THE DIESEL ENGINE IN PRACTICE

MEGSON AND JONES

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IN
PRACTICE

By

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PREFACE

The interest which has been aroused in this country over the Diesel engine in the past few years is remarkable, but not nearly so much so as the engine itself. Until four years ago there were but few builders of the Diesel engine in America. At the present time there are twenty or more manufacturers building different types of Diesel engines, several of them adopting foreign designs. Between four hundred and five hundred plants in the United States are now being operated with engines of the Diesel type, ranging from one to as high as eighteen engines in a plant.

It has been the duty of one of the authors to visit most of these plants in the capacity of an instructor, and in so doing he became acquainted with the men who are operating and also the knowledge they had of their work.

It is safe to state that not ten per cent of the operators of Diesel engines know one-quarter as much about their engines as the average steam engineer knows about his engine. Naturally there is a reason for this—a steam engineer, before he receives his license, is generally compelled to fire a boiler for two or three years and sometimes longer. Then he receives a fireman's license, and in two or three years more of firing the boiler, if he can pass a certain examination, he is eligible to a third class steam engineer's license. They do all this work gladly to learn the business.

With the men who are employed to operate the Diesel engine it is different. No license is required and the majority of men who are employed by the purchaser of a Diesel engine expect to be chief engineers in three weeks.

The Diesel engine, like any other high class machine, needs proper care and attention to get the best results. In fact it requires much more attention than the steam engine and closer attention due to its larger number of working parts, but any average steam engineer after three weeks' thorough instruction and proper application should be able to properly care for and operate an engine of this type without the least trouble.

It is the purpose of this book to give all engineers and those who are interested in the Diesel engine the benefit of many years of practical experience in operating the Diesel engine. As far as the authors know all other books published on the Diesel engine have omitted to deal with this important subject, which after all, is the information most necessary to the purchaser and his engineer; and it is to them that this book is respectfully dedicated.

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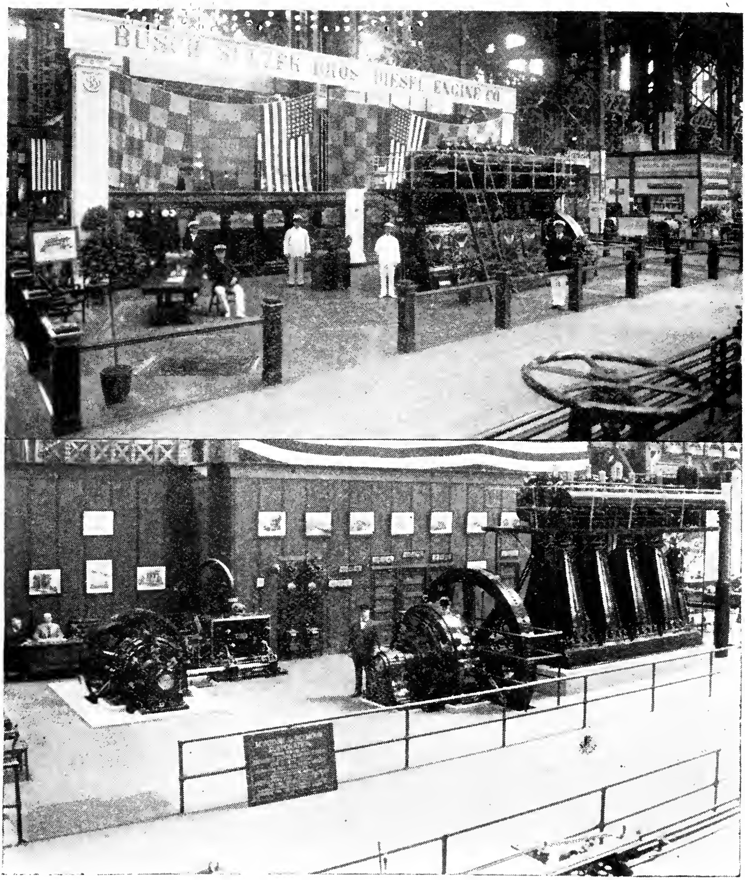


Busch-Sulzer Bros. and McIntosh & Seymour Co. Diesel Engine Exhibits at Panama-Pacific International Exposition

THE DIESEL ENGINE IN PRACTICE

CHAPTER I

HISTORICAL

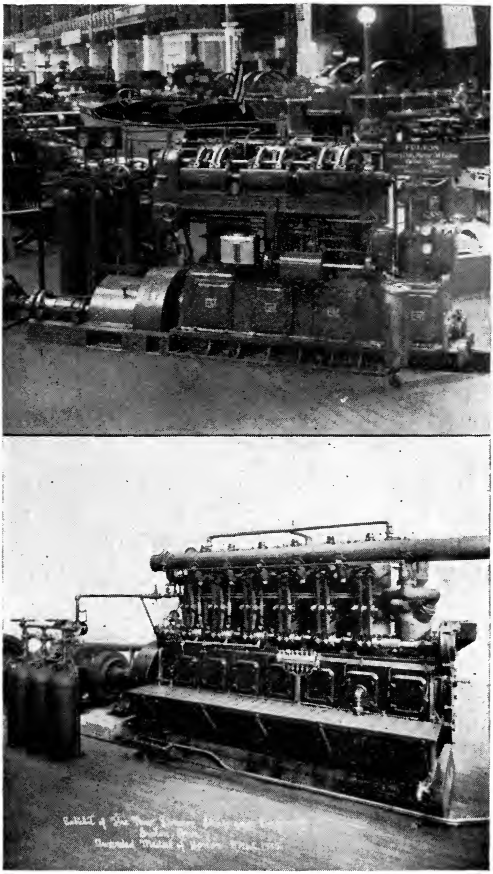
Interest in the Diesel engine is so widespread and the questions presented so varied that it may be well to review the early history of this remarkable invention.

The Diesel engine was invented in 1892 by the late Dr. Rudolph Diesel of Munich, Germany. The invention was the result of years of painstaking labor, and the one point that stands out most clearly is that had not Diesel been so positive regarding the correctness of his mathematical and thermal calculations he would not have been so persistent with the actual construction of the engine. So we find the calculations of an engineer coupled with the persistence of a genius as responsible for this epoch-making invention.

In the first Diesel engine, constructed in 1893, the piston was fitted with a piston rod and external crosshead, the vertical cylinder having no water jacket. The cam shaft was placed very low and the valves were operated by means of long rods. A wrought iron pipe with riveted flanges was used for storing starting air pressure and there was no air supply pump, the fuel being injected directly. This engine never ran, as at the first injection of fuel, the engine being driven by outside power, an explosion destroyed it. This proved to Dr. Diesel, however, that pure air could be compressed to such a high point that fuel injected into it would ignite and burn.

A second crude engine was then built. It had a base similar to the first, but was provided with a water jacketed cylinder, and the cam shaft was placed higher. The most important difference was that the injection of fuel was operated by air supplied by a pump driven directly from the engine. The second machine would not run and was always a source of danger, but indicator cards were obtained during the few revolutions that it did operate. The first two engines together proved the practical possibility of carrying out the combustion process that had been developed theoretically years before and which had been regarded mpossible by the technical world.

Patents were obtained in all of the principal countries, those obtained in England bearing the date of August, 1892. The patents in the United States were taken out slightly later and extended for seventeen years, the life of a patent in this country. During the patent, the use of the invention was limited to one licensee in each of the principal countries. The late Mr. Adolphus Busch of St. Louis, Mo., obtained the sole rights to Diesel's patents in the United States and Canada after a thorough investigation had been made in his behalf by Colonel E. D. Meier, late president of the American Society of Mechanical Engi-



Fulton Iron Works and New London Ship & Engine Co. Exhibits at Panama-Pacific International Exposition neers. The patents, however, simply stated what was to be done, and were of small practical value from an operating standpoint, as the actual construction of the engine had hardly been started at this time. A company was formed in the United States called the American Diesel Engine Company, organized to build and sell the engine under Diesel's patents. Mr. Busch was a stockholder in this company but his principal contribution lay in the value of the patents he had acquired.

In 1898 a twin cylinder 60 h.p. engine was built, a crude but practicable machine, which was placed in commercial operation under load, being the first Diesel engine in the world to be so operated.

The question is frequently asked why the Diesel engine has made such strides abroad and so little progress has been made in this country. This is due to several reasons:

First: Coal is much cheaper in the United States than in Europe and therefore it is more wastefully used; while the leading idea in Europe is economy in operating cost, the leading idea in the United States is economy in first cost. The word efficiency is unknown to a vast proportion of businessmen and buyers of machinery in this country while abroad it forms the basis for every contract.

Second: The steam engine in America is much cheaper than abroad, but the Diesel engine is not and will never be a cheap engine. It aims to be the best engine and must be constructed of the highest class of materials with the most skilled workmanship. This makes it difficult for it to compete with the cheaper type of steam engine in the United States. We are accustomed to engines at a low price and the price of the Diesel per pound seems exorbitant.

Third: The lack of capital on the part of the prospective purchasers and the high rate of interest on capital and investment in the United States hinders the advance of the Diesel.

Fourth: In the last decades the general business profits in America have been so large that little thought was given to the most economical methods of production and the strictest economy in the fuel bill, as well as other expenses, was not taken into earnest consideration, the main object being to manufacture quickly and in quantities, regardless of cost. America has not had to compete with the industrial countries of the world as Europe has.

To these reasons may be added that the financial strength of the American Diesel Engine Company was never vigorous and the exploitation was consequently retarded. The fact that before the expiration of the patents approximately 50,000 h.p. in Diesels were in operation in this country may not appear as so bad a record when all the obstacles it had to overcome are taken into consideration. The American company adhered to practically one basic type during nearly the whole term of the patents, though it has since been superseded and the engines now placed on the market in the United States are abreast of the best European designs in the stationary types of engines. They have not, however, advanced to the large sizes prevailing abroad, for there are at present in operation in Europe engines of 4000 brake h.p., while the largest engine manufactured in this country to date is less than 1000 h.p. in four cylinders.

