive applications such as trucks, tractors, and small motor boats where previously only a few experimental models existed. Since 1931 one American company alone has produced 2,500,000 horsepower in small diesels where previously it produced none. Almost all of the diesel streamliners have been put into service in the last five years.

CHANGE IN THINKING

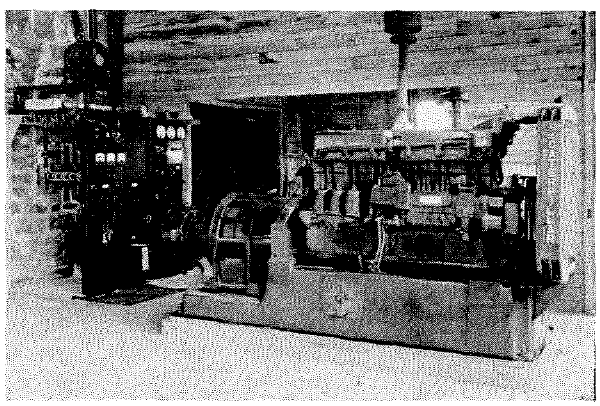
The interesting thing about this tremendous growth is that it has come about because of a change in thinking rather than because of any changed economic condition, a change in thinking on the part of engineers the world over who dealt with the internal combustion engine. Formerly, an engineer was not considered well educated unless he "knew" that a diesel engine was inherently an efficient but slow-speed, heavy and expensive engine, practical only in large sizes. Until about 1925 the diesel remained exactly that, but today we realize that those were qualities in our thinking and not inherent in the diesel itself. Today diesels whose top speed is 4,000 R.P.M. are sold in France, whereas one-fifth that speed was considered high ten years ago. This same engine has a displacement of only 27 cubic inches per cylinder, which is less than that of any American six cylinder passenger car engine. Germany has for several years used diesels in commercial airline operation weighing two pounds per horsepower. It is true these examples are the superlatives to date, but at least they are commercial realities and not sporadic laboratory performances.

When Americans first realized about a decade ago that the theretofore sedate diesel was capable of far more than the inhibitions which chaperoned it in the past had permitted, there was naturally a wave of enthusiastic reaction. The ballyhoo that swept over the diesel industry at the start of the present decade was hardly more conducive to level headed, orderly development than were the previous prejudices. Today, however, the diesel is being evaluated more from middle ground. We know the diesel has certain capabilities and certain limitations, not necessarily "inherent," but definitely present.

HIGH EFFICIENCY

The primary advantage of the diesel has been and still is its operating efficiency. Fig. 1 shows a comparison of fuel consumption of typical diesel and gasoline motors. Not only has the diesel a lower curve but it has a flatter curve over the load range. In a truck application where the engine operates over a wide load range the diesel shows the greatest advantage, operators finding that the diesel truck gets 80 per cent more miles per gallon than the gasoline truck, in addition to the fact that the fuel costs less. The second most important advantage of the diesel is its reduced fire hazard, a factor which was mainly responsible for the U. S. Navy converting its shore boat fleet from gasoline to diesel. Other items, as the reduced carbon monoxide in the exhaust are advantages in special applications as mines, are not important generally.

The chief disadvantage of the present diesel is its first cost. In spite of all our progress the diesel is still more expensive to build than either the large steam plant or the small gasoline engine. For this reason it is necessary for the diesel to run a minimum number of hours per year to show economy over other power. For example in England, where there is the American equivalent of a tax of 13 cents per gallon on both fuel oil and gasoline, a London omnibus must run at least 22,000 miles per year to pay as a diesel. Diesels still weigh more than the equivalent gasoline engine, be it aircraft, truck, tractor, or marine service.



