DIESEL

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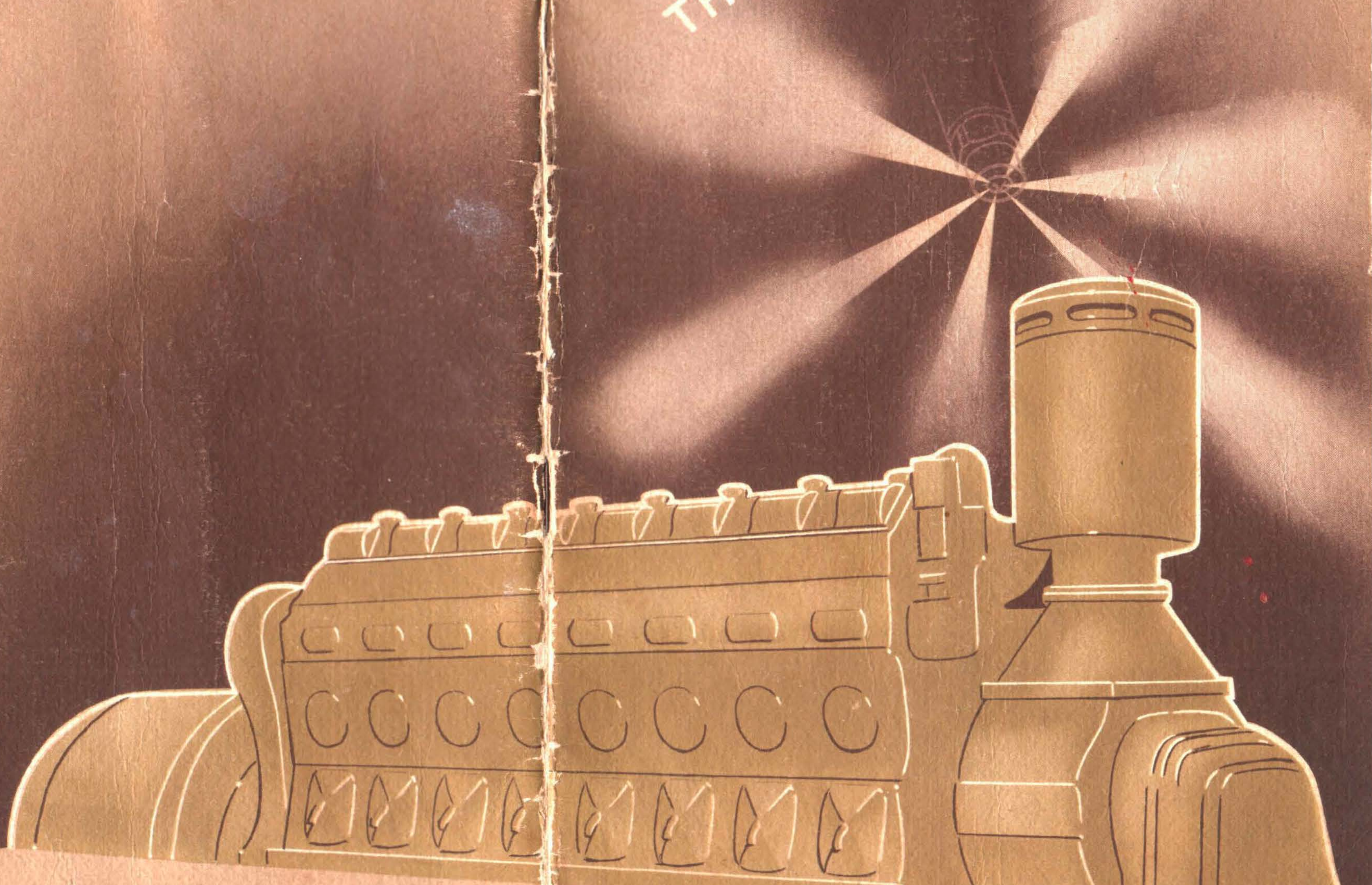
THE MODERN POWER



DIESEL

THE MODERN POWER

by

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'Tis strange—but true; for truth is always strange,

Stranger than fiction.

BYRON

DRAWINGS BY E. W. SCANES

THE MYSTERIOUS DISAPPEARANCE OF RUDOLPH DIESEL

The police, the newspapers and the public have long ago ceased to be interested in the fate of Dr. Diesel, who mysteriously disappeared in the fall of 1913. The present dramatic performances of the Diesel engine, which is playing such an important part in railroad, marine, bus, truck, and power plant development, makes the story back of the early work on this engine again of interest.

Rudolph Diesel was born in 1858 of German parents living in Paris. He went to school in Paris until the war of 1870 between Germany and France forced his family to move to England. Later, he went to the Munich Technical College, where he graduated as an engineer when he was twenty-one.

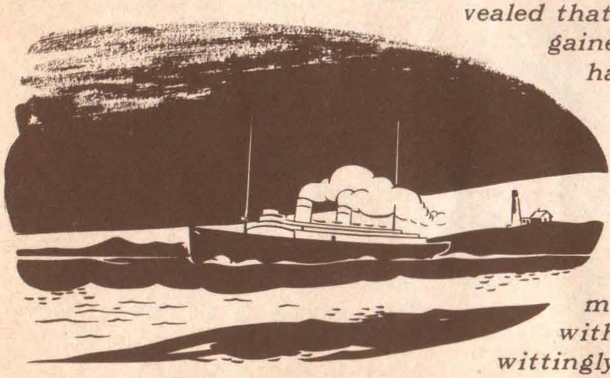
While attending college, his professor in thermodynamics was the famous von Linde, the first man to liquefy air. Listening to von Linde's description of the low efficiency of the steam engine, he determined to develop a better engine. After proving mathematically that such an engine was practical, he built the first engine in 1892. When he tried to start it, the first explosion wrecked the engine. The experiment did prove that the compression-ignition engine would work. But by 1897 he had constructed the first successful Diesel engine which immediately attracted world-wide attention.

Unlike many inventors, Dr. Diesel gained a fortune from his engine. Everywhere he went, he was honored and acclained. In the spring of 1912 he visited the United States and gave a paper on the Diesel engine before the American Society of Mechanical Engineers. Among other things, he said, "The Diesel engine has doubled the resources of mankind as regards power production, and has made new and hitherto unutilized products of nature available for motor power." *He finished by saying,* "And I must call to your mind the fact that nowhere in the world are the possibilities for this prime mover as great as in this country." *This prophecy is now coming true, over a quarter of a century after it was made.*

When Dr. Diesel returned to Europe, he was again busy consulting with the English and German Diesel engine manufacturers. In the fall of 1913, only a few months before the beginning of the Great War, he was called to England to attend an important meeting of English manufacturers.

On September 29, 1913, Dr. Diesel boarded the cross-channel steamer, "Dresden," at Antwerp, bound for London. It was a clear evening and the water was calm. He had many important papers with him. Dr. Diesel himself was in good health and at the height of his fame. Diesel engines were being used more and more. They had made the submarine possible. As far as is known, he strolled around the deck in the early evening and then retired to his cabin.

When the "Dresden" docked the next morning Dr. Diesel was missing with all his important documents. His bed had not been slept in. No one had seen him during the night. Passengers and crew could give no information.



Many theories were advanced, and many stories have been printed since. The war stopped all investigations and for years these strange stories could not be verified. It was said that the next day his family received a telegram signed with his name saying he was safe in London, but a check-up showed the telegram had been sent from Geneva. One newspaper story said that he had been seen leaving the ship, dressed as a member of the crew. It was thought he had gone to Canada, where he was hiding on a ranch. But several weeks after the disappearance a body was recovered which was partially identified as Dr. Diesel's by the gold-rimmed glasses which were found upon it.

In 1917, curiosity was revived by the story of a former member of a German submarine crew. He claimed Dr. Diesel had been pushed overboard because he knew too much about the new submarines.

Not until recently has any more definite information come to light. It has now been revealed that the fortune he had gained from his engine had been wiped out. In 1913 Dr. Diesel faced the prospect of bankruptcy; not only was he penniless, he owed large sums of money. He had discussed methods of suicide with his son, who all unwittingly mentioned leaping from a ship as his idea of the best method. The evidence, while circumstantial, is the most conclusive yet presented.

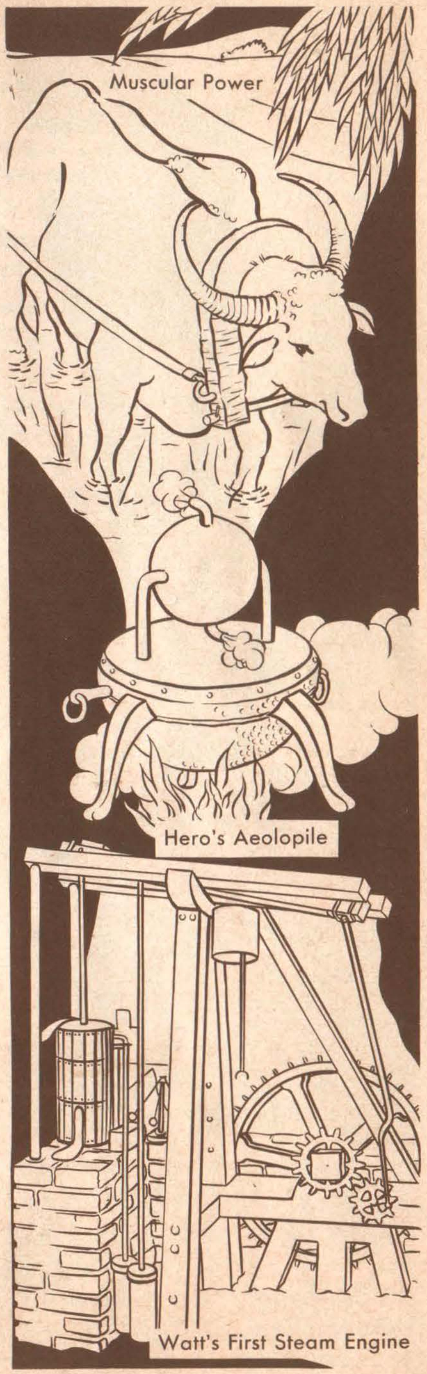
But regardless of the nature of his death, the future of his engine is assured. Capable minds have been steadily at work developing better Diesel engines and finding new uses for them.