CHAPTER II

BASIS OF OPERATION

The operation of the four-stroke-cycle Diesel engine may be simply described as follows, with the assistance of the diagrams shown in Fig. 1. The first diagram represents the downward stroke of the piston, the valve being open, admitting air from the atmosphere to completely fill the cylinder when the piston is at the bottom end of its stroke. The second diagram represents the second or upstroke of the piston, called

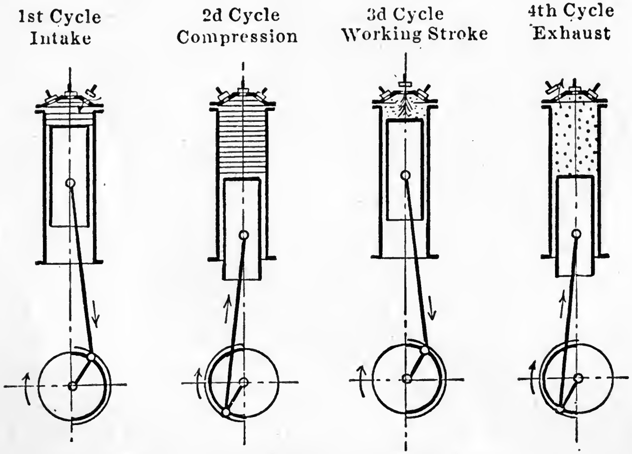


Fig. 1. Four-stroke Diesel Diagram.

the compression stroke, all the valves being closed. When the piston reaches the top of stroke, leaving only the small distance between the top of the piston and the head, the air has reached a pressure of about 500 lb. per sq. in. and as compression of air increases its temperature, the 500 lb. per sq. in. corresponds to 1000

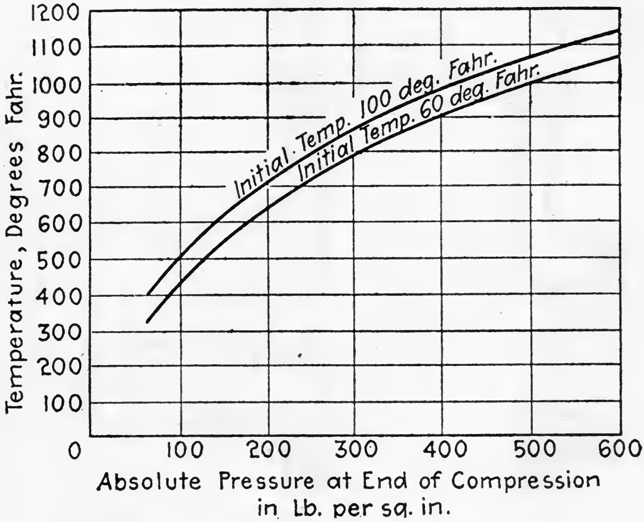


Fig. 2. Compression Temperatures for Diesel Engines.

deg. Fahrenheit, as may be plainly seen in Fig. 2. At this point, when the piston commences the downward stroke, fuel oil is sprayed or atomized into the cylinder during a definite period of the down stroke. When it comes in contact with the compressed and heated air it burns and expands, giving the necessary pressure for the power stroke. When the piston has practically reached the lowest point the exhaust valve opens and relieves the pressure during the upward stroke, the piston expelling and exhausting the burnt gases, completing the cycle in readiness for the down stroke. This is what Dr. Diesel finally accomplished in his engine and represents the most economical, practical, and probably the most efficient conversion of energy ever developed. The cycle just described represents a four-stroke-cycle, the one most used for smaller engines, in fact the one most frequently used in this country, there being but few companies making a two-stroke-cycle stationary engine in the United States.

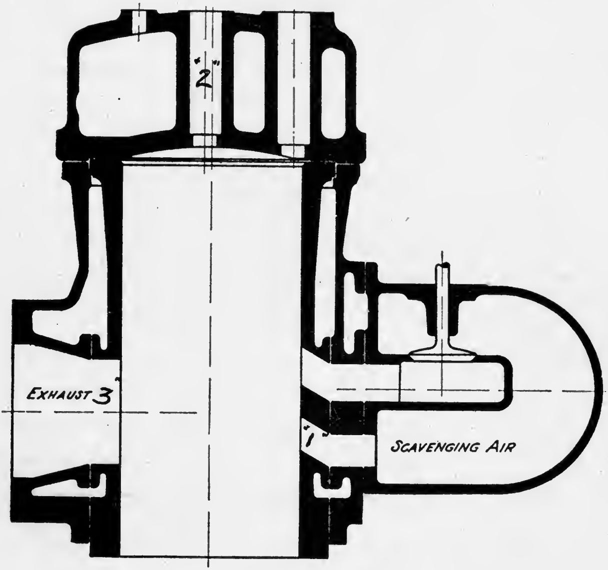


Fig. 3. Diagram Illustrating Two-stroke Diesel.

The two-stroke-cycle may be described with the assistance of Fig. 3. Assume the piston in its extreme lowest position, valve No. 1 represents an opening in the cylinder which is uncovered when the piston is in this position. This is called the admission or inlet port and delivers air at from 5 to 6 lb. per sq. in. provided by a scavenger pump. No. 3 represents the exhaust port which opens slightly before No. 1, allowing the exhaust gases to pass out. When No. 1 opens the inrush of air under slight pressure hastens and assists the burnt gases to escape. On the upstroke the full cylinder of air remains and is compressed to about 500 lb. per sq. in. with the accompanying rise in temperature. Valve 2 then opens and fuel oil under pressure is sprayed or atomized as in the four-stroke-cycle. This figure shows the later type of two-stroke-cycle cylinder with a valve in the scavenger air inlet to assist filling the cylinder with low pressure air,

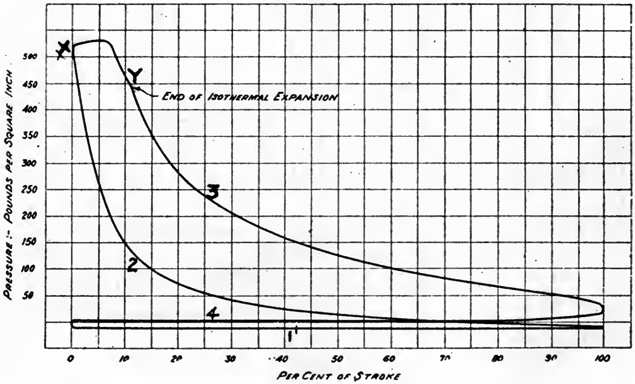


Fig. 4. Four-stroke Cycle Diesel Indicator Card.

after the exhaust is partially covered. The burning of the oil forces the piston downward, giving a power stroke every two strokes in place of every four strokes, as in the four-stroke-cycle engine, usually called four-cycle. Fig. 4 represents an indicator diagram from a four-stroke-cycle engine and if we assume, for example, a vertical engine, the line 1 represents the downward stroke of the piston and the drawing in of the air at approximately atmospheric pressure. The line 2, the upstroke of the piston, the vertical rise in this line showing the gradual increase in the pressure, while the trend to the left shows the decreasing distance between piston and the head until the point "X" is reached, a short distance before the top center when the fuel is allowed to enter and continues until the point "Y" is reached. The balance of the line 3 being the continuance of the expansion, due to the burning of the oil. The line 4 shows the up-

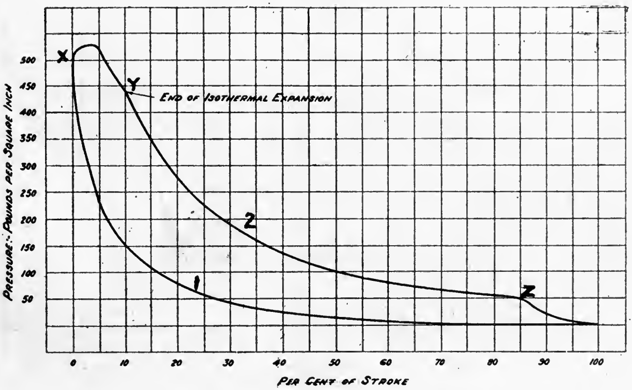


Fig. 5. Two-stroke Cycle Diesel Indicator Card.

ward stroke and the exhaust of the burnt gases to the atmosphere.

Fig. 5 shows a diagram from a two-stroke-cycle engine. The difference from the four-stroke-cycle is easily noticeable. The line 1 represents the upstroke in a vertical engine; point "X" point of fuel injection and "Y" the point of closing of the fuel valve. The line 2 shows the burning and expansion of the oil; the

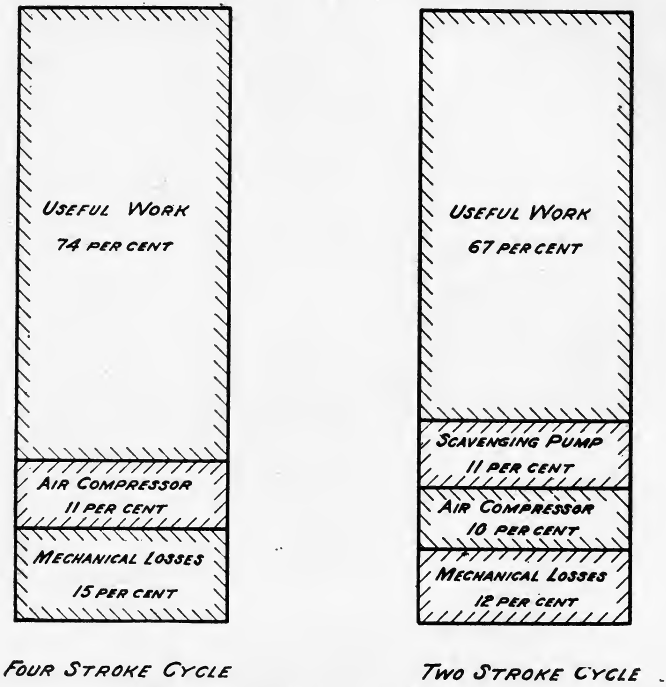


Fig. 6. Comparative Efficiencies of Two-stroke and Four-stroke Cycles.

point "Z" being the starting of the opening of the exhaust port, being slightly before the scavenger air is allowed to enter. The necessity of uncovering the exhaust port when the pressure is at a higher point than in the four-stroke-cycle would appear to lessen the efficiency of the cycle. This, however, is nearly compensated for by the loop in the four-stroke-cycle shown in Fig. 4, between the lines "1" and "4." The necessity of a scavenger cylinder and the power to drive it makes the two-cycle engine of lower overall efficiency than the four-stroke-cycle. The comparison is shown in Figs. 6 and 7. Fig. 6 shows the four-stroke-cycle to be 74 per cent mechanically efficient and the two-stroke-cycle 67 per cent. These efficiencies, however, should not be confused with the thermal efficiency which ranges between 30 and 35 per cent.

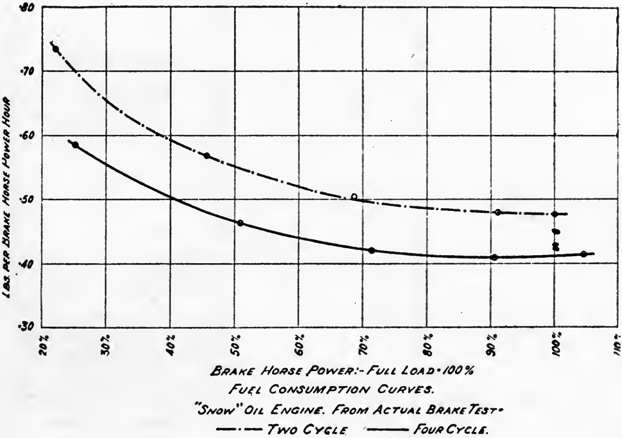
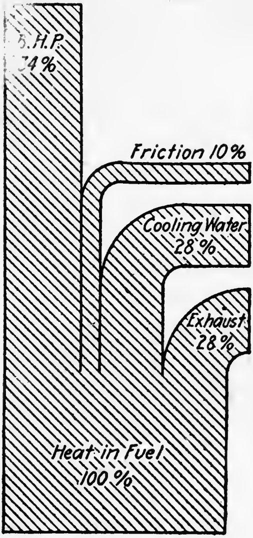


Fig. 7. Fuel Consumption Curves.