Diesel Engine and 60 K.W. Generator

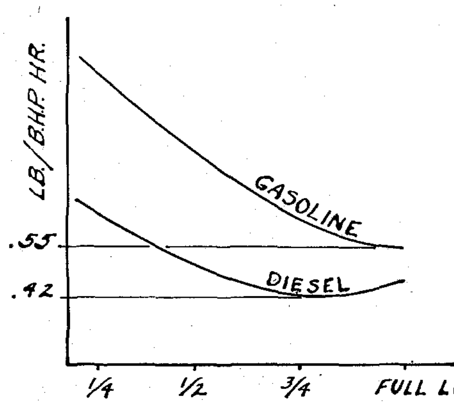


Fig. 1—*Load Economy Curves for Diesel and Gasoline Engines.*

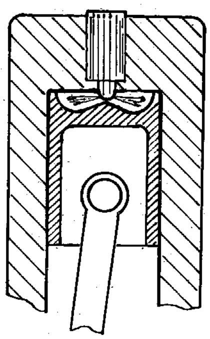


Fig. 2—*Direct Injection Chamber.*

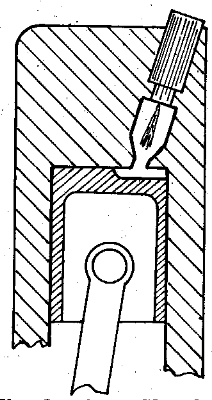


Fig. 3—*Ante Chamber.*

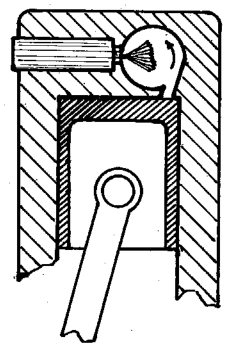


Fig. 4—*Swirl Chamber.*

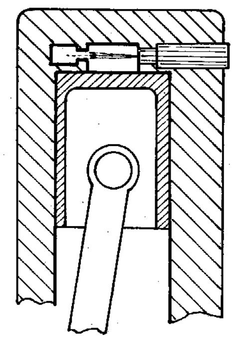


Fig. 5—*Energy Cell Chamber.*

In the small diesel the starting problem is quite a disadvantage. A diesel of say 75 horsepower needs about one-fourth that power to crank it at low temperatures, necessitating either a huge 24 volt starting system or a small gasoline motor with a clutch which is engaged after the gasoline motor has been started by hand.

Diesels are not only noisy, but rough, due mainly to the fast rate of combustion. This gives a big torque fluctuation, especially at low speeds, and a 75 H.P. diesel in a truck will usually require a heavier clutch, transmission, and rear axle than a 75 H.P. gasoline engine. In most cases, but not all, the servicing costs of the diesel are higher than those of the power it replaces. On streamliners running between Chicago and the Pacific Coast it is customary to shut off one engine while going down grade from the Rockies to remove all its pistons, clean the carbon, and inspect the rings. It is only by such servicing that these trains maintain their high availability and annual mileage.

The big field for the technician today is in attacking these very problems, most of which are tied in with the injection and burning of the fuel. In fact, nearly all of the important progress in getting diesels to their present usefulness has come of work on injection systems and combustion chambers. The study of this problem is somewhat new; it may be an art, but it is certainly far from a science. Most of the laboratories have been engaged in a cut-and-try *search* rather than a *research,* but even so their results are of interest.

A diesel engine is, by definition, one in which combustion starts by compression-ignition. A full charge of air is compressed to about 1,000° F., or nearly a dull red heat in metal, into which fuel oil is sprayed at a velocity of several hundred miles per hour. The amount of this fuel oil is very small by volume, being a maximum of about 1/14,000 of the cylinder displacement which in a passenger car sized engine amounts to a cube about 1/7 of an inch on a side. More than this small amount of fuel will not burn completely but will cause the exhaust gases and the engine parts to become black with carbon, and lowers the efficiency. Even to burn all of that little charge we have to break up the fuel into millions of droplets whose combined surface is several hundred times that of the hypothetical cube, hence the high spray velocity, and hence injection pressures of often over a ton per square inch.

INJECTORS EXPENSIVE

Parts to handle such small volumes and big pressures are expensive. Injection equipment for a diesel costs more than a complete gasoline engine of the same power, and it is this equipment that is largely responsible for the high first cost of the diesel engine. The situation has been rather unfortunate for the consumer; engine builders could not sell in quantities until they could buy cheaper injection pumps and nozzles, and the makers of this equipment could not sell cheaper until the engine builders bought in quantities. The net result has been that many engine builders, even though not well equipped to make parts accurate to within 20 millionths of an inch, began making their own pumps and nozzles, compromising by saving selling and handling costs. In many cases this saving was small compared to the possible saving that could be effected by having a very few companies produce in large quantities injection equipment designed for mass production. However, with production on all sides increasing, this situation is being constantly improved.

The newly announced General Motors small diesel is of interest from a cost viewpoint since this engine, while not new in a technical way, is unique in a manufacturing way. Mass production will be achieved by the high interchangeability of parts. One single cylinder injection system and one cylinder size only will be made, but these will be made into 3, 4, and 6 cylinder model engines. Thus the principal variation among all models will be length, offering big possibilities for low production costs.

COMBUSTION PROBLEM

The problem of good combustion has been one of intimately mixing the fuel and air at the proper time. Some combustion chambers are designed so that the fuel must find the air, others so that the air meets the fuel more than halfway. In the first case the nozzle must direct the fuel to all parts of the combustion space, as shown in Fig. 2. This type of chamber is used by Cummings and General Motors. Several spray orifices of only a few thousandths of an inch in diameter are used. Since their cross-sectional area is naturally fixed, the injection pressure goes up as the square of the engine speed,, and it is interesting to note that pressures well over 25,000 pounds per square inch have been recorded in the G. M. nozzle.