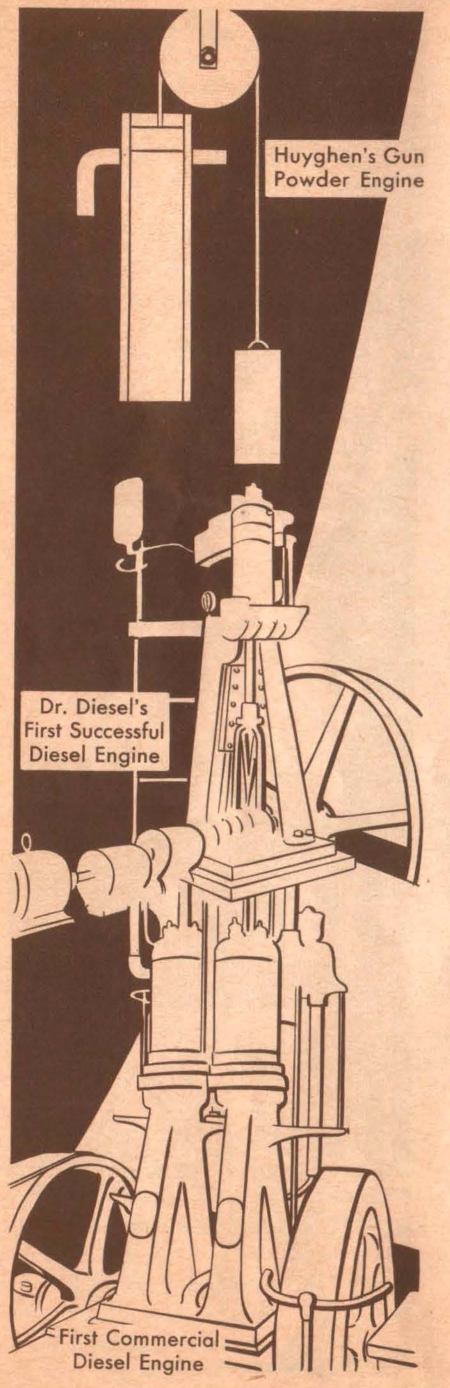
THE SEARCH FOR POWER

Man has been searching for means of augmenting the power of his muscles since the earliest days of history. He could always think of more things to do than his relatively puny strength could accomplish. First, he domesticated animals and utilized their greater strength to carry his burdens and do his heavy work. The horse, ox, elephant, camel, and even dog have been used for centuries to lighten man's manual tasks. But muscle power can be obtained in only relatively small amounts and is greatly subject to fatigue. In general, a strong back is a very inefficient source of power.

Early in history men began to think of mechanical means of obtaining power. It is related that in 130 B.C. Hero built the first steam engine. However, over nineteen centuries were to pass before James Watt made the steam engine a practical means of doing work. From Watt's time on, the development of the steam engine and its utilization were extremely rapid. On rails, on water, and in industry it was almost supreme for a hundred years. Steam engines are at their best when large units are needed. But they are still not as efficient as internal combustion engines. Portable steam plants are difficult to build small enough for uses where weight and space are factors.

Even before the time of the first successful steam engine, men





were considering other engines for developing power. In 1680, almost a hundred years before the Declaration of Independence, a Dutch scientist, Christian Huyghens, described an internal combustion engine utilizing gunpowder. But it was only in relatively recent times that successful internal combustion engines were developed. The type which burns a mixture of gasoline and air is the familiar power plant in our automobiles.

AN INVENTION DURING THE NINETIES

Dr. Rudolph Diesel, after studying the methods of obtaining power from coal and other fuels, was dissatisfied with the efficiencies obtained. He wanted to develop an engine which would convert more of the energy stored up in the fuel into work. After studying the problem for years, he patented the Diesel engine in 1892. The original patent described an engine for burning powdered coal blown into the engine cylinder by compressed air. The application did mention that any kind of fuel, liquid, gaseous or solid, could be used, and in the modern engines liquid fuels are used almost exclusively. The first engine built by Dr. Diesel in Germany exploded and was wrecked. Dr. Diesel himself was injured and might have been killed. But the wrecked engine was only a temporary disappointment. The explosion which wrecked the engine proved that the compression ignition principle was right.

The first successful engine was finally completed in 1897 when Dr. Diesel was 39 years old. It was a single cylinder, 25 horsepower unit.

To the United States belongs the credit for the first commercial Diesel engine to be put into regular service. This engine was a 60 horsepower, two-cylinder unit built at St. Louis in 1898. It was only a few years until thousands of engines were in use in sizes up to several thousand horsepower.

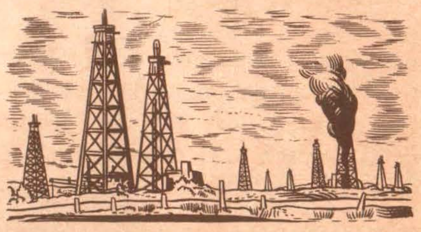
Until recently, however, the Diesel engine has been a large, heavy, slow engine unsuitable for anything but stationary power plants or large boats. Engines often weighed as much as 250 pounds for each horsepower developed. The Diesel's weight made it too expensive for many uses, although its high efficiency partially made up for its cost and weight. It could often be substituted for the steam engine, but seldom for the gasoline engine, or in any service where the engine had to haul itself along with its load. At present, a small six cylinder Diesel engine weighs only about ten pounds per horsepower. Railroad Diesels weigh only about seventeen pounds per horsepower.

PRODUCING MORE POWER FOR LESS FUEL

The Diesel is inherently the most efficient type of engine built today. It converts several times as much of the energy in a fuel into work as does the ordinary steam engine. It is even somewhat better than our most highly developed gasoline automobile or airplane engines. The only power plant which obtains anywhere near the efficiencies of the Diesel are some of the mercury-steam plants. Their weight is, however, even greater than the steam power plant. The chart gives the average efficiencies of a number of engine types.

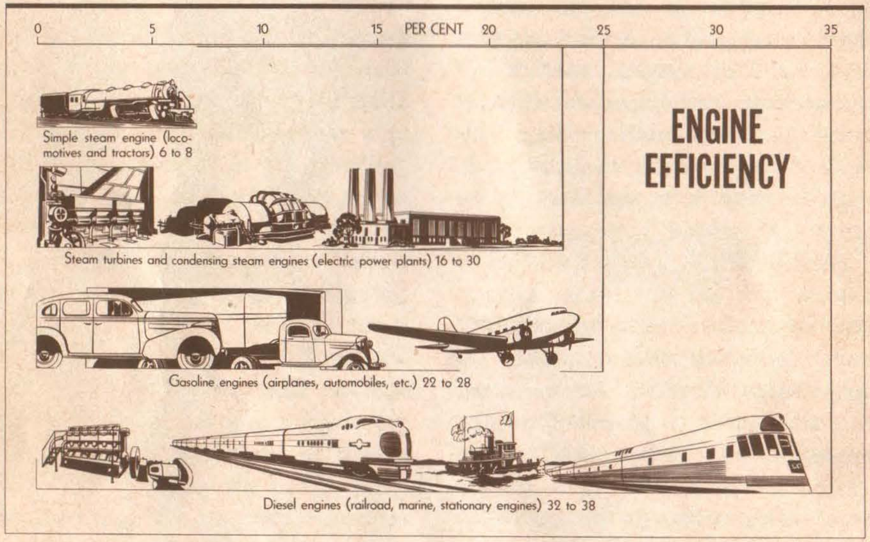
Efficiency is a measure of the percentage of heat in the fuel which an engine converts into useful work. All fuels are a storehouse of potential energy. The energy in gasoline, fuel oil and coal was obtained from the sun by prehistoric plants and stored in the ground waiting for man to devise a way to reconvert the sun's heat energy into useful work. The potential energy of a fuel is measured in heat units per pound of fuel.

An engine is a machine for converting these stored heat units in the fuel into a form which can be used to do man's back breaking



tasks. The more of these heat units converted into work, the higher the efficiency. High efficiency means low fuel consumption.

Suppose the percentage figures given in the chart are converted into these heat units. A pound of a typical petroleum oil will contain about 18,500 heat units or, as engineers say, British Thermal Units (B.T.U.) If 18,500 B.T.U.'s are burned in an engine the table



TYPE ENGINE	B. T. U.'s Useful Work	B. T. U.'s Lost
Simple steam engine	1110 - 1480	17,020 - 16,390
Steam turbine and condensing engine	2960 - 5550	15,540 - 12,950
Gasoline engine	4060 - 5200	14,440 - 13,300
Diesel engine	5920 - 7040	12,580 - 11,460

will show the number that will be usefully converted into work and the amount lost through waste heat, friction and cooling by the different engines.

THE INTERNAL COMBUSTION ENGINE

In a few years, it is likely that Diesel engines will be a much more common means of developing power than they are even today. Many people will therefore want to know more about Diesel engines—how they run, the fuel they use and the reasons for their high efficiency. Let us start with an explanation of the similarities and differences between the Diesel and the gasoline engine.

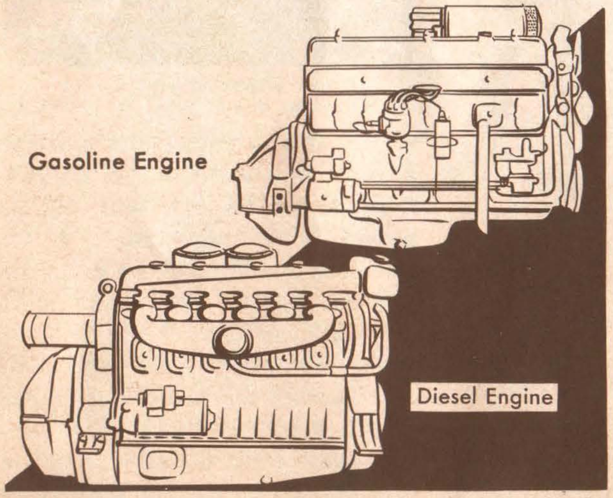
Both of them are internal combustion engines which convert the heat of natural fuel into work in the cylinder of the engine itself. The two most familiar types are the gasoline engine, as used in motor cars, and the Diesel engine, used for the streamlined trains, boats, trucks, buses, and power plants. If two engines of the same size were built and placed side by side, one a Diesel, the other a gasoline engine, they would look almost alike. Both engines have cylinders, pistons, connecting rods and crankshafts which are practically identical. Both engines use a liquid fuel and burn it inside the cylinder. The valve mechanism may be similar on both engines.