This is shown by the following example by referring to Fig. 7. Assuming a four-stroke-cycle engine and oil to contain 18,000 B.t.u. per pound the full load consumption of the four-stroke-cycle is shown to be .41 of a pound of oil per brake horsepower hour, .41 × 18,000 = 7380 B.t.u. are fed to the engine for each h.p. developed for one hour's operation. A horsepower hour contains 2545 B.t.u., so dividing the output in heat units by the input in heat units gives 2545/7380 = .345 or 34.5 per cent thermal efficiency. The thermal efficiency of the two-stroke-cycle, based on the con-



4-Cycle
Diesel Engine Plant.

Fig. 8. Graphic Illustration of Heat Balance.

sumption shown in the same figure is $2545/.48 \times 18{,}000 = 29$ per cent thermal efficiency for the two-stroke-cycle. These are, however, both actual overall thermal efficiencies and moreover the ones that may be easily expected in practice and covered by rigid guarantees offered by the manufacturers. The efficiency of the theoretical cycle does not include the mechanical losses which range between 10 and 15 per cent. A graphic illustration of the heat balance of a Diesel engine is shown in Fig. 8.

The actual use of these two kinds of engines is based on several considerations. The largest and most varied experience has been had with the four-stroke-cycle of low speed. They have higher efficiency than the two-stroke-cycle, and their absolute reliability has been proven beyond a doubt. So the reason for changing to two-stroke-cycle in smaller and moderate sized engines is but slight.

However, when larger sizes are approached the size of cylinders becomes too large and the two-stroke-cycle is forced into consideration, and here it has its most economical application. The value of the money to be invested in the engine, the cost of fuel to run it and the cost of freight on the engine should be taken into consideration in each separate case in balancing the one type against the other.

The problem is settled by the manufacturer, however, by placing low cost of manufacture against economy of operation, in other words, a low first cost for the purchaser versus a low operating cost. These can only be balanced when all the conditions of operation are taken into consideration. Practically all the American engines operating on the Diesel principle are of the four-stroke-cycles, but some manufacturers adhere to the two-stroke-cycle, even in sizes as low as 80 h.p. in two cylinders. The simplicity of the two-cycle engine, with its absence of valves except for fuel and starting, is a decided advantage, but there must be balanced against this the fact that cooling the cylinders and pistons is much more difficult, as twice the heat must be removed in a given cylinder size in a two-stroke-cycle engine. The latest types of two-stroke-cycle are provided with mechanically operated scavenging ports in addition to the uncovering function of the pistons. In this way the scavenging air enters the cylinder after the exhaust port is closed, and increases its volumetric capacity, due to the excess pressure of the scavenger air above that of the atmosphere.

Carnot's law, as applying to heat engines, is well understood: the higher the initial temperature and the lower the terminal temperature, or the higher the initial compression pressure and the lower the terminal pressure, the higher will be the theoretical thermal efficiency of the engine. But the actually attainable efficiency is limited by the characteristics of the available materials; and modified by the mechanical losses, affected by the weight and dimensions of the moving elements of the engine. Dr. Diesel demonstrated that, although the theoretical thermal efficiency increased slightly beyond this point, the highest mechanical efficiency was attained with a compression pressure of 30 atmospheres, (450 lb. per sq. in.), and a compression temperature of 500 deg. C. (868 deg. F.) Balancing these advantages against one another, that the highest actual efficiency, and the greatest useful power development per unit of cylinder volume, would be obtained by compressing the air to a pressure of between 30 and 40 atmospheres, (450 to 600 lb. per sq. in), and a temperature between 500 and 600 deg. C. (868 deg. to 1048 deg. F.) and introducing the fuel in such manner as to obtain combustion at constant pressure with a maximum combustion temperature between 1600 and 1800 deg. C. (2848 and 3200 deg. F.) On either side of these limits, the actual efficiency of the engine diminished. These deductions do not appear to have been proven incorrect after twenty years of practical and diversified experience. It is self-evident that the stated compression temperature is "far in excess of that required" solely for the ignition of any carbonaceous substance which would ordinarily be used as fuel; also that, to avoid ignition during the progress of the compression, the fuel must not enter the cylinder until after the full compression has been attained.

CHAPTER III

EXPERIENCE WITH EARLIER INSTALLATIONS

One of the first plants to be operated commercially in America with Diesel engines was owned by the Manhattan Transit Company, located at Forty-seventh street and Second avenue, New York City. In 1902 this company purchased a 30 h.p. single cylinder Diesel engine, the cylinder dimensions being 10 by 15 in. The power was to be used in generating current for charging electric vehicles. It was superseded by two twin cylinder engines of 60 h.p. each. These were, in turn, superseded by two 75 h.p. triple cylinder machines.

The first three engines installed were belted to direct current generators. The last two 75 h.p. were direct connected to the same type of electric generator. All of these engines had separately driven air compressors of the two-stage Ingersoll-Rand type. The two last engines installed are still in operation. The first three, however, have been junked. All of these engines were of the splash lubrication type. The last two 75 h.p triple cylinder machines installed were of the same type and design as those built by the American Diesel Engine Company until the latter part of 1914.

In the first engines installed the admission valves were automatically operated, opening inward, being closed by a spring. The exhaust valves and fuel valves were operated by an eccentric and pin operating a rod connecting to the valves which were closed by springs, while the fuel valves were of the horizontal type. One of these engines was wrecked, due to a broken connecting rod which at that time was made of cast iron. The second one was wrecked due to mechanical troubles.

The two last 75 h.p. engines installed in this plant, having three 25 h.p. cylinders, were designed by the late Mr. James McPherson and manufactured in Providence, R. I., at the old Corliss engine works, the dimensions of the cylinders being 10 by 15 in. They had splash lubrication and a cam shaft running through the crank case with cams to open the exhaust and fuel valve; the admission valve of this engine was automatic, similar to that on the first design. This type was a distinct advantage over the first American design, one of the new features being removable heads, which were adopted with this engine for the first time in this country. Six air bottles or steel tanks were supplied with each engine of approximately 8 in. in diameter and 8 ft. in length; they were imported from abroad and tested at 3000 lb. per sq. in. Pennsylvania crude oil was used for fuel, being purchased in barrels at a cost of 4 cents a gallon. The plant was visited daily by prominent men of New York City, especially from Wall street. The owners of the Manhattan Transit Company were important figures in the financial district and enthusiastic about Diesel engines.

The machines operated 24 hours a day and after the last engines were installed furnished lights for the business block as well as furnishing current for charging the electric vehicles. Mr. McPherson, in designing this last engine, in no way followed European practice and after the successful operation of this size he designed engines of 120 h.p., 170 h.p. and 225 h.p. All engines were built with three cylinders with com-

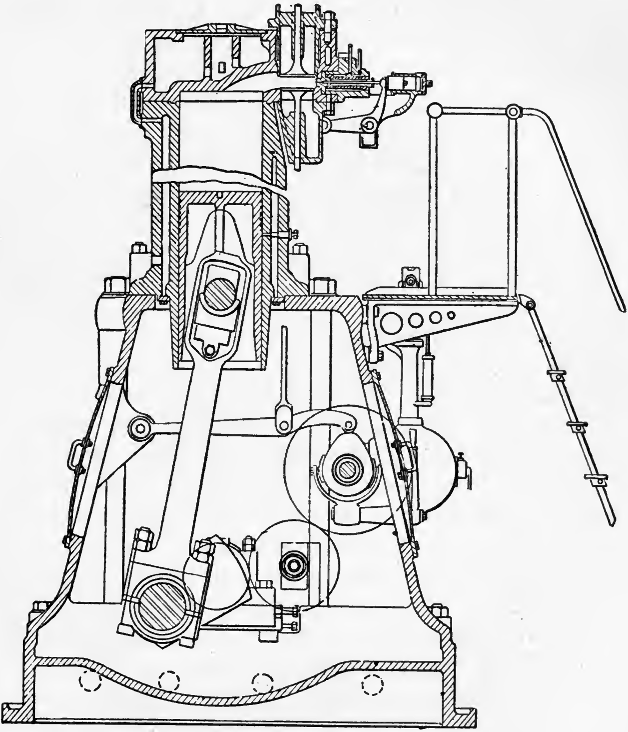


Fig. 9. Sectional Drawing of American Diesel Engine.

pressors either belt driven from the engine or motor driven. The 225 h.p. engine shown in Fig. 9 consisted of three 16 in. by 24 in. cylinders, the cranks being set at 120 degrees; the connecting rods with wrist pin bolts were made of forged steel, while for the first time all valves were mechanically operated from cams. The admission valve was set in a cage while the exhaust valve had no cage, the seat being part of the head. The fuel needle was set horizontally and was mechanically operated from the cam shaft, the atomizers being made of bronze. The clearance at the top of the pistons was ⅛ in., this clearance giving a compression of 500 lb. per sq. in. and a consequent temperature of 1000 deg. Fahrenheit, the pistons having four compression rings but without wiper rings. The combustion chamber extended over between the exhaust and admission valve. The cylinders were solid, being of one casting, having no liners, as in the present types. These cylinders were water jacketed and a bypass led the water into the head while cooling water was also used in the exhaust chambers. The main bearings were babbitt lined and permitted of adjustment by wedges. These engines were started from one cylinder which was provided with a starting valve in addition to the usual inlet, exhaust and fuel valves.

The first three engines of 225 h.p. were shipped to St. Louis and installed in the Tyrolean Alps, a concession in the Louisiana Purchase Exposition in 1904. The engines were direct connected to direct current generators and supplied light and power for the Tyrolean Alps. The first engine was started at 11 a. m. and ran until midnight, the other two were cut in at dusk. During the entire fair there was no time that they were without light and power. After the fair one engine was sold to the Baldwin Locomotive Works in Philadelphia, and two to Ball Brothers Glass Company, Muncie, Indiana. All three are still in operation in connection with others afterwards purchased and installed in the same plants. The power house at the Tyrolean Alps was typical, laid out and set up in the latest and most approved manner at that time, two engines being arranged on one side of the room, the third being on the opposite side. The three compressors were set to one side of the engine room, one being of the Ingersoll-Rand type, two-stage horizontal and two built by the American Diesel Engine Company at Providence, R. I., of the two-stage vertical type, all motor driven. These engines at the Tyrolean Alps attracted a great deal of attention, thousands of people stopping daily to observe what was termed at that time the handsomest machinery in the world. The engines were painted with black enamel paint and had gold trimmings, the room was fitted with hardwood polished floor, in fact everything appeared as if it was intended for permanent operation. Of course, at that time there were few people who knew much, if anything about the Diesel engine, and it was a great curiosity.