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DIESEL SITUATION

(Continued from page 4)

The type of chamber in which the air also seeks out the unburned fuel droplets is called the "divided chamber" as distinguished from the "direct" type just mentioned. Fig. 3 is a divided chamber of the **ante-chamber** or **precombustion chamber** design, and is similar to that manufactured by Caterpillar and International Harvester. More of these engines have been built in this country by these companies than all others combined. Here we have a chamber in which the object is to provide a high air velocity through the throat connecting the two halves to mix the fuel and air before and during combustion. A single orifice nozzle is used. Fig. 4 shows a form of the rotational **swirl** type of chamber, similar to the designs made by Fairbanks-Morse, Hercules, and Waukesha in this country. As the piston rises, the air rushing through the throat into the spherical chamber gives itself a high rotational swirl, into which a single spray is injected. It has been found that the R.P.M. of the air should be about 25 times that of the engine. Over 2,000,000 horsepower of the swirl type are in use today throughout the world.

Fig. 5 shows the **energy-cell** chamber and is the design built by Buda, and by Chrysler and Mack Truck in their recently announced diesel trucks. Here a very narrow spray shoots across a gap over the center of the piston into a cell which contains only a small part of the total air of the chamber. High air velocities begin **after** combustion first starts, and a jet of burning gas meets the rest of the spray from the nozzle and mixes it with the remaining air. Pressures well over 1,000 pounds per square inch occur in the cell only.

The direct injection chamber has the advantage of a lower heat loss from the gas to the cooling water, since the ratio of surface to volume is lower than in the divided chamber and the turbulence is less. Because of this the economy of the direct type is usually higher and cold starting is easier. To assist starting in the divided type a "glow plug" is often used. This is a small loop of resistance wire which is placed near the spray and heated electrically red hot before the starter button is pushed.

Most diesels running over 2,000 R.P.M. are of the divided type, since that design provides an air turbulence that increases with speed, thus keeping the combustion period somewhat constant in terms of crank angle. The divided chamber is thus a more "flexible" engine, but more than that, it is often the quieter and smoother of the two since the mixing of air and fuel can be better controlled. Where the entire burden of mixing is not put on the injection system, injection pressures can be lower and the system made cheaper. Also, the single orifice nozzle usually used with such chambers can be made in the variable area type, so that as the speed increases excessive pressures do not result.

On the other hand, the direct injection type lends itself to 2 stroke design very well, and by this means rather than by mere high speed more power can also be obtained per unit weight of the engine. Several manufacturers of large diesels, and General Motors in the small field, make use of the 2 stroke principle, adding a blower to the engine to scavenge out the exhaust gases and in some cases to give a supercharge. Since in the diesel we are scavenging with pure air the problem is greatly simplified over that of the 2 stroke gasoline engine where much of the incoming mixture was lost in the exhaust with the burnt gasses it was attempting to push out.

DIESEL FUTURE

What of the future of the high speed diesel? In the railroad field it seems destined to supplant the reciprocating steam engine, now that it is a lightweight powerplant, as surely as it has this engine in the marine field. However, we have given it every known advantage in the form of a special lightweight, streamlined train, and it competes against locomotives that are our most inefficient prime movers thermodynamically in use today. Shortly we are to see how it stacks up against really modern steam railroad equipment.

For aircraft use, the spark ignited engine has so far been two jumps ahead of the diesel on specific weight. In the laboratory it is using "safety fuels" which compare well with diesel fuel oil for fire safety. In the laboratory it is also ahead in efficiency; a standard aircraft engine, using 100 octane fuel instead of gasoline, and special pistons and supercharger gears has shown an economy of 0.35 pounds per brake horsepower hour. As to specific output, spark ignition test engines have produced 540 lb./sq. in. brake mean effective pressure. In the face of such spectacular performances there is little incentive for diesel aircraft development, although a number of excellent engines have been built commercially the world over that a few years ago would have been satisfactory for American aircraft use.

As for passenger car applications, at present the diesel is too expensive in first cost to be economical, even with the present price differential between gasoline and fuel oil. Possible economy would seem to be its sole advantage for such use. Some years ago an American automobile manufacturer offered diesel power as an option, but apparently without success for the option was soon withdrawn. In Europe such cars are available, five manufacturers are offering diesels suitable, by European standards, for passenger cars. The advantages for taxi service in Europe, where gasoline costs several times what it does here, seem excellent. Americans have been spoiled by fine gasoline motors, and even the best of diesels when installed in a passenger car seems at low speeds rather rough and noisy, though at high speeds it is impossible to detect the difference.

The next big field for the American diesel would seem to be the light truck. The engines for these may not be more efficient than the diesels available in the past, but they will be cheaper. Until the diesel is satisfactory for this field it probably will not be so for passenger cars.

Besides becoming cheaper, the diesel will continue to become cleaner burning, more flexible, smoother, lighter, and easier to start. American ingenuity will continue to "make it better and cheaper." Some men today say we know too many facts about effects, too few about causes. Others say we know all the facts we need but don't know how to use them. The improved diesel of tomorrow will probably be indebted to both these groups.

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