But despite this similarity, there are still fundamental differences. In the gasoline engine the fuel and air are mixed before they enter the cylinder. In the Diesel, the fuel and air are mixed inside the cylinder. The gasoline engine compresses a mixture of gasoline and air which is ignited by an electric spark. The Diesel engine compresses only a charge of air and ignition is accomplished by the heat of compression. This fact accounts for all of the resulting differences between the two types of engines. The engineer thinks of the difference between the Diesel and gasoline engine in terms of the difference in the compression ratio and expansion ratio and so our explanation will deal with these engines from the same standpoint.

"HIGH COMPRESSION" ENGINES

In an internal combustion engine, either a Diesel or gasoline type, the higher the compression ratio the greater the efficiency. Engineers prove this mathematically by thermodynamics. However, this is unnecessary for our purposes because almost everyone is familiar with the effect of increasing the compression ratio in automobile engines. The compression ratio of automobile engines has been increased year by year for fifteen years. Each increase has resulted in more efficient engines. The greater efficiency of the high compression automobile engine results in greater power and less fuel consumption. In terms of performance of the automobile on the road, it has meant more miles per gallon, higher speeds, better hill climbing and faster "get-away."

The Diesel engine is a high compression internal combustion engine. In a Diesel engine the compression ratio is far above that used for even the highest compression ratio automobile. engine.



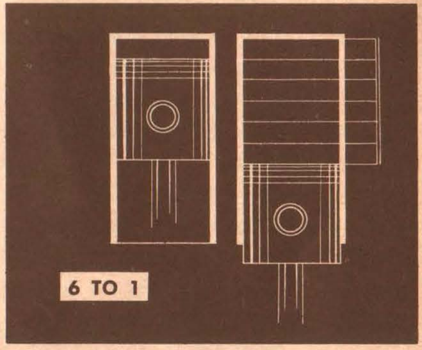
6 TO 1 OR 16 TO 1

Compression ratio is an engineering term which is really quite simple. If we say an engine has a compression ratio of 6 to 1, it means that the volume above the piston is six times as much when the piston is at the bottom of its stroke as it is when the piston is at the top. If the cylinder in the first two illustrations would hold six pints with the piston at the bottom of the cylinder, and one pint with the piston at the top of the cylinder, it would have a 6 to 1 compression ratio. Likewise, if the capacity was sixteen pints at the bottom and one pint at the top, as in the second two illustrations, the compression ratio would be 16 to 1. These two compression ratios, 6 to 1 and 16 to 1, are typical of those for a gasoline engine and Diesel engine respectively.

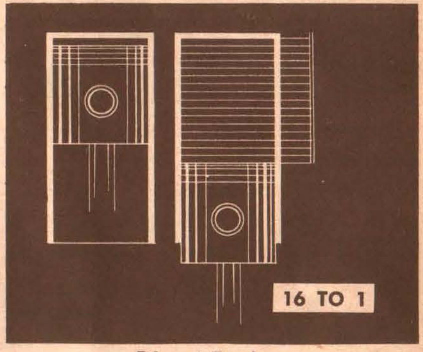
This means that if the cylinder is full of air or a mixture of gasoline and air when the piston is at the bottom of the stroke, it is squeezed to one-sixth of its volume in the gasoline engine and to one-sixteenth of its volume in the Diesel engine when the piston reaches the top of the stroke.

It means, likewise, that from the top of the stroke to the bottom of the stroke of the piston, the hot gas will have expanded six times in the gasoline engine and sixteen times in the Diesel engine. One pint of gas above the piston in the gasoline engine will push the piston until the cylinder will hold six pints. In the Diesel engine, one pint will push the piston until the cylinder will hold sixteen pints. This is shown in the illustrations.

The above explanation may be summed up by comparing the



Gasoline Engine



Diesel Engine

action of the Diesel and gasoline engines with a sled on an icy hill. Suppose we have a long hill as shown in the illustration. If we have the operation as we do in the gasoline engine, we would start our slide one-sixth of the distance from the top. In the operation representing the Diesel engine, we would start the sled only one-sixteenth of the distance from the top. We know that the sled which

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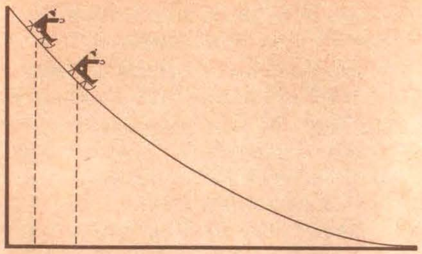


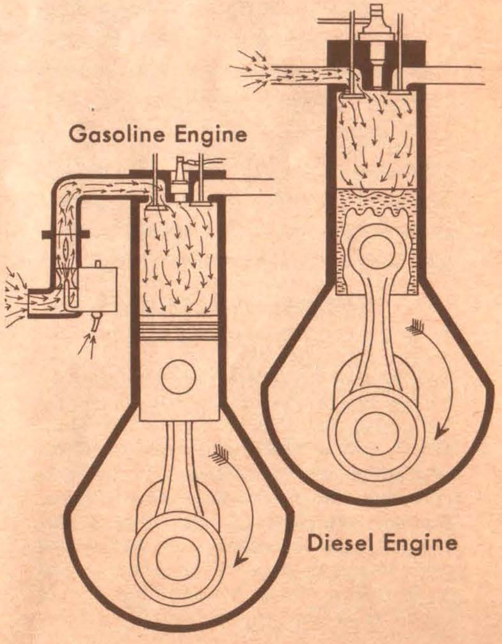
started the nearest to the top would be able to transmit the greatest amount of energy by the time it reached the bottom. By similar reasoning, we also know that the piston of an engine which starts with the hot gases at a higher level of pressure transmits the greatest energy. Both the sled and the piston of the Diesel engine would do more useful work than the sled and piston of the gasoline engine. We would therefore get more work out of the Diesel sled. This is another way of saying that the Diesel engine is more efficient than the gasoline engine. High efficiency means economy in fuel consumption.

COMPRESSED AIR AND COMPRESSED MIXTURE

When the charge is compressed as much as 16 times it is heated to about 1000 degrees Fahrenheit. If we increased the compression ratio in a gasoline engine to 16 to 1, this high temperature would start the mixture of air and gasoline burning in the cylinder long before it should. The mixture would start burning while the piston was on its up stroke and cause a violent "knock," or even force the piston back down the cylinder and cause the engine to start running backwards. Even the best commercial anti-knock gasoline would not stop this fuel knock. To prevent this premature burning in the Diesel engine, only air is compressed. This is another difference between the Diesel and the gasoline engine. Only air is compressed in the Diesel engine and a mixture of air and gasoline is compressed in the gasoline engine.

CARBURETOR AND FUEL INJECTORS

The carburetor is therefore unnecessary in the Diesel engine because its purpose is to mix air and gasoline in the correct proportions before they enter the cylinder. Compressing the air until its temperature reaches 1000 degrees means that the fuel, which



would start burning at 450 degrees, must not enter until the engine is ready to burn it. A fuel injection system is the device used to blow, or force, the fuel into this superheated air just before the piston reaches the top of the stroke. There is this difference between the ways the Diesel and gasoline engines handle the fuel. The gasoline engine uses a carburetor to mix air and gasoline before it is compressed. The Diesel engine uses an injection system to force the fuel into the cylinder after the air is compressed.

ELECTRIC IGNITION AND COMPRESSION IGNITION

In the gasoline engine, when the mixture is compressed by the upward stroke of the piston, it is necessary to supply a spark to start it burning. The electric ignition system supplies the spark. In the Diesel engine, compressing the air 16 times heats it to a high enough temperature so the fuel will start burning by itself as soon as it is injected. It catches fire just like the flashing of grease in a frying pan. No spark plug is necessary to start it burning.

PUTTING MOLECULES TO WORK

Let us start out with an explanation of the operation of the Diesel engine by going back to molecules. As you know, molecules are minute particles of matter. Everything in the world is composed of molecules—the air, our bodies, our homes, the earth, our food and drink, vegetation. Molecules are the tiny bricks which nature used in building the universe. They are so small that the most powerful microscope cannot make them visible for they are only about seven ten-billionths of an inch in diameter.

These particles of matter are always in a state of motion like a swarm of angry bees. At room temperatures and ordinary atmospheric pressure each molecule travels with an average speed of about 1000 miles an hour. As they race about they bounce against each other and the sides of the container which they may be in. As you sit reading this, you are constantly being hit with the molecules of the air.

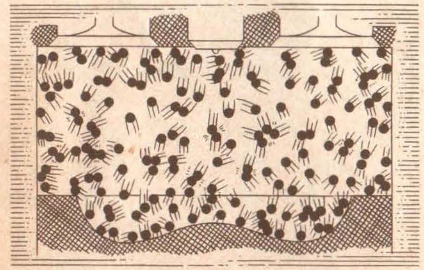
Suppose we have an engine cylinder full of air. The tiny molecules pound against the sides and against the piston. When the piston is pushed up, the molecules are squeezed closer together. Because there is less space for them to move about in, they hit the walls more often. The constant pounding against the cylinder walls produces a pressure. The more often the molecules hit the walls, the higher the pressure goes.

The above is exactly what happens in a Diesel engine. Air enters the cylinder and the piston moving up compresses it into a small fraction of the space it formerly occupied. To compress this air takes work, as anyone knows who has pumped up a tire by hand. When work is done heat is often produced. Many examples of this statement can be thought of. It takes work to pound a piece of steel with a hammer, bend a wire back and forth, or stop a moving car with the brakes. In each of these instances heat is produced. The piece of steel, the wire and the brakes all get hot. When work is done in compressing the air in the cylinder, the air also gets extremely hot. In fact, it is compressed enough in the Diesel engine so the temperature is the same as that of red hot iron.