Machinery Hall at the St. Louis Fair was an extremely large building. Many different designs of steam engines were installed and in operation, but at that time the semi-Diesel, as they call it today, was not even known. The Mietz & Weiss Co. of New York, exhibited a coal-oil engine and the Otto Gas Engine Company were about the only ones in the hall, a Webber gas producer being set up out in the boiler room and at that time was looked upon as being somewhat dangerous.

The real business of the American Diesel Engine Company, we might say, started at the St. Louis Exposition. A large number of engines were sold from this exhibit and during the year there was a plant installed in Sherman, Tex., for lighting the city. This plant afterwards was bought by the Texas Power & Light Company, who now have in operation approximately 20 or more Diesel engines and are still buying, even though they have a large and up to date steam turbine plant for some of their work. The Gorham Silver Company at Providence, R. I., The Prairie Pebble Phosphate Company of Mulberry, Fla., and numerous other plants were sold in this year.

The Prairie Pebble Phosphate Company purchased engines in 1904, 1910, 1912 and 1914 so that all told they have 19 Diesel engines in operation daily, Sixteen of their engines are set up in double units, making eight 300 kw. sets. These engines all run in parallel, driving sixty cycle alternating current generators of 2300 volts. The power in this plant is used for driving centrifugal pumps for hydraulicing the banks of phosphate rock, which is used as a fertilizer and a large majority of the thousands of tons obtained daily are shipped to foreign countries, largely to Germany.

The Sherman, Texas, plant furnishes light for the city of Sherman, supplying 24 hours service. The tests on this engine are shown in the accompanying table as having been made in January, 1905, the yearly operating log being shown also. During the year from March, 1912, to February, 1913, it is interesting to note how nearly the fuel consumption over the year's operation approached the fuel consumption on full load tests seven years before, showing conclusively that the Diesel not only maintains its original economy but also is extremely economical on the fluctuating loads of a central station.

TABLE I. OFFICIAL ACCEPTANCE TEST, SHERMAN, TEX., JANUARY 1, 1905.

Three Cylinder 16x24, 225 B.H.P. Diesel Engine No. 138.

Time.	Volts.	Amp.	R.P.M.	Oil.	Oil Consumed Gal.	Air Pressure.	K.W.
5 p. m.	242	640	162	.....	.....	72 atm.	.....
7 p. m.	242	635	164	19.0	16.0	71 atm.	156.7
9 p. m.	240	655	163	18.0	15.5	70 atm.	159.0
11 p. m.	243	620	164	15.5	15.5	67 atm.	158.0
1 a. m.	238	640	104	13.0	13.0	....	159.0
3 a. m.	239	655	163	14.0	14.0	69 atm.	157.0
5 a. m.	240	650	164	14.5	14.5	69 atm.	161.0
7 a. m.	239	665	164	14.0	14.0	69 atm.	160.0
9 a. m.	238	670	163	14.0	14.0	70 atm.	160.0
11 a. m.	240	655	164	13.5	13.5	70 atm.	160.5
1 p. m.	238	665	164	14.0	14.0	70 atm.	157.0
3 p. m.	242	660	162	15.75	15.75	70 atm.	161.6
5 p. m.	243	675	160	17.75	17.75	72 atm.	168.5

Total KW. Developed During Test.

Total hours run................24
Total kw. developed............38325
Average kw. developed per hr..159.6—232.4 h.p. at 92% Gen. Eff.
Max. kw. developed in 1 hr.....168.5—245.0 h.p. at 92% Gen. Eff.
Average air pressure...........70 atmospheres

(Oil consumption as shown averages 9.41 gal. per 100 kw.-hr.—6.46 gal. per b.h.p. hr.)

450 kw. Diesel Engine, Central Station Installation.

Month.	Output kw.-hr.	Load Factor. Per Cent.	Total Operation and Maintenance. Mills Per kw.-hr.
1912.			
March	95,328	28.4	5.31
April	77,915	24.0	6.88
May	76,820	23.0	6.70
June	70,230	21.7	7.96
July	91,704	27.4	8.05
August	85,105	25.4	9.50
September	105,506	32.5	5.83
October	117,360	34.7	7.28
November	114,048	35.2	6.43
December	117,499	35.1	4.69
1913			
January	115,212	34.1	6.22
February	101,300	33.5	5.10
Total	1,168,027	....	....
Average	97,335	29.6	6.66

Physical Data.

H.P. rating of plant, 675. No. of engines, 3. Size of each, 225 h..p
Cost of fuel oil f.o.b. plant, per bbl., $1.05. Per gal., .025.
B.t.u. of oil, 18,000. Average gal. fuel oil per 100 kw.-hr., 10.2.
Wages of men per day, $9; 1 at $3.33; 1 at $2.17; 1 at $2; 1 at $1.50.

Another interesting plant is that of the Key West Electric Company at Key West, Florida, who were among the early purchasers of Diesel engines. They operated at first in connection with their steam plant two 225 h.p. engines belted to a jack-shaft, to which also was belted their steam engines and from that a large belt running to a generator. In the spring of 1907 they installed a third 225 h.p. to operate their trolley system and these engines are all in operation at the present time. In 1908 the Diesels were disconnected from the jack-shaft and individual generators installed, direct connected to the engines. The engine that operates their trolley system also operates their electric fan circuit, and as Key West is a city of 25,000 and quite warm the year round, the fan load is considerable. This engine does 18 hours a day service year in and year out. The conditions at Key West, Fla., make it hard to maintain any kind of machinery, as the salt atmosphere necessitates the changing of all water piping every six months or at least once a year. The water used for circulation is of the worst kind, as naturally there is no fresh water on the island of Key West, excepting rain water, which is only used for household purposes, all other water being obtained from inland wells whose water is brackish on account of its proximity to the ocean.

A great many Diesel engines of this same type with some improvements, have been sold and put in operation in over half the states of the Union and in fifty-nine or more different kinds of industries. Diesel engines today are driving ice machines, flour mills, chocolate factories, woolen mills, cotton mills, paper mills and innumerable other industries. One flour mill with a capacity of 1000 barrels per 24 hr. formerly used

55 to 58 bbl. of fuel oil under boilers every 24 hr. This plant now with Diesel engines turns out the same amount of flour on from 11 to 13 bbl., a saving of over $1100 a month in fuel alone. There are ice plants being operated with Diesel engines in some of our hottest states, such as Louisiana, that are making ice at a fuel expense of 18 cents a ton.

The public, in general, has heard more or less of the troubles with Diesel engines, but it is the same thing with any new invention placed upon the market. In a steam plant, for instance, the boiler could blow up and kill a half dozen people. Someone would say, "Why, that's too bad, but we will have to buy a new boiler." But when it comes to the Diesel engine, if a minor difficulty should occur and cause the lights or power to be off for ten minutes, everyone would have "their sign out"—"I told you so. That engine is no good," etc. Diesel engines up to the present time have never had an honest chance. A great majority of those put out into the world are operated by men who simply know if they open this valve or that, that the engine will start or stop, with no idea of the care that is necessary to make an engine operate successfully.

Another thing that has always seemed strange is that the purchaser of a $25,000 steam plant will want the best steam engineer he can obtain at almost any price to care for and operate his plant, a man who has had years of training along this line, but when the same man or one of his type, purchases a Diesel engine plant costing $25,000, he generally tries to get the cheapest man possible to operate it. Diesel engines require more care and attention than steam engines, not considering the boiler plant or pumps and auxiliaries.

There are approximately five times as many parts, or more, to a Diesel engine as there are to a steam engine, and lost motion on all these parts is considerable. The writer recalls a plant that he visited at one time in Arizona. The engine had been operating almost continuously, night and day, for four years, furnishing power for a water pumping station. As he entered the plant the engine sounded more like a stone crusher than an engine and this noise all came from lost motion in the valve gear, caused by neglect and lack of knowledge. The following day when the engine was shut down for inspection the lost motion was found between the cams and the rollers connected to the rods that open the exhaust and admission valves to have from ½ in. to ¾ in. clearance instead of only 1/32 in. On asking the engineer what this meant he said not to blame him; that the man who erected the engine set the rollers that way, four years before, and he had never touched them. That was his idea of operating and caring for a Diesel engine!

CHAPTER IV

FUEL OIL

Although almost all forms of carbonaceous and hydro-carbon fuels, from powdered coal to gas, have been tried experimentally in Diesel engines, commercially successful operation has been confined to liquid fuels—more particularly to mineral oils and coal tar. In the United States the relative value of tar is so high, on account of the marketable products obtainable from it and its use for roofing and similar purposes, that there has been no inducement to use it for Diesel engine fuel in preference to the cheap petroleum fuels. It was for this reason alone, that one large gas company, after successfully using the tar from its own works as fuel in its Diesel engines for some years, changed to oil, finding it possible to sell the tar for more than the cost of the oil.

There does not appear to be any limitation to the possibility of using mineral oils in Diesel engines, from the heaviest crudes to refined kerosene, but commercial and practical considerations tend to give preference to fuel oils ranging between 24 degrees and 36 degrees Beaume. The available supply of these fuels is large in proportion to the demand for them, so that they may generally be purchased at prices as low as, or lower, than those of crudes, from which the valuable lighter and heavier constituents have not been abstracted.

Fuel oils, for use in Diesel engines, should contain the lowest proportions of the following impurities, compatible with the prices demanded:

Water—because it is charged for at the fuel oil price; it reduces the efficiency of the engine; it increases the maintenance costs; and it has a detrimental effect upon the regulation. More than one-third of one per cent of water should be considered excessive; and, if fuel containing more than this has been accepted, the water should be settled out, by heating the oil by means of a steam coil.

Sulphur—if in excess of 1½ per cent, the combination of the sulphurous fumes with the vapors of the water combustion, will corrode and pit the exhaust valves and seats, and rapidly eat out the exhaust piping.

Ash—a comparatively minute percentage of entirely noncombustible matter in the fuel causes an accumulation on the oily cylinder walls, between these and the piston, which will result in excessive wear.

Asphaltum—this much abused term is susceptible to so many and various interpretations, that it has no definite significance. Nor has the method for its determination been standardized. The various chemical and mechanical (penetration) determinations have little or no bearing upon the real issue under consideration here; viz., the complete combustibility in a Diesel cylinder under the conditions existing in it and within the available time. A comparison of results obtained in actual use for the above purpose, with oils containing a substance, other than ash, which will not volatilize under certain definite conditions, appears to be the best guide as to the proportion of this substance which will render necessary an excessively frequent cleaning of the cylinder and its adjuncts. Several years of careful observation and records have induced the oldest Diesel engine builders in this country to adopt, for such comparisons, the percentage of residue remaining after the sample of oil has been gradually brought to a temperature of 570 deg. F. and then subjected to this temperature for 120 hours, in a closed furnace, in which combustion does not take place. Under this treatment the sample is reduced to practically constant weight. It has been determined that, so long as this residue is less than 10 per cent of the original weight of the sample, unreasonably frequent cleaning is not necessary. This percentage is equivalent to anywhere from 7 to 30 per cent of "asphaltum," according to the various methods of determination in use. If the fuel oil contains more than the above-mentioned 10 per cent of residue, its use must be guided by the relative cost of the oil, and the cost and inconvenience of labor and stoppages required for the more frequent cleaning. The form of the atomizer does not appear to have any bearing upon this question, as the substance does not become objectionable until after the fuel has entered the cylinder and its most volatile constituents have become gasified; although it may render the fuel so "heavy" that warming is necessary to enable the oil to flow to and be handled by the fuel pump of the engine.