When the air gets hot, it means the molecules are moving faster. The faster they move, the more often they hit the walls of the cylinder and the greater is the pressure. Thus, two things give an effect of greater pressure in the cylinder—compressing the molecules into a closer space and speeding up their motion. They then hit more often and harder against the walls of the enclosure. At the point when the air molecules are moving the fastest, with the air at the temperature of red hot iron, oil is injected into the cylinder in a fine fog-like spray. The oil at once starts to burn and the molecules are still further speeded up. They beat against the walls of the cylinder and piston at a tremendously increased rate. The billions and trillions of tiny blows on the piston, added together, move it downward with great force.

As the piston moves downward, more space is made available for the cylinder full of rapidly moving molecules. They hit the piston less often. Part of the energy in the gases has been given up and the speed of the molecules is slowed down. At the bottom of the stroke, the spent gas is expelled to the outside and a new charge of air enters the cylinder ready to start the process over again.

Let us compare the action in the Diesel engine with the action in a gasoline engine. In the gasoline engine the cylinder is filled with a mixture of air and gasoline. The piston moves up, compressing the swarming molecules of air and gasoline into a smaller space. They beat against the walls of the cylinder and top of the piston with greater and greater force.



Molecules in Cylinder

In the Diesel engine enough work was done in compressing the cylinder full of air molecules to increase the temperature to that of red hot iron. In the gasoline engine we cannot speed the molecules up too fast before the piston reaches the top of its stroke or they would batter it down and make the engine run backward. We cannot then do as much work on the mixture of air and gasoline as we could on the air alone in the Diesel. Consequently, in a gasoline engine the mixture is not compressed into as small a space as was the air in the Diesel engine.

As a result, it does not get hot enough to start burning by itself, so it is necessary to supply an outside spark to start the mixture of fuel and air burning. When the piston nears the top of its stroke and the rapidly moving molecules are packed as closely together as we dare, the spark plug starts the mixture burning. From this point on, the action in the Diesel and the gasoline engine is similar. The heat caused by the burning fuel simply means to the molecules that their motion is speeded up to a terrific velocity. They pound against the top of the piston like trillions of tiny pile drivers. The minute particles hit so fast and so often that the piston is pushed downward with a tremendous, smooth force. It is this downward force of the piston, caused by the battering of the invisible racing molecules, which is transferred to the crankshaft and makes the engine run.

With the above explanation of the action of the molecules in the cylinder of the two types of engines, we have the basis for the reasons for the higher efficiency of the Diesel engine. Suppose we had a Diesel engine and a gasoline engine each with a cylinder holding one quart when the piston *is at the bottom of the stroke. We have seen that the molecules in the Diesel can be squeezed closer together than those in the gasoline engine, and that, as a result, they hit the piston more often. The molecules are also speeded up faster in the Diesel engine and hit the piston harder. It follows, then, that the molecules in the quart in the Diesel cylinder do more work in pushing the piston than those in the gasoline engine. This is just another way of saying the engine is more efficient. The more useful work obtained from a given quantity of fuel, the more efficient the engine.*

LOAFING EFFICIENCY

Engines are not always run to develop their full power and speed. In the automobile we seldom have the foot accelerator all the way down to the floor boards. The smaller the amount of power used and the slower the speed at which we run, the lower is the efficiency. In the Diesel engine the efficiency does not drop off with a decrease in power output, it actually increases. The reason is quite simple.

In the gasoline engine, you will recall, a mixture of air and fuel is compressed in the cylinder. The mixture must contain the correct proportion of fuel and air or it will not burn when the spark plug fires. If there is not enough gasoline, we say the mixture is too lean to burn. If there is too much gasoline we say the mixture is too rich to burn. In other words, the entire charge of air and gasoline in the cylinder must be in just the right proportions or the engine won't burn it. We call this failure to burn "missing." Ordinarily the mixture must be in the proportions of about one pound of gasoline to fifteen pounds of air. This means that one gallon of gasoline must be mixed with 9000 gallons of air at room temperature and pressure. When the accelerator is only part way down in the automobile, a smaller amount of this mixture is pulled into the engine cylinder. The mixture, however, must be of the correct proportions so it will burn, no matter how small a quantity is allowed to go into the cylinder.

In the Diesel engine, air alone is compressed until its temperature is 1000°F. The fuel oil is sprayed into this hot air in a fine fog where it immediately starts to burn, no matter how small a quantity of fuel oil is injected. In the Diesel engine we always have the same amount of air entering the cylinder and only the amount of oil is varied to change the engine speed and power. The proportion of fuel to air is unimportant and, in fact, the Diesel always has more than enough air to burn the quantity of fuel injected into it, no matter how large or how small the charge may be.

In the gasoline engine, the air and fuel are always in the ratio of about fifteen parts by weight of air to one part of fuel. When the mixture is burned, the final temperature is very high, no matter how much of the mixture the cylinder contains. If the engine runs at half load, the cylinder is only partly full of the mixture but the temperature is the same as at full

load. One part of fuel always has to heat fifteen parts of air.

In the Diesel engine, the quantity of air in the cylinder is always the same. To vary the load and speed, the quantity of fuel which is injected is changed. This means, in the Diesel, that one part of fuel always has to heat more than fifteen parts of air. In fact, one part of fuel usually has to heat more than twice that amount, and it may even be three or four times that amount. The temperature is therefore not as high in the Diesel as in the gasoline engine.

It is a common experience that the higher the temperature the easier and faster the heat will flow. The gasoline engine, with its higher temperature in the cylinder, will transfer heat faster to the cooling water and engine parts than the Diesel engine will. Since the heat which goes into the cooling water is wasted, the Diesel engine will waste less of the heat in the fuel and more of the heat is usefully used to move the piston. No matter what the speed or load on the gasoline engine, the temperatures in the cylinder are always the same. The temperatures in the Diesel engine decrease with the speed and load and the heat loss is less as the power output decreases.

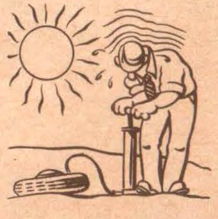
This is one of the reasons for the higher efficiencies of the Diesel. It wastes less heat, at both full and part throttle because the temperature within the cylinder is lower than in the gasoline engine.

ENGINES MOVE IN CYCLES

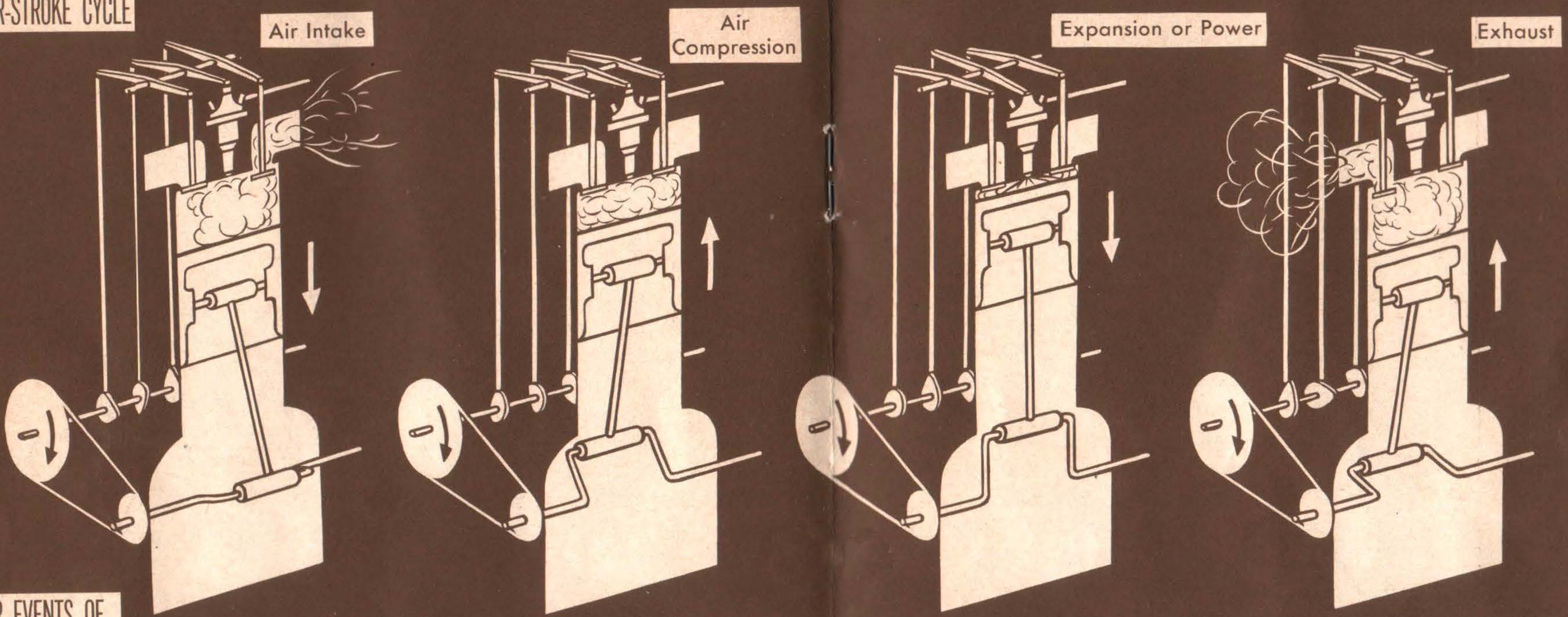
Let us examine the operation of the mechanical parts of the engine. All the events take place in an orderly fashion, one after another according to a predetermined schedule. As the pistons move up and down in the cylinders, the valves are opened and closed at the proper time, and the fuel oil is sprayed into the cylinder at exactly the right point and for the correct duration of time. Diesel engines, as well as gasoline engines, may be operated on two schedules, one called the four-stroke cycle, the other the two-stroke cycle.

THE FOUR-STROKE CYCLE

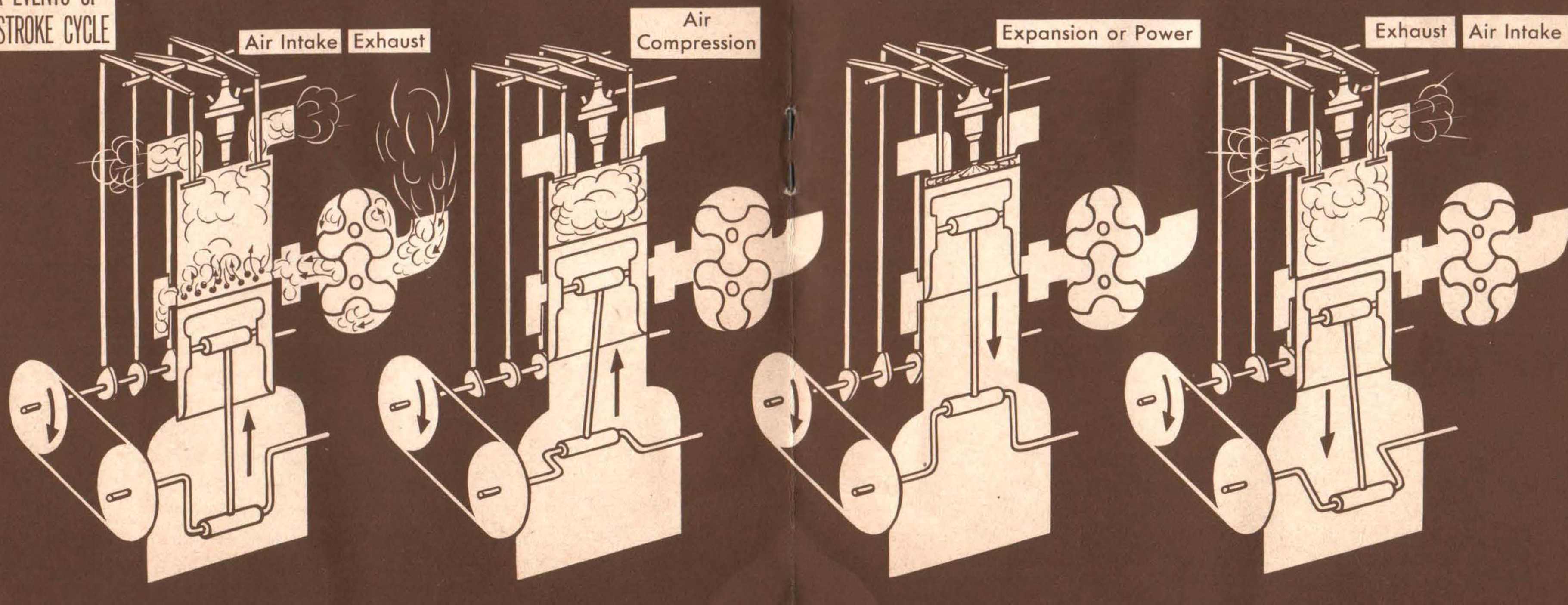
The first stroke of the four-stroke cycle Diesel engine is the intake of a charge of fresh air. With the inlet valve open, the piston moving downward pumps in air to fill the cylinder. When the piston passes the bottom of its stroke, the inlet valve closes. The second stroke compresses the air to 500 or 600 pounds per square inch. When air is compressed, its temperature rises. This is a common experience. When pumping up a tire with a hand pump, the hose leading from the pump to the tire often gets too hot to hold. As



FOUR EVENTS OF FOUR-STROKE CYCLE



FOUR EVENTS OF TWO-STROKE CYCLE



was stated before, in the Diesel engine the temperature of the compressed air may reach as high as 1000 degrees Fahrenheit. This is the temperature of red hot iron.

The fuel is injected into this hot air. Since the oil is in a fine, fog-like spray, it starts to burn immediately. The injector continues to spray fuel oil into the cylinder until all of the charge is injected. The pressure in the cylinder rises to 800 to 850 pounds per square inch.

The third stroke is the power stroke. The hot gases expand and force the piston downward. The chemical energy of the fuel is converted into mechanical energy to move the piston.

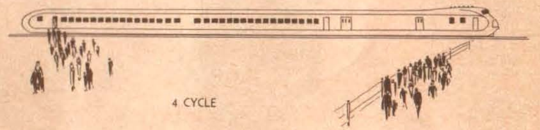
The fourth stroke is the exhaust stroke. The exhaust valve opens and the piston moving upward, forces the burned gases out to make room for a new charge of air. The engine starts over again with the intake stroke. This explains the essential operations of the four-stroke cycle Diesel engine.

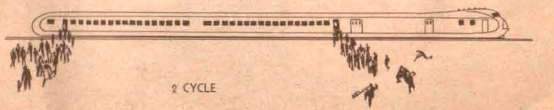
THE TWO-STROKE CYCLE

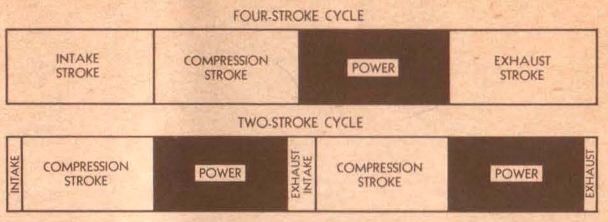
The two-stroke cycle Diesel engine has one power impluse for every two strokes of the piston. The four-stroke cycle has one power impluse for every four strokes of the piston. The two-stroke cycle therefore gives twice as many power strokes as the four-stroke cycle. For the same size engine, the two-stroke cycle should give twice the power of the four-stroke cycle.

The events of compression, injection and expansion take place in the same order as they do in a four-stroke cycle. The up-stroke of the piston compresses the air. Injection of the fuel oil occurs when the piston nears the top of the stroke. The hot gases expand against the piston forcing it downward on the power stroke.

When the piston nears the bottom of the power or expansion stroke, the exhaust valve in the top of the cylinder opens. The hot burned gases rush past the valve. As the piston moves further downward, the intake air ports in the cylinder wall near the lower end are uncovered. Intake and exhaust take place at the same time. Fresh air enters at the lower end of the cylinder forcing the remaining burned gases out the exhaust valve at the top of the cylinder and filling it with fresh air. The exhaust valve then closes and the engine is ready to start another cycle. The intake of fresh air and exhaust of burned gases take place at the same time.





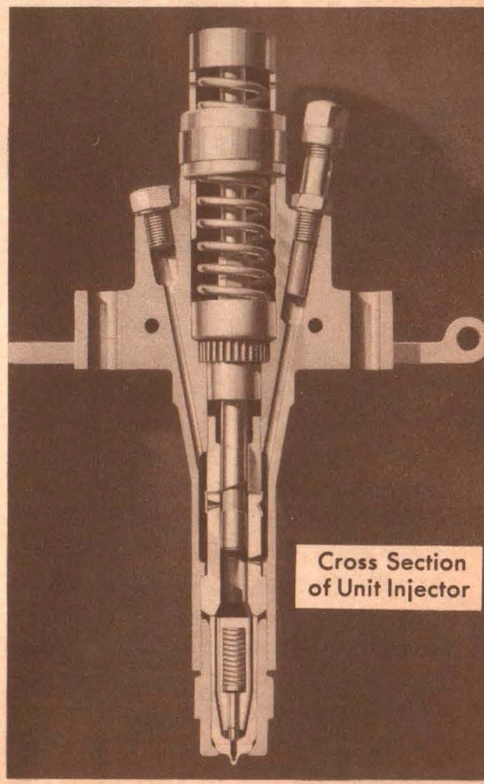


We can think of the difference between the intake and exhaust in the two-stroke cycle and four-stroke cycle as we would the difference between two methods of loading and unloading the passengers on a train. The four-stroke cycle train would discharge all its passengers through the doors in one end of the train before any new passengers were allowed to board it, both groups using the same end of the train. The two-stroke cycle train would discharge its passengers at one end while the new passengers were getting aboard at the other end. The straight-through flow of passengers is similar to the straight-through flow of air in the two-cycle Diesel.

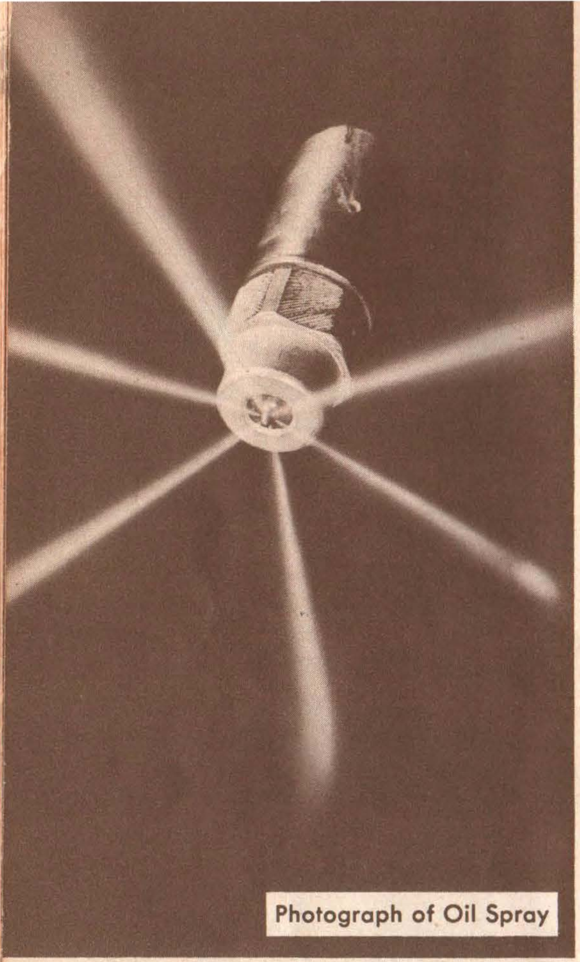
The two-stroke cycle and four-stroke cycle may also be compared by following the events which happen in each engine during four strokes of the piston—two up and two down. It can readily be seen that the expansion, or power, stroke occurs twice in the two-stroke cycle for once in the four-stroke cycle and that therefore the two-stroke cycle engine would develop twice the power.