Fig. 10 illustrates the consumption of fuel oils of widely varying gravity, in the same engine.

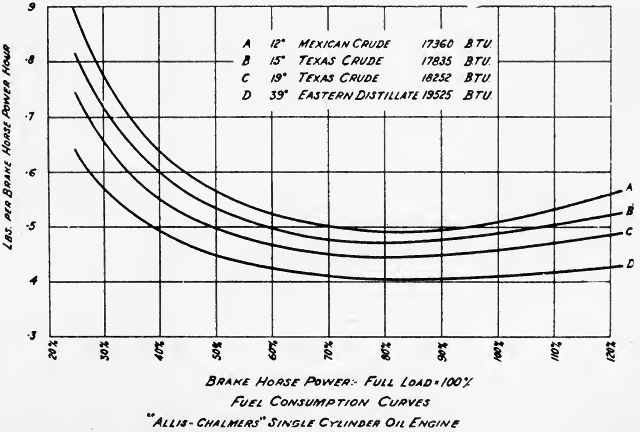


Fig. 10. Fuel Consumption Curves.

The fuel oils of the West that are available on the Pacific Coast all fall within the limits set forth by the Diesel manufacturers and a table showing their composition follows:

Composition of Fuel Oils.

	No. 1	2	3	4	5
Producer:	Standard Oil Co.	Union Oil Co.	Union Oil Co.	King Oil Co.	Coalinga
Trade Name:	"Calol"	Regular	"Diesol"		
Heat Value.	Fuel Oil.	Fuel Oil.	Fuel Oil.	Crude Oil.	Crude.
B.t.u. per lb....	19,250	19,136	19,100	19,229	18,642
Gr. °B at 60° F..	27.20	15.7	25	29.2	19.4
Flash Point °F..	212	146	200	130	149
Burning Point °F.	234	304	235	145	201
Sulphur........	.74%	.89%	.73%	1.18%	.66%
Water	.08%	.08%	.08%	.08%	.68%
Residue	3. %	15.1 %	3.9 %	.2 %	9.8 %
Asphaltum	25. %	50. %	20. %		
Price f.o.b...... Refinery per bbl.	80c	70c	80c	65c f.o.b. Field.	60c f.o.b. Field.

	Mexican Crude.			
B.t.u. per lb.............	18,127	18,097	18,776	18,499
Gravity °B at 60° F......	17.46	19.5	17.6	18.5
Flash Point °F..........	186	182	268	97
Burning Point °F........	213	212	237	138
Sulphur	2.12%	2.0%	2.44%	3.92%
Asphaltum	39.3 %	43.7%	53.0 %	54.9 %

This table shows the percentage of asphalt by the evaporation, as usual with oil companies, and also by the test as mentioned above for the determination of asphaltum or residue. Nos. 1, 2 and 3 are products of the refinery, having the gasoline removed. The oils sell for approximately the price noted, the California fuel oil least fitted for use in the engine, No. 2 of the table is the most economical if the selling price is from 1-8 to 1-10 of a cent less per gallon than such oil as "Calol" fuel oil No. 1 or "Diesol" fuel oil No. 3, considered to be the most adaptable, commercially, of the

California oils. It would appear more economical to use No. 2, not taking into consideration the cost of heating this low gravity oil to make it flow readily to the fuel oil pump. The Mexican oils are expensive at any price, due to the high sulphur content. It may be roughly stated that any oil that will flow through a 1 in. pipe from a gravity tank and available for purchase on the Pacific Coast can be used in the Diesel engine. If the oil is at such a gravity that it will not flow at room temperature it must be heated. This can be easily accomplished by making use of the water for cooling the engine which usually flows out at 110 degrees to 130 degrees. Fig. 11 shows the effect of temperature upon gravity. A 20 degree Beaume oil at 60 degrees Fahr. heated to 100 degrees Fahr. is equivalent to a 22.5 degree Beaume oil and its viscosity will be increased· and the oil will flow more readily. Although oil is generally spoken of in degrees Beaume the real comparison should be based on specific grav-

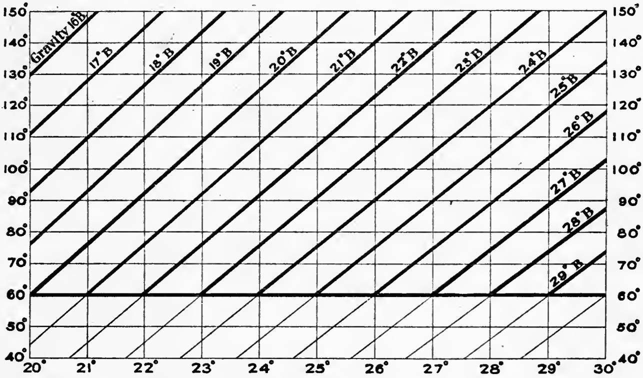


Fig. 11. Gravity Correction Curve for Temperature.

ity, the relative weight per unit of volume compared to water at a given temperature. The table showing this comparison follows:

Data for Fuel Oil.

Specific Gravity.	B.°	Wgt. Gal.	Wgt. Bbl.	Wgt. Cu. Ft.	Cu. Ft. Ton.	Gal. Ton.	Bbl. Ton.
1.0000	10	8.33	349.86	62.355	35.9	268.9	6.43
.9929	11	8.27	347.34	61.912	36.1	270.8	6.46
.9859	12	8.21	344.82	61.475	36.5	272.8	6.50
.9790	13	8.16	342.72	61.045	36.7	274.6	6.54
.9722	14	8.10	340.20	60.621	36.9	276.6	6.59
.9655	15	8.04	337.68	60.202	37.2	278.6	6.65
.9589	16	7.99	335.58	59.792	37.5	280.3	6.69
.9523	17	7.93	333.06	59.380	37.7	282.4	6.73
.9459	18	7.88	330.96	58,981	38.1	284.2	6.77
.9395	19	7.83	328.86	58.582	38.3	286.	6.82
.9333	20	7.78	326.76	58,195	38.5	287.9	6.86
.9271	21	7.72	324.24	57.809	38.8	290.	6.91
.9210	22	7.67	322.14	57,428	39.	292.	6.96
.9150	23	7.62	320.04	57.053	39.2	293.9	7.01
.9090	24	7.57	317.94	56.680	39.5	295.7	7.06
.9032	25	7.53	316.26	56.319	39.8	297.4	7.09
.8974	26	7.48	314.16	55.957	40.1	299.4	7.14
.8917	27	7.43	312.06	55.601	40.3	301.4	7.18
.8860	28	7.38	309.96	55.149	40.6	303.5	7.24
.8805	29	7.34	308.28	54.903	40.8	305.2	7.28
.8750	30	7.29	306.18	54.560	41.1	307.2	7.32
.8484	35	7.07	296.94	52.991	42.4	316.8	7.55
.8235	40	6.86	288.12	51,349	43.7	326.3	7.78

The above table is based on the formula $\frac{140}{130 + ° \text{Be.}} = \text{Sp. Gr.}$

For each 10° F. above 60° F. add 0.7° Be.
For each 10° F. below 60° F. subtract 0.7° Be.
42 gal. = 1 bbl. 1 ton = 2,240 lb.

The matter of using the lower gravity and lower priced oil is a matter that must be determined in each separate installation, based on the character of the service the engine has to perform. Uniformity of the oil that has passed through the refinery is of extreme value, its composition between limits being guaranteed by the seller while the composition of native crude oil is exceedingly uncertain. It is easy to understand that the cheapest oil is not always the most economical, for the cost of repairs and attention will necessarily increase as the quality of the oil decreases. It has been the experience of a large majority of Diesel users that the slight increase in the cost of the better oil is economical and advisable in the long run, just as the use of fuel under boilers, particularly of coal, the cheapest coal is not necessarily the most economic fuel.

Guarantees for fuel consumption will be maintained with oil falling within the following limits:

Gravity at 60 degrees F. not heavier than 20 degrees nor lighter than 40 degrees Beaume.

Flash point between 125 and 250 degrees F. burning point between 160 and 300 degrees F.

Sulphur between .5 per cent to 1½ per cent.

Water not over .3 per cent.

Ash not over .01 per cent.

Residue not over 10 or 15 per cent.

Heat Value: The heat value usually ranges between 18,000 British thermal units (B.t.u.) per pound and 19,000 B.t.u. per pound.

Flash and burning points are specified on account of the hazard of storage. If the oil is stored underground a flashpoint as low as 95 degrees F. and 125 degrees F. may be used. On the newer type engines sulphur as high as 2½ per cent is not objectionable.

A residue of 10 per cent is conservative. Many plants are in operation successfully with fuel as high as 15 per cent based on the test for 120 hours. This is equivalent to approximately 30 per cent asphaltum by evaporation. It may be stated, however, that usually manufacturers are very conservative as to the quality of oil recommended for use in the engine, while some others are prone to make extravagant statements that cannot be lived up to in practice with good service.

The production of fuel oil and its future is a question that presents itself to every prospective Diesel engine purchaser. The table shown herewith gives the production of oil as compiled by the United States Geological Survey. As the oil generally used in a Diesel engine throughout the United States is practically a by-product of gasoline, there is little likelihood of it ever increasing in price beyond a reasonable limit. The fact that all of the principal oil producing companies in the United States have oil to offer that is acceptable to the Diesel engine users and competition may at all times be expected is another point to be taken into consideration in regard to an advance in price. The oil for Diesel engines is not available in drums or barrels being shipped in tank cars of from 6500 gallons to 13,000 gallons capacity. The plant usually has a tank of sufficient capacity to take a carload with a slight overlap, a 20,000 gallon tank being sufficient with the size tank car now in use.

Oil Production in Barrels.

State.	1914.	1913
California	103,000,000	97,788,525
Oklahoma	98,000,000	63,579,384
Illinois	21,000,000	23,893,899
Texas	20,000,000	15,009,478
Louisiana	15,000,000	12,498,828
West Virginia	11,000,000	11,567,299
Ohio	7,500,000	8,781,468
Pennsylvania	7,000,000	7,963,282
Wyoming	4,600,000	2,406,522
Kansas	2,700,000	2,375,029
Indiana	700,000	956,095
New York	800,000	902,211
Kentucky	500,000	524,568
Colorado	150,000	188,790
Other States	50,000	10,843
	292,000,000	248,446,230

CHAPTER V

EFFECT OF ALTITUDE

Due to the reduced density, that is the weight per cubic foot of the atmosphere at higher altitudes, the amount of oxygen drawn into an engine cylinder is lessened and therefore the quantity of fuel with which it will combine and burn is relatively decreased. Consequently a Diesel engine will not develop as much power at a higher elevation as it will at lower altitudes. For altitudes less than 500 ft. above sea level no reduction in horsepower or alteration of fuel consumption need be contemplated but at higher elevations a reduction in horsepower is necessary in accordance with the accompanying table:

Effect of Altitude.