FUEL INJECTION SYSTEM

The heart of the Diesel engine is the fuel injection system. It is often stated that the Diesel engine is simpler than the gasoline engine because it eliminates the carburetor and ignition system. However, the



Cross Section of Unit Injector



Photograph of Oil Spray

fuel injection system on the Diesel, which must be substituted for these parts, brings up problems as highly involved as those in the carburetor and electric ignition system. The reasons will be obvious from the description of a typical injector used on a modern Diesel engine.

The first engines used compressed air to blow the fuel oil into the cylinder. Air at over 1000 pounds per square inch pressure was necessary to inject and atomize the oil. This is just about the water pressure half a mile down in the sea.

Most Diesel engines built today use a pump to inject the fuel. "Solid injection" is the term applied to this system. There are many types of pumps designed for solid injection. They force the oil into the cylinder at the tremendous pressures of from 3,000 to 20,000 pounds per square inch. A mile deep in the sea the water pressure is about 3,000 pounds and at nine miles it would be 20,000 pounds.

It would be impossible in this booklet to describe and explain all the methods of injecting oil into the cylinder of a Diesel engine. We shall therefore explain only one of the newest and most successful systems, and the one used on the two-cycle engines—the unit injector.

In any solid injection system it is necessary to have a pump that will force the oil into the cylinder against the compression pressure of 500 or 600 pounds per square inch. In the unit injection system there is a small pump for each cylinder which is operated by a mechanism similar to that which operates the valves. The fuel must be split up into a fine fog as it enters the cylinder so it will burn rapidly and completely. A nozzle with a number of holes about the diameter of a small needle, breaks the oil into a fine spray. Its operation is similar to that of an atomizer. The unit injector has a

pump and spray nozzle for each cylinder. The pump and nozzle are in one piece—hence the term, unit injector.

The unit injector has few moving parts but those it does have are made with a high degree of accuracy. The pump piston is fitted to the pump cylinder to an accuracy of a quarter of a tenth of a thousandth of an inch. This does not mean much to us unless we compare it with something we are familiar with. If the thickness of a human hair, or the paper on which this is printed, were divided into 120 equal parts we would obtain a dimension equal to that of the clearance between the pump piston and cylinder. This accuracy is necessary to prevent leakage of the oil past the piston, for the pressure in the fuel pump may reach 20,000 pounds per square inch. Under the usual conditions of operation the pressure is 15,000 pounds per square inch.

High pressures are necessary to force the oil through the fine holes in the spray nozzle in the proper amount and at the right time. The smaller the holes, the finer the spray and the better the fuel oil burns. Oil under ordinary pressures is not compressible, but when 15,000 to 20,000 pounds pressure is used it acts like rubber. A long column of oil under these pressures would expand and contract like a rubber rod. If there were such a long column in the fuel injection system of a Diesel engine, the amount of oil and the timing of its injection could not be accurately controlled. For this reason the pump and nozzle are built in one unit close together so that only a small amount of oil at a time is under this pressure.

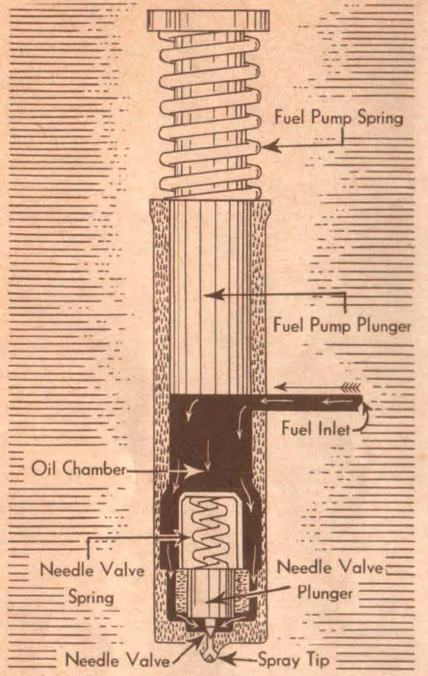
The pump forces the fuel oil through the small holes in the spray tip at 13 miles a minute—780 miles an hour. The high velocity breaks the oil up into a fine, penetrating fog. This oil fog, entering the cylinder of hot compressed air, starts to burn. The fuel injection continues for the proper time and in the proper amount to obtain good combustion. The injector must pump just the right amount of fuel oil at the right moment and at the correct rate. In the streamline train engines, the total amount of fuel oil in one charge to one cylinder varies between a drop the size of a grain of rice and one the size of a pencil eraser. In small engines the charge is correspondingly smaller.

A simple diagrammatic pump and injection nozzle will be used to explain the operation of the unit injector. The parts are named in the first diagram.

THE FUEL PUMP IS CHARGED

The injector in this diagram is in neutral position, just ready for an injection stroke. The fuel inlet pipe opening in the shell has been uncovered by the fuel pump plunger allowing a charge of oil to fill the oil chamber.

Oil Fills Injector Pump

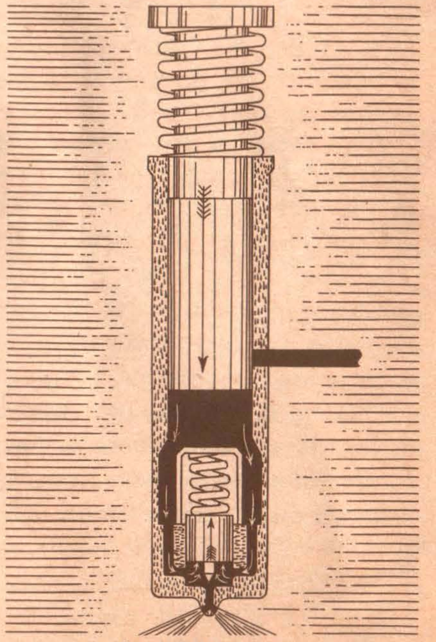


As the plunger moves down, the fuel inlet opening is covered up. This stops the flow of oil from the fuel tank and allows the plunger to start forcing the oil downward.

INJECTING THE FUEL

After the start of injection, the injector parts are in the position shown in the second diagram. The fuel pump plunger moving downward forces the oil before it and builds up an oil pressure in the injector of several thousand pounds per square inch. This pressure, acting on the lower end of the needle valve plunger, lifts the needle valve off its seat. A free passage is thus opened up so the oil can be forced out of the fine holes in the spray tip into the cylinder of hot compressed air. Injection is timed to occur just before the piston of the engine reaches the top of its stroke.

It is necessary to vary the amount of fuel which the injector pumps into the cylinders because the engine takes less fuel when it is running slowly or when it is not necessary to pull the full power load. In the gasoline engine we have a throttle or accelerator which varies the amount of the gasoline-air mixture with which the engine is supplied. In the Diesel, the throttle varies the amount of fuel which the injector sprays into the engine cylinder. In the simple injector diagram it was not possible to show this action. However, in the unit injector less fuel is injected by varying the effective stroke of



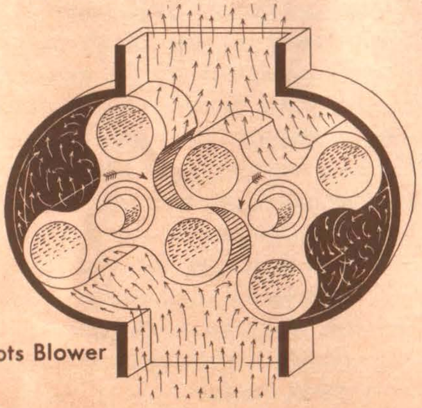
Fuel Oil Injector

the fuel pump plunger. The unit injector is intricate in structure because of the provision for this operation.

THE BLOWER SUPPLIES THE AIR

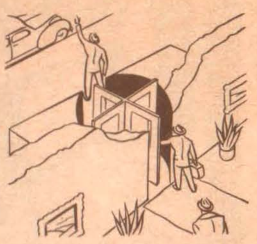
In the four-stroke cycle engine the air is pulled into the cylinder by the downward movement of the piston on the intake stroke. The two-stroke cycle engine does not have a complete intake stroke, so an external method must be used to fill the cylinder with air. In other words, the four-stroke cycle engine uses the engine as an air pump half of the time; the two-stroke cycle engine uses an efficient external air pump to fill the cylinder with a fresh charge of air. A number of methods are possible. Almost any type of air pump can be used. One type will serve as an example of the air pumps which are most successful. This pump also may be called a blower.

The blower which is shown in the illustration is called a Roots type. It has three lobes in each



Roots Blower

rotor, shaped something like giant gear teeth. The lobes in the two rotors mesh when they are rotated just as the teeth in two gears mesh. The blower is driven by the engine through a set of gears.



When the rotors revolve in the direction shown, air enters at the bottom opening and is trapped between the rotors and the case which surrounds them. The air is discharged at the top opening. This air is piped to the intake ports surrounding the cylinder. The revolving door in many of our office buildings acts something like one side of the Roots blower. Each person who is trapped between the doors and the side represents a charge of air in the blower.

The drawing shows a simple Roots blower which gives a pulsating flow of air. To give a constant stream of air and to reduce the noise, spiral rotors are used.

When the 1200 horsepower, 16 cylinder engine is running full speed, the blower pumps over 6,000 cubic feet of air every minute. This is capacity enough to pump all the air out of two large size living rooms every minute. And the blowers keep this up hour after hour as long as the engine runs.

WHAT ABOUT DIESEL FUEL?

Diesel engines have been run on various types of fuels: powdered coal, tar, vegetable oils, animal fats, and petroleum oils. However, it is not correct to say that any Diesel engine will run satisfactorily on all of these fuels. Your furnace will probably burn many kinds of fuel also. Paper, straw, oils, wood, and coal of various grades can all be used. However, you know from experience that one type of fuel is best. It gives less ash, holds the fire well, burns without smoking and gassing, does not soot up the furnace. Likewise in the Diesel engine, one fuel burns best. Diesels do not, as a rule, burn crude oil.