Table of Altitudes in feet above sea-level; with corresponding approximate Barometric Readings, Atmospheric Pressures and proportionate Densities.

(The capacity of an internal combustion engine at higher altitudes, as compared with its capacity at sea-level, is practically proportional to the atmospheric densities.)

Altitude in Feet.	Barometer in Inches.	Atmospheric Pressure in lb. per sq. in.	Proportionate Atmospheric Density.
0.00	30.0	14.72	1.00
500.	29.5	14.45	0.98
1000.	28.9	14.18	0.96
1500.	28.4	13.94	0.94
2000.	27.9	13.69	0.93
2500.	27.4	13.45	0.91
3000.	26.9	13.20	0.89
4000.	26.0	12.75	0.86
5000.	25.1	12.30	0.83
6000.	24.2	11.85	0.80
7000.	23.3	11.44	0.77
8000.	22.5	11.04	0.75
9000.	21.7	10.65	0.73
10000.	20.9	10.26	0.70

This table shows the height of the barometer in inches and the equivalent density of the atmosphere. The horsepower output of the engine will be proportionate to the equivalent density, that is, a 500 h.p. at sea level, at 5000 ft. elevation 500 x .83 or 415 h.p. The fuel consumption of this engine, however, must also be revised, an addition of 1 per cent or fraction thereof being made for each 1000 ft. elevation.

The capacity of the cylinder also definitely limits the output of an internal combustion cylinder at any altitude, as the combustion of the fuel depends entirely upon the amount of oxygen in the cylinder, a certain amount of oxygen giving complete combustion to a certain amount of fuel oil, which in turn develops a certain amount of power. Ordinarily internal combustion engines are rated at 10 per cent below their ultimate capacity and it is dangerous and uneconomical to operate the engines at a greater load than specified by the manufacturers, although this may be possible for short intervals. The evidence of smoke coming from the exhaust shows that the combustion in the cylinder has not been complete and is the forerunner of a flame in place of the usual exhaust dry gas. This flame will burn and destroy the exhaust valve.

The electric generator manufacturers supply a generator especially rated for internal combustion engines. These machines are not capable of standing the usual overload guarantee of 25 per cent for 2 hours but instead will only carry 15 per cent overload, corresponding to the overload capacity of internal combustion engines. It would be manifestly uneconomical to purchase a generator having a greater ultimate capacity than that of the engine.

It cannot be emphasized too strongly that when a generator is part of the Diesel equipment its selection must be given as much care as the engine itself and the reliability of the manufacturer and the guarantees offered must be carefully analyzed. In alternating current applications the ability of the generators to operate in parallel when driven by oil engines must be thoroughly understood and guaranteed by the electrical manufacturer.

Foundation.

An important element in the erection of the Diesel engine is the foundation, which on good ground will vary, depending upon the size of engine, from 40 cu. yd. for a 100 h.p. to 125 cu. yd. for a 500 h.p. engine of the vertical type. This foundation should be constructed of concrete, 1 part cement, 2½ parts sand and 5 parts clean stone broken to pass a 2 in. ring, to be mixed wet and rammed every 8 in. depth until water appears on the surface. The templets which are set for the anchor bolts should remain open to permit ramming. Concrete should not be allowed to set hard before other concrete is placed on it, otherwise sound bonding between portions is impossible. Around each foundation bolt a wooden box approximately 4 in. square and at least 4 ft. long should be placed, the box to have a taper toward the top so that the box may be removed. If preferred, 4 in. diameter galvanized spouting may be used and left in the foundation, projecting not more than ½ in. above the concrete. Grouting should be of equal parts of Portland cement and clean sand mixed wet enough to flow readily. The grouting must fill all of the space around the foundation bolts.

CHAPTER VI

OPERATION AND CARE OF ENGINES

With the type of engine now most extensively used in the United States, that is the Diesel with the splash lubrication system, there is any amount of unpleasant work, especially when the engine requires attention inside the crank case. Few men, unless they are reasonably paid, are willing to do this "dirty" work, as it might be called, together with the fine attention required by the main bearings, keeping the shaft in line and other adjustments that are made inside the crank case.

The Diesel engines that are being manufactured today of the later type are greatly improved in this respect; the majority of them have forced lubrication so the inside of the engine is naturally cleaner for working.

One of the most important things in connection with the Diesel engine is cleanliness. Nine times out of ten if you should meet the engineer outside of his plant at any time during his watch you could safely judge the condition of his engine from his personal appearance. An engineer who lacks pride in keeping himself clean will never have a clean engine room. In a great many plants visited by the writer the engine or engines were so dirty and covered with oil that it was impossible to go near them until they had been thoroughly cleaned. Sometimes this would take a day or two. There is no leak around a Diesel engine that cannot be stopped. It is an old saying that little things make big ones and if small leaks, when they are first seen, are attended to there will be no large leaks. As a general rule all of these leaks are either a loss of fuel oil or lubricating oil, either one of which is an expense to the owner.

All true Diesel engines work along the same lines and require about the same care, but some, due to their construction, require more attention in regard to cleanliness than others. As to the operation of the engine there is but one way to be successful and that is to be clean about all your work in connection with the engine, as dirt to any extent is the worst enemy of machinery and especially a Diesel engine. It is always wise for the engineer to be on duty in ample time to carry out the necessary preparations for starting the engine without undue haste.

Some instructions will tell the engineer to place his engine in starting position as soon as the engine is shut down. I do not agree with this. It is well to get the engine on the right revolution for starting but not to bring up to the starting position until almost time to commence operation. If the engine is placed in starting position and left over night, with some types, the starting valve is held open during the time by the starting valve cam. This valve is closed by a spring and as there is always more or less moisture in the starting air it will cause corrosion around the valve stem and often times the valve will not close as quickly as it should, causing a false start. It is the writer's belief that just this trouble was often the cause of broken shafts in the early days of the Diesel engine. If the engine is left just back of starting center until the time of starting when it is turned up into starting position it will move this valve and break the corrosion if it has set in.

There are so many different designs of the Diesel engine being built at this time that it is hard to describe the starting moves of each engine, but the result of all is the same. After the engine is placed in starting position, the engineer is ready to prime the fuel oil pump or start a flow of oil through the pump to the telltale, according to the design of the engine, it being necessary to get a solid stream of oil at the telltale before the pump is ready to operate. If air should be in the oil line or pump it is doubtful if the engine will pick up or start work at once and it often is the cause of a false start and the loss of starting air, which, of course, is undesirable in connection with the Diesel engine. The engineer should always see that the circulating water is running through the engine before it is started; if this should be neglected and the water is low in the cylinder and closed when starting the engine so that regardless of the decrease of air in the starting bottles the spray bottle pressure will be kept as high as possible and must always be at least 100 lb. above the compression in the engine cylinders. If the pressure in the spray bottle should get lower than the pressure in the cylinder when the fuel needle opens, there would be insufficient spray air pressure to blow the fuel into the cylinder and the heat from the compression would be liable to ignite the oil in the atomizer and cause severe trouble.

After the engine is started it is always wise to refill the starting bottles as soon as possible and close the valves tightly to prevent loss of air.

Then all lubricators should be looked after to see that they are doing their work and kept well filled. The circulating water should be regulated according to the load on the engine so that it is not above 130 degrees Fahrenheit or cooler than 90 degrees Fahrenheit.

With engines of the enclosed crank case type and splash lubrication many engineers have found it turned on after the engine is started it is often the cause of cracked cylinder heads, as the piston of the Diesel engine only has to make a few strokes before the heat of the compression and the burning oil would raise the temperature of the head to such a degree that water coming in contact with it would cause it to crack.

With all Diesel engines air bottles, or tanks, or vessels as they may be called, are shipped with the engine forming part of the installation. These bottles are all tested to 3000 lb. and as a general rule are shipped from the factory containing air at 1200 lb. per sq. in. Some builders ship six bottles, some three. Where there are six bottles four are for starting and used for this purpose only. The other two are used for atomizing or spray air. Two starting bottles are used at one time and one spray bottle where six bottles are provided. The header which connects the bottles together is always provided with a valve between the starting set and spray bottles. This valve should always be level and the right mixture. Practically all of the

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ERRATA NOTE

Lines 8 to 27, page 45, should follow line 20, page 44.

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Then all lubricators should be looked after to see that they are doing their work and kept well filled. The circulating water should be regulated according to the load on the engine so that it is not above 130 degrees Fahrenheit or cooler than 90 degrees Fahrenheit.

With engines of the enclosed crank case type and splash lubrication many engineers have found it turned on after the engine is started it is often the cause of cracked cylinder heads, as the piston of the Diesel engine only has to make a few strokes before the heat of the compression and the burning oil would raise the temperature of the head to such a degree that water coming in contact with it would cause it to crack.

With all Diesel engines air bottles, or tanks, or vessels as they may be called, are shipped with the engine forming part of the installation. These bottles are all tested to 3000 lb. and as a general rule are shipped from the factory containing air at 1200 lb. per sq. in. Some builders ship six bottles, some three. Where there are six bottles four are for starting and used for this purpose only. The other two are used for atomizing or spray air. Two starting bottles are used at one time and one spray bottle where six bottles are provided. The header which connects the bottles together is always provided with a valve between the starting set and spray bottles. This valve should always be level and the right mixture. Practically all of the engines of this type have a 1½ in. plug in the top of each door. If before the engine is started the engineer is sure that the oil and water are about the right mixture and height in the crank case he should, after starting the engine, remove the plugs and by putting his finger into the hole in the door he will soon become accustomed to the amount of oil and water that splashes so that any time while the engine is running he can do this and feel sure as to the amount of oil and water in the engine. This has been found to be the simplest and most satisfactory way to obtain this troublesome to keep the water and oil at the proper information.

When the engine is running, careful watch must be kept on the pressure of the spray air. The appearance of the exhaust will indicate whether the air is too low or too high. If it is too high, a pound will be heard on the fuel valve and white smoke will appear. If too low, black smoky exhaust will appear. It is always advisable, if possible, to let the circulating water run for ten or fifteen minutes after the engine is shut down so as to cool it off gradually. The tops of the pistons in a Diesel engine naturally become very warm while running under load and when the engine is shut down, if the circulating water is cut off at once, the pistons in a stationary position will heat the water in the cylinder jacket around them so hot that the lubricating oil will run off the pistons and there will be nothing left to lubricate them when the engine is again started. This would naturally add to the loss of compression and sometimes causes trouble in starting. Then again the hot pistons would cause the gummy oil that is around the rings to fry and cook and naturally cause the rings to stick. Also the heat from the piston will heat the wrist pin at this time, which causes the oil to run off of that, and when the engine is started it is some time before lubricating oil can again reach this point.

In stopping the engine, if possible, throw the load off gradually. If it is necessary at any time to shut the engine down quickly in case of accident or for some other reason, the quickest way is to shut off the fuel and let the engine stop or die with the load on.

In nearly all Diesel engines there is a small hole provided somewhere in the exhaust valve cage which allows the engineer to inject a little coal oil on the exhaust valve stem. The reason for this is that with a small load on the engine the exhaust valve stem is liable to become gummed with the unburnt oil. This, of course, greatly depends upon the kind of fuel oil being used. A fuel oil high in asphalt is more liable to cause gumming than oil with a paraffine base. When using an oil with an asphalt base it is always quite necessary to put coal oil in the exhaust valve stems before shutting down. The spray air should never be shut off the engine until it is almost stopped. The first thing to do is to shut off the fuel, which is the life of the engine. As the engine starts to slow down the bleeders on the air compressor should be opened. When the engine is at a standstill close the lubricators on the engine and the compressor and close the valves on the air bottle as tightly as possible.

The care of the valves of a Diesel engine is a very important thing, as the success of the operation depends entirely upon their being kept tight. The writer would advise the owner of a Diesel engine or a prospective purchaser, to always have a number of spare parts on hand, the most essential being one admission valve and one exhaust valve complete. By this is meant the valves and the cages in which they set. In this way on Sunday, if that is the day the engine is to be shut down for a few hours' inspection, the admission valve and exhaust valve can be taken out of one cylinder and the two valves in perfect condition put in their place. The following week the engineer could see that those taken out were put in condition and ready for the next change. This could be continued, say every three or four weeks, so there never would be a time when it was necessary to shut the engine down to grind valves, and by so doing the valves would always be in good condition. If the engineer tries to grind valves on a Sunday, or any day that might be selected for the two or three hour shut down, he naturally does the work in a hurry, the valves being more or less hot and the work is not done properly. In grinding either the exhaust or admission valve it may be often observed after grinding a few minutes that the valve and seat will appear to be in perfect condition but it is always a good idea to test the seats before putting the valves together. A good way to do that is to wipe the seat of the cage and the valve as clean as possible and then mark the seat crosswise about 1 inch apart all the way around with a lead pencil. Then put the valve in place and give it half a turn. If by so doing all pencil marks are cut off the valve has a perfect seat. If any of the marks are left it is necessary to keep on grinding until they all come off by turning the valve, giving an absolute assurance of a good seat.

Nearly all Diesel engine builders furnish with the engine a number of spare parts, consisting of one fuel needle, one atomizer, one fuel pump plunger, one fuel pump suction valve, one fuel pump discharge valve, one complete set of springs for all valves and one complete set of gaskets. But to have a safe supply of spare parts everything they furnish singly should be brought up to the number of cylinders on the engine. In this way if it is a three-cylinder engine there should be three of each of the parts, while if of four cylinders four of each except gaskets. Of these there cannot be too many, and it is always advisable to have at least a half dozen piston rings on hand. The cylinder heads should be lifted at least once a year, the pistons taken from the engine, the wrist pin taken out and the bearings examined and refitted. All rings should be removed from the piston, the ring grooves and rings thoroughly cleaned and if any of the rings show wear they should be replaced. At such a time during the overhauling of the engine all bearing caps should be lifted and the shaft and bearings examined, as much as possible, then the caps reset and locked.

If the engine is of splash lubrication the lubricating oil should be cleaned out of the crank case at least once in six months. If there is leakage by the rings due to wear or stuck rings, it is necessary to clean the crank case at shorter intervals. The engineer can always judge the condition of the oil in the crank case by its color. Even though the oil might look dark, by taking a small quantity on your finger and going to the sunlight, if you can get a green shade the oil is still good. If the oil shows black in the sunlight it is time to clean the crank case. The proper way of doing this work is to bail out all the oil and water that can be taken from the crank case. It is good practice, at such a time, to start the engine up with the doors off and watch the lost motion or anything that might be loose in the crank case and cannot be seen at any other time, but it is inadvisable to run the engine longer than five minutes as the crank pins will get hot. After this inspection is finished put in the regular amount of water that would ordinarily be followed by a new supply of lubricating oil, then add three or four pails of fuel oil to each crank pit, put the doors on and start the engine and run it for 15 minutes. It will be found when the doors are taken off that the working parts of the engine are thoroughly washed off, this method cleaning the bearings where it is impossible to wipe out the dirt. It also prevents either the lint from rags or waste that might be used in cleaning remaining in the crank case and finally after running collecting in the lubricating holes of the bearings. The water and oil should then be bailed out and thrown away, the usual amount of water and lubricating oil placed in the case ready for running. Waste should never be used at any time inside of the engine, or in any place where it might fall in while the doors are off.

In the setting of the main bearing caps it is a good idea, in order that the clearance may be known exactly, to use No. 10 fuse wire, placing four pieces across the shaft, one at each end and two near the center, then putting the cap on and pulling down as hard on the nuts as possible so as to allow about .006 clearance, then mark the nuts and bearing with a center punch so that they may be brought back to the same place. After removing the wires build up with metal shims until it is all you can do to pull the nuts down to the marked places. Then your cap will be solid and you know the clearance is correct.

After once going over the engine in this way and resetting caps with thin shims it will be easier to make the adjustments from that on as one can be taken out from each side, the cap pulled down as hard as possible and the engine turned over; if it turns free it is all right to go ahead with another run or until it is necessary to overhaul again.

The admission valve is contained in a cage designed to permit the removal of both valve and seat to allow of easy access for grinding. If the valve should get into bad condition it may be necessary to ream the seat and face the valve. This should rarely be necessary, but if done, great care should be used in maintaining a true and even pressure on both valve and seat at an angle of 45 degrees. Every precaution must be exercised to remove all cuttings or emery and all parts should be thoroughly cleaned. When replacing the admission valve cage into the cylinder head see that all contact surfaces of both the head and cage are well cleaned and that the gasket is in good condition. Tighten the holding down nuts with a wrench only. Do not use a hammer or length of pipe on the wrench and be careful to get the cage down evenly on the joint. After starting the engine watch the valve for evidence of leak, and should there be a sign of one carefully draw up on the nuts. Do not delay doing this or the gasket will rapidly burn at the leak and have to be replaced. A leaky admission cage will cause a serious loss of power.

The casting which contains the fuel needle and the other accessories to the fuel valve is known as the fuel cage. This cage is an iron casting which is subjected to high pressure. The high pressure in this valve is confined in the steel bushing which is pressed into the casting. The injection air and fuel oil connections are both screwed into steel bushings. Water circulated around the bushings keeps it cool and prevents overheating of the fuel oil. The fuel needle is made of a special alloy with a cast iron spring case on the outer end in which the spring operates to close the valve against the action of the fuel cam.

The best quality of woven vulcabeston, or similar material, should be used for packing the fuel needle stuffing box; the packing must contain no rubber or gutta percha, as oil quickly softens and destroys these materials.

The atomizer where the injection air and fuel oil meet before entering the cylinder must be frequently examined to see that it is not clogged with dirt, which may come in the oil, or scale from the pipes. As a precaution against the clogging of the atomizer keep the oil strainer clean. The fuel needle seat should show a ring all around about 1/32 in. wide and should not require grinding very often. A reamer and guide should be on hand to ream this seat when necessary, and great care must be taken to apply an even pressure to the reamer to prevent chatter marks which would spoil the seat. To prevent undue wearing of the needle withdraw it once a week and oil the packing with graphite and cylinder oil applied by means of a rag on a wire. The needle may readily be withdrawn after loosening the gland nuts.

The exhaust valve seats in some engines are not removable. It may be reamed when necessary, using the guide furnished with the reamer which fits into the head. Care must be exercised to cut as little as possible from the seat and to maintain an equal pressure on the reamer to insure a true and smooth surface. When the valve needs refacing it should be put into a lathe and skimmed off by a competent man, removing no more material than necessary to true up the face and maintain an angle of 45 degrees.

It is the writer's opinion that all Diesels should be provided with a safety valve on each working cylinder. This valve is intended to relieve any undue pressure in the cylinder and is set to open at 800 lb. per sq. in. The piston traveling slowly downward at the time the first ignition takes place allows the pressure to increase above the normal; the relief valve is intended to take care of this increased pressure. Also in case needle should stick open and allow the fuel to enter the cylinder during the compression stroke a premature ignition will occur, this increased pressure causing the relief valve to pop and give warning that the fuel needle is sticking.

The fuel pump consists in general of fuel plungers, suction valves and discharge valves, together with their driving and controlling mechanism. The plungers are driven by eccentrics and are attached to the suction valve mechanism by means of connecting rods and eccentric levers. Oil is delivered to the chamber in which the plunger travels through a mechanically operated suction valve. The plunger in its turn delivers the oil through the discharge valve to the fuel valve on the engine cylinder. The opening of the suction valve is controlled by an eccentric fulcrum, the position of which is regulated by a governor according to the load on the engine. At full load the suction valve starts to open at about mid-position of the plunger on its downward suction stroke and closes about mid-position on the upward delivery stroke. At no load the suction valve remains open during complete upward stroke of the plunger. The fuel pump suction valve is made of steel and the valve stems are nickel steel. The stuffing boxes of these valves should be packed with Blackhawk or similar packing, just tightly enough to prevent leakage as excessive friction prevents the springs from closing the valves promptly and affects the regulation of the engine.

Careful straining of the fuel oil is an important factor in the successful operation of these valves. Dirt or scale may mar the seats sufficiently to affect the operation of the engine. In case of such injury to a suction valve the seat should be reamed with a tool provided for this purpose and the valve trued up in a good lathe by a careful workman. The valve should then be ground in the seat with very fine emery and finished with pumice stone.

When replacing the valve cage after having cleaned all parts of the valve, be sure to get the lower joint tight, otherwise no oil will be delivered to the fuel value and no work done in the cylinder. This joint is made with a corrugated brass gasket. Both surfaces of the joint must be thoroughly cleaned and the hole in the gasket must be large enough not to interfere with the operation of the valve.

The fuel pump discharge valves usually consist of hardened steel balls in steel cages. When the fuel oil is thoroughly strained and contains no grit, these valves require little attention. Should they become worn the seats must be reamed and a new ball put in place. To seat the new ball only one solid tap of a hammer is necessary. A ball set should be used for this work, using the guide which comes with the reamer as a guide for the ball set. The ball set is made of brass or steel with a brass tip so that the ball will not be marred. The lift of the ball should not be greater than 1/16 in. When it becomes greater than this, due to wear or reaming of the valve seat, it is necessary to use a new cage. Test the discharge valve to know that it is tight. To do this, disconnect the supply pipe between the discharge valve and the fuel valve. Place a cage on the outlet of the discharge valve and operate the fuel pump by hand to obtain a pressure of 75 atmospheres on the cage. If the pressure does not remain constant, look for a leak in the gasket, the discharge valve or the suction valve.