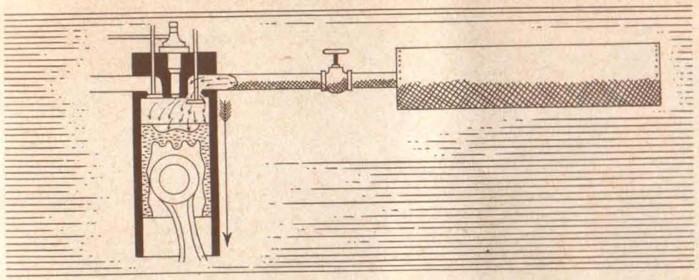
The Diesel requires a petroleum fuel oil which is held to specifications as strict as those for the gasoline used in your car. First, it must be fluid enough so it can be pumped and injected into the cylinder. Second, it must be clean or else the closely fitted parts of the fuel system will wear rapidly and the fine holes and passages will be plugged. Third, it must have the proper ignition properties so it will burn rapidly when it is injected into the hot compressed air in the cylinder and so the engine will start readily. Fourth, it should be reasonable in price.

This last factor, price, is often misunderstood. It is only partly true that the Diesel engine runs on a cheaper fuel than the gasoline engine. At the present time the fuel oil used is much the same as the fuel oil used in household oil burners. The price per gallon of this oil and of gasoline is almost the same at the refinery. The big difference to the customer comes in the extra costs of distribution and especially the tax on gasoline. If we added these extras to fuel oil, the price would be nearly that of gasoline. If more processing of the fuel oil becomes necessary to suit the requirements mentioned in the preceding paragraph, the difference between the cost of Diesel fuel oil and gasoline may disappear entirely.

However, there are two factors which operate in favor of the Diesel insofar as fuel costs are concerned. First, the Diesel engine is more efficient than the gasoline engine, when running at full speed and developing full power. Second, the Diesel is very much better than the gasoline engine when developing only part of the full rated power.

The real reason for the lower fuel costs on a Diesel engine is not because it burns a cheaper fuel, but because it obtains more useful work from the fuel.

Air Starter



STARTING AND REVERSING ARE SIMPLE

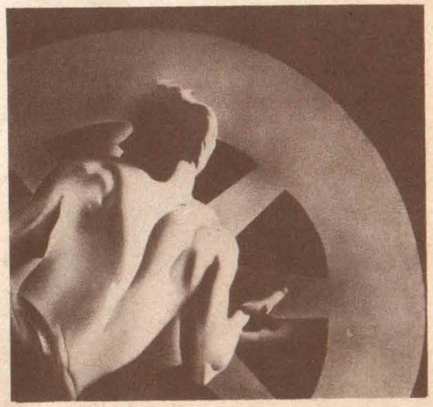
To start a large size Diesel engine it is only necessary to start it turning over with the throttle partly open. This initial movement can be obtained in a number of different ways. A common method in large engines is to inject compressed air into the cylinders. The illustration shows the method. Air from a tank is connected to a valve in the top of the cylinder. When the valve is open, the highly compressed air forces the piston downward. After a few revolutions, using the compressed air to rotate the engine, the fuel will ignite and keep it going.

When the Diesel engine is connected to an electric generator, the generator is often used as a motor to turn the engine over. Smaller engines are started by using an electric starter similar to the type used on an automobile.

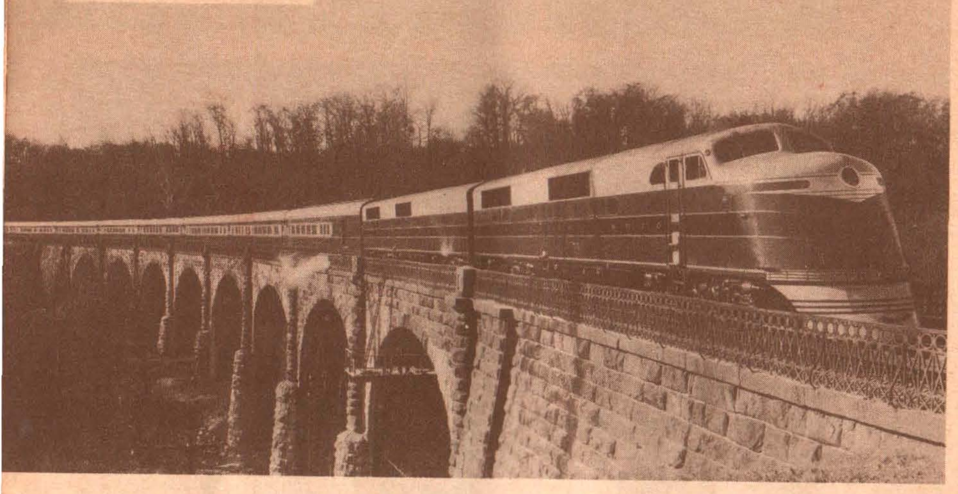
It is often necessary to be able to run a Diesel engine in reverse. This is especially true in boats where the engine is directly connected to the propeller. To meet this need, the engine may be designed to run either forward or backward. The engine is brought to a stop and the camshaft is moved by a reversing lever to open the valves at the right time for reverse operation. This may mean moving a second set of cams on the camshaft into contact with the valve mechanism. The engine is then started up by compressed air or any other method, just as it is in the forward direction. The engine operates in reverse just as it does in forward movement. The same events take place: air intake, compression, injection, expansion, and exhaust. The two-stroke cycle engines are easily converted to either direction of rotation.

DIESELS WORK AT MANY TASKS

The most spectacular application of Diesel power was the instal-



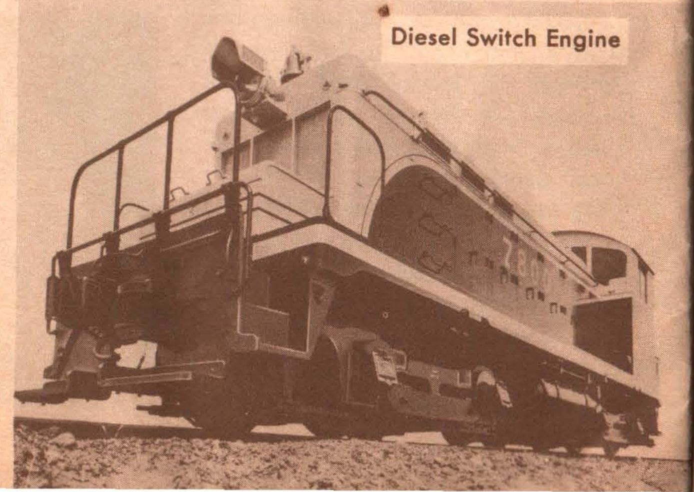
Diesel Powered Train



lation in the streamlined trains in 1934. Record speeds of 120 miles an hour were at once established. Within a few months, record long distance runs were made. Denver to Chicago, a distance of over a thousand miles, was made at an average speed of 77.6 miles per hour. The transcontinental run from Los Angeles to New York, over three thousand miles, was made in 56 hours and 55 minutes, bettering the previous time by almost a day. A regular schedule was established for service between Chicago and Portland of 39¾ hours, dropping 19 hours from the previous time.

However, the greatest contribution of the sleek little three and four car streamliners was proving that high speed schedules for modern, comfortable air conditioned trains would bring back lost passenger traffic to the railroads. On some Diesel powered train runs, all space has been booked ahead for months. With the small, high speed trains as a start, it has taken only a few years to develop larger trains and new streamlined locomotives. The first three-car, Diesel powered, streamlined train completed in 1934 was powered by one 600 horsepower, two-cycle Diesel engine. At present Diesel locomotives with ten times the power, 6000 horsepower, are in regular

Diesel Switch Engine



service. These giant locomotives, the largest Diesel powered ever built, are longer than the whole original streamlined Diesel train. They are made up of three power cars, each holding two 1000 horsepower main Diesel engines. Speeds well over 100 miles an hour are easily attained.

An automobile owner would feel quite at home in the cab of a Diesel locomotive. The comfortable, upholstered seat would do credit to any automobile. He would find that the windows were made of safety glass, and were equipped with a windshield wiper, defroster, and sun glare shield similar to those on his car. There would be an instrument panel with many familiar dials — speedometer, oil gauges, and temperature gauges—but there would be more of them. The controls would be different but very simple—a throttle lever, brake lever and reverse lever, with the addition of a foot pedal which automatically stops the train if the operator's foot is removed. These four essential levers control the 6000 h.p. in the largest locomotives.

Less spectacular, but equally useful, are the smaller Diesel locomotives. Many of the large railroad systems use Diesel switch engines which are built in sizes from 600 to 900 horsepower. These engines save up to three quarters of the fuel cost and can be operated 24 hours a day. They may be run continuously for several days with one filling of oil and water.

In all the Diesel locomotives, the Diesel engine is used to drive powerful electric generators. The electric current which they generate is used to operate large electric motors built into the axles of the driving wheels of the locomotive. This makes a flexible drive between the Diesel engine and the wheels, giving great pulling power to start and high maximum speeds.

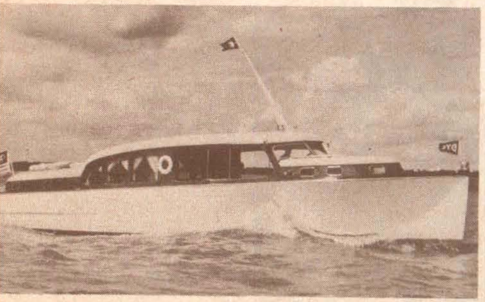
Diesel Powered Fire Boat

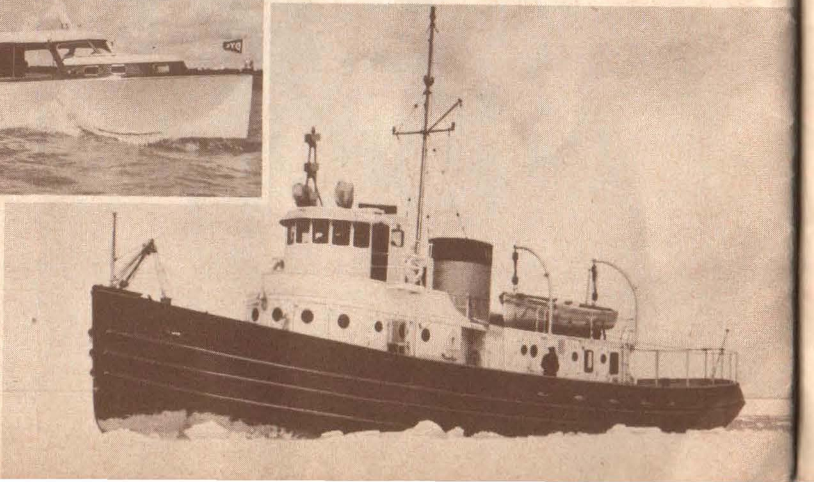
Diesel Powered Tug

To the passengers of the railroad, the Diesel trains have meant speedier travel in comfortable, air conditioned coaches. To the railroads, the Diesel has meant lower operating costs, high fuel savings, and less time in the roundhouse. Schedules never before attempted have been made possible. In arid regions where water is difficult to obtain, the Diesel locomotive makes it unnecessary to maintain an expensive water supply. Because it is available more of the time, one Diesel locomotive can often be substituted for several steam locomotives. To cities and land owners along the railroad, the Diesel means freedom from smoke and cinders, with the resulting cleanliness.

Two-cycle Diesel engines are now built in a wide range of sizes for almost any purpose where a low cost, dependable source of power is required. The smallest engine is a one-cylinder unit developing fifteen horsepower. The largest develops 1500 horsepower and is a 16-cylinder, Vee type engine. Many intermediate sizes with one, two, three, four, and six cylinders are built for developing the proper amount of power for the particular application it is required to fit.

Two-cycle Diesels power vehicles on rails and road, and boats of many sizes. They drive electric generators or are connected to machinery directly through belts





Boats Powered by Diesel

Diesel Bus

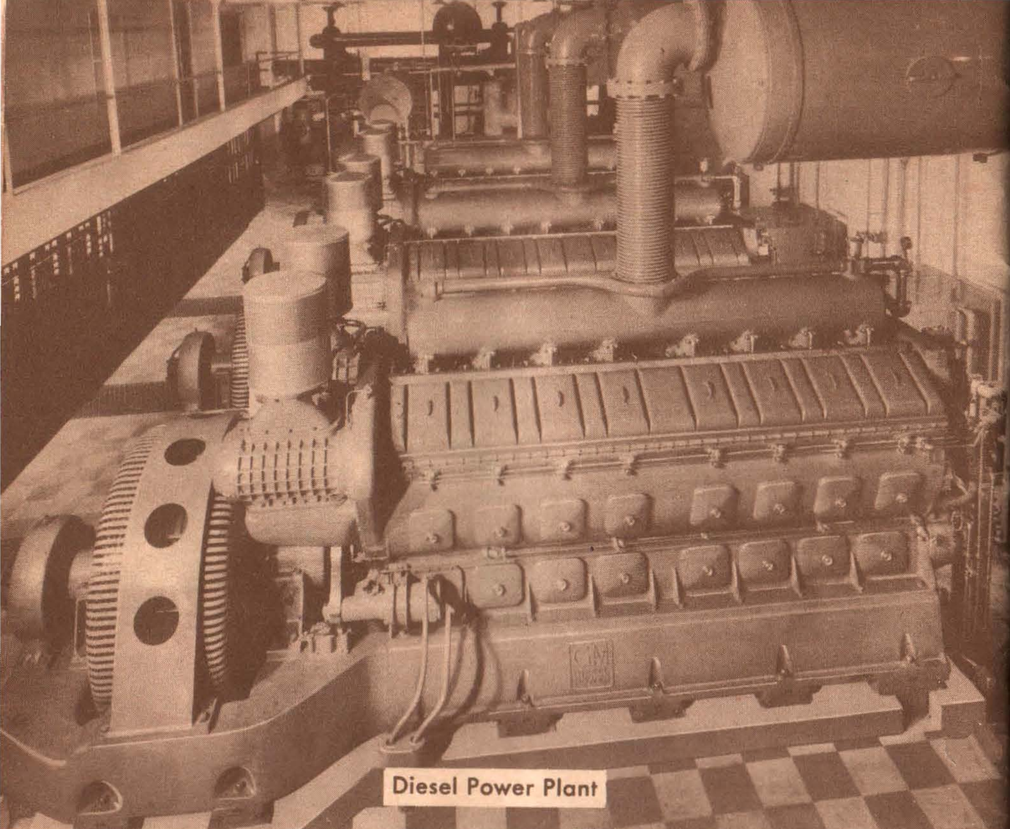
or shafts. Whether the engine pulls itself or whether it is firmly fastened to a foundation; whether the service is continuous or intermittent; whether the speed is constant or changing; the two-cycle Diesel has proved to be an economical, dependable source of power.

For marine power the Diesel cannot be surpassed. It has been used for everything from small pleasure craft to large freighters. The engines may be directly connected to the propeller or drive may be through a reduction gear, depending upon the size of the boat and the installation. In some installations a Diesel electric drive similar to that in the locomotives is used. In large yachts, tugs and towboats, the need for flexibility warrants the use of electric drive.

The fireboat, "Fire Fighter," of the New York Fire Department is two-cycle Diesel engine powered. The two 16 cylinder Diesels, driving two electric generators, give the boat a speed of 16 knots. At a fire the current generated by Diesel power drives the pumps to deliver 20,000 gallons of water per minute at 150 pounds per square inch pressure. This is the largest fire boat in the world.

In the motor vehicle field, the two-cycle Diesel engine has been applied to buses and large trucks. For commercial vehicles the economy and reliability of the Diesel engine results in large savings in operating costs. The Diesel obtains almost twice the fuel mileage of the conventional gasoline power

Diesel Truck



Diesel Power Plant

commercial vehicle. Where buses are often driven 300,000 miles per year, 25 times the distance for an average passenger car, the resulting savings are important. Inter-city trucks show a similar saving in operation.

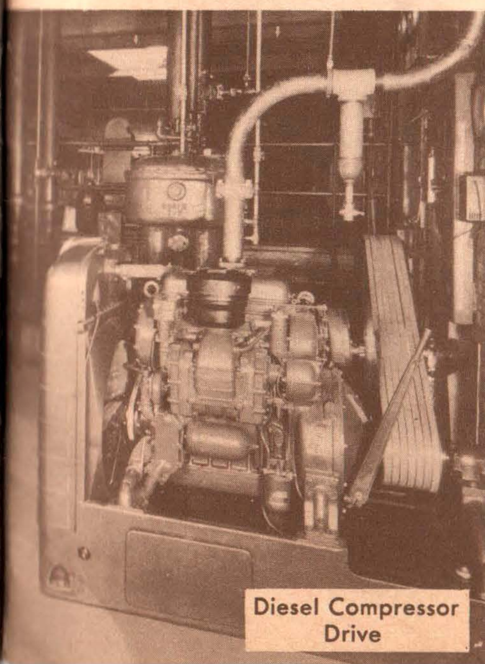
The two-cycle Diesel is particularly suited to a wide variety of uses isolated from the usual power sources. Small factories, mills, oil pipe lines, pumping stations, mines, quarries, canneries and refrigeration plants find sizes suited to their needs. The engines can be used to drive the equipment direct or by belt. If electric power is also required, the Diesel can be used to drive an electric generator. It makes a reliable means of driving pumps of all kinds, air compressors, tractors, hoists and winches, air blowers, mill machinery, cotton gins, refrigerating machinery, shovels and draglines, and many other

Gold Mining Machinery Powered by Diesel

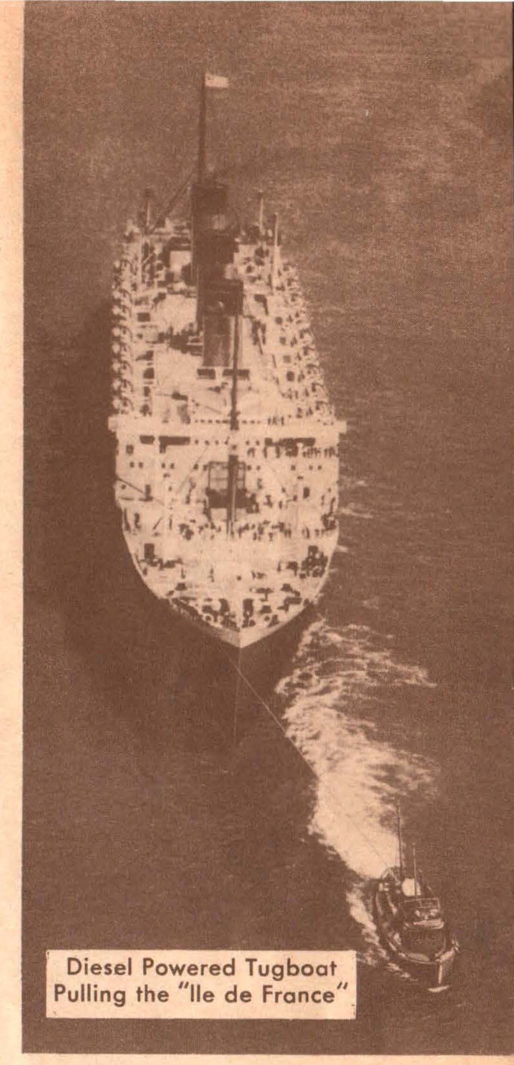
things. Where power is needed in lots from 15 horsepower to 1500 horsepower, the two-cycle Diesel will supply a low cost, reliable source, and by the use of more units almost any desired quantity of power can be obtained.

The application of the Diesel engine is in its infancy. Each year sees an expansion in its use. The Diesel history, as far as public interest is concerned, dates back to the high speed streamliners of 1934. At present it is a sizeable industry and growing rapidly. The present engines are not at all like the first heavy engines of 40 years ago.

With the light weight Diesel of the present, the Diesel engine can be used in hundreds of places never before practical. A new



Diesel Compressor Drive



Diesel Powered Tugboat Pulling the "Ile de France"

economical source of power using readily available fuel is supplied. Small or large, the Diesel is highly efficient and reliable. In many fields it is already powering the machinery and transportation of the world of tomorrow. A new industry has been born — Diesel, the Modern Power.

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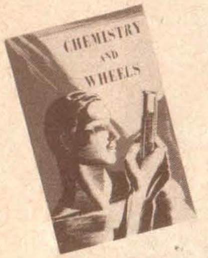
A description of the operation of the automobile from the pistons to the rear wheels, using familiar objects from the home and office to illustrate the principles involved.



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