The injection air pressure should be graduated according to the load. At half load, and under, it should range from 50 to 60 atmospheres, or 450 lb. to 900 lb. per sq. in. Above half load from 65 to 70 atmospheres, 975 to 1050 lb. per sq. in. It is desirable when the peak of the load runs over the rated load of the engine, to use 75 atmospheres, 1125 lb. per sq. in If this pressure is too low for the load of the engine the exhaust will smoke. If it is too high the engine will knock. The pressure of 75 atmospheres is absolutely safe, as all high pressure fittings furnished are tested to a pressure of 3000 lb., the valves to 2500 lb. and the tubing to 6000 lb. The gauges which indicate the injection pressure should be frequently calibrated.

In every engine room there should be one gauge fitted with a valve and this valve kept closed. This gauge may then be used at any time for comparison with others. By holding one gauge in reserve the others may frequently be checked and when found incorrect, easily adjusted. A sudden increase or decrease of pressure often causes a gauge to read incorrectly. To positively check gauges for correctness they should, say every six months, be tested by means of a gauge tester. Gauges in use for some time tend to read high and lack of air pressure will make the engine appear overloaded.

The cylinders of practically all Diesel engines are lubricated by force feeding. The lubricating pump in some types is driven from the end of the cam shaft and must always receive proper care. The connecting rod boxes, shaft bearings, cam rollers and all wearing surfaces enclosed in the crank case are kept well oiled by the splash or forced lubrication. In splash lubrication the oil is thrown by the crank and conveyed to the various parts by oil grooves and oil holes designed for the purpose.

The oil cups on the fuel pump and governor must be kept well filled. No lubrication is necessary for the admission or exhaust valves, but the admission valve dash pot should occasionally be oiled. Where splash lubrication is employed three or four pints of oil should be added every four hours to crank pits. Three or four bucketsful of water should also be added to crank pits at this time. Some engines will evaporate more water than others. The engineer should use his judgment in order to keep the level in the crank case about right.

It is of the utmost importance that the fuel valve be correctly timed, that is, that it opens to admit fuel at the proper time and closes at the correct moment after the fuel is all injected. Every Diesel engine builder will furnish with his engine a table giving the correct measurements for his special engine. A typical diagram is shown in Fig. 10. If the fuel valve opens too early the pressure in the cylinder will increase. This condition should be avoided as it causes excessive wear of the engine bearings without increasing the engine capacity. Do not increase the lead beyond that given in the table, with the idea of forcing the engine to pull more load. The figures given are sufficient and if the engine will not pull its rated load when adjusted correctly look elsewhere for the trouble.

If the fuel valve opens too late difficulty may be encountered in pulling the rated load. If the fuel valve closes too early the engine may have a smoky exhaust and burn too much fuel for the load which it is running. If the fuel valve closes too late injection air will be wasted. When setting the fuel valve compressed air in the air storage bottle should be used to indicate the exact time of the opening of the needle.

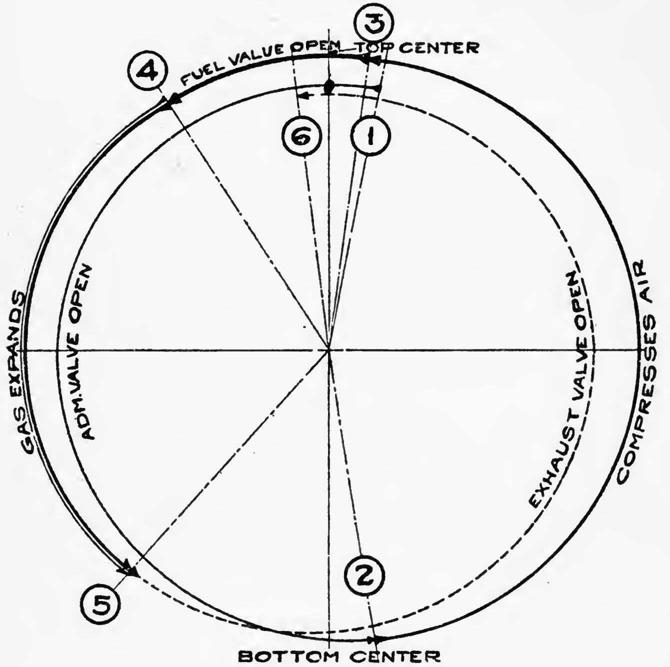


Fig. 10. Typical Valve Timing Diagram.

To ascertain the point of opening this valve proceed as follows:

By barring the fly wheel, set the engine a few inches back of the position at which the valve should open. Pull up lever that relieves the compression on the cylinder or take out the indicator plug. Then turn the fly wheel ahead until the required lead is reached, whether it be 2½ or 5 inches or more before the dead center-mark on the wheel when set at the proper measurement according to your table for the lead; turn on the injection air and listen at the indicator hole for a leak by the needle into the cylinder. If you hear nothing, change the adjustment of the valve rod until you just hear the least bit of air blowing by. Be very careful about this adjustment and see that the blow is the same after you have regulated your adjustment.

To ascertain the point of closing of the fuel valve turn the fly wheel ahead slowly until no air is heard to escape from the fuel valve when valve on the air line is open. Determine the point of closing by measuring from this point to dead center position. If the correct opening and closing of this valve cannot be accomplished by adjusting the vertical push rod it is then necessary to move the fuel cam nose slightly forward or backward, as the case may be, in the cam body. When the fuel nose is in its correct position any space between the ends of same and the fuel cam body should be carefully and tightly filled with metal shims to insure the nose remaining securely in its place. It is good policy to check the timing of these valves at least once a month. Always check and properly time these valves after a fuel needle or atomizer has been removed or reground, and also at any time that it has been found necessary to take the needle out or to remove the valve cage.

There are quite a number of differently designed Diesel engines at this time and no doubt the number will increase rapidly, due to the number of manufacturers going into the Diesel engine building, but all true Diesels work along the same lines. Some are horizontal and some vertical, but the timing of the valves is practically the same. Some of the latest designs have all valves in the top of the head. This type of engine does not require as high a spray pressure as some of the others, air pressure ranging from 40 to 65 atmospheres, 600 to 975 lb. per sq. in., according to the load.

CHAPTER VII

DIESEL'S LIFE AND RELIABILITY.

The life of a Diesel engine is something that is often discussed. It is not unusual to find steam engines and steam pumps which have been in service thirty years, maintained in fair state of up-keep by repairs and renewals. The frame, shaft, flywheel and foundation, representing a large part of their original cost, continue in service. Yet, the engine and pumps represent less than forty per cent of the cost of a steam installation—about sixty per cent being in the boilers, heaters, condensers, stack and piping. Some of these features, the boilers notably, each year show a marked deterioriation and loss in efficiency. None of these features exist in the Diesel, and its life will compare most favorably with the entire equipment of a steam plant, its efficiency throughout its life remaining practically unimpaired.

The story of the Diesel engine is quite different from that of gradual obsolescence of the old steam plant. Ten, even fifteen years ago, when the Diesel was first built, it showed the same extraordinary efficiency. No builder of Diesels abroad, nor do we here, expect to increase its thermal efficiency to a very great extent. Diesel progress has been one of increasing refinements, a lengthening of its life, an increasing of its reliability and facility in handling and a perfection of its governing under varying loads. In these it is unapproached by any other type of prime mover.

The heavily designed frame, the shaft, and connecting rods, the massive fly wheel, etc., form a much larger proportionate cost of Diesel equipment than do these parts in a steam installation. Since these non-wearing parts form the larger cost, those parts which wear and deteriorate most, of necessity, form a less proportionate part of Diesel equipment than they do of steam equipment. It is easy to realize this by recalling that the entire boiler equipment, with all its auxiliaries, is eliminated, and that wear and tear is confined to parts which represent less than one-third of the original Diesel investment.

In the steam engine and in all explosive and hot-bulb types of internal combustion engines, leaky valves and worn cylinders result in reduced efficiency, the cause of which is not always apparent. If the engine is not loaded to capacity this consequently may not be detected until much damage has been done and much money lost. The Diesel, depending upon perfect compression for its ignition, does not permit a continuance of such losses; if compression fails ignition ceases and the engine stops. In other words such conditions as militate against the life of engines and their economy absolutely cannot exist long enough in the Diesel to do serious damage, or consume fuel in useless effort.

Another feature of the Diesel which adds to its life, and which sets the Diesel apart from all explosive types, is the absence of any sudden rise in pressure at instant of combustion. Gradual introduction of fuel during ten per cent to twelve per cent of the combustion stroke results in a more uniform stress and longer life.

Two 225 h.p. Diesel engines in a Texas power house during the nine years since they were installed, have operated on an average eighteen hours per day. Their cylinders were rebored after nine years' service. With the same handling in the future as they have had in the past, they should outlive a steam plant of like capacity.

With late designs, the wear and tear on the operating parts will be much less than in the older design. In the first engines, the cylinders were solid, so that in five or six years, as they became worn, it was necessary to bore them out and purchase new pistons. In the later designs the cylinders are fitted with a liner so that they may be replaced by merely lifting them out and slipping new ones in their place. These liners are made of cast iron and require only a small amount of machine work, so naturally are not expensive—simply a case of cast iron at so much a pound. With this system, new pistons are not required, as the piston of a Diesel engine never wears, simply the rings and the cylinder walls.

Reliability.

The reliability of the Diesel engine has been doubted for many years, not from the performance of the engine itself but from false reports. However, judging from the experience of the numerous plants that have been in continuous operation, they have proven very successful.

The water pumping station at Sherman, Texas, owned by the city, is a fair example. This is an installation of two 170 h.p. engines which for the past four years have been operating continuously 24 hours a day on 30 day runs. At the end of this time the engines are shut down, inspected and adjustments made if they are required.

There are any number of plants that have but one engine used for city lighting service and in manufacturing industries. If the engines in either case are operated on 24 hour schedule they arrange to shut down for a few hours on Sunday for inspection.

The City of Donaldsonville, Louisiana, purchased two 170 h.p. Diesels in about 1912. These engines furnished the light and the power for the city water works system. While a great many cities in the south have a standpipe in connection with their water service, Donaldsonville pumps directly into their lines, the pumps being driven with motors operated automatically to hold 50 lb. pressure on the system. The reliability of the Diesel engines in this plant was highly endorsed by the Fire Underwriters and the plant shows a wonderful saving over their old steam plant. The steam plant used 32 barrels of oil in 24 hours or 90 barrels of coal, while the Diesel plant, with practically the same load, uses 3½ barrels of oil per 24 hours, a saving of between $1000 and $1100 a month in fuel for the city.

The Texas & Pacific Railroad Company operate two of their railroad shops with Diesel engines, one at Marshall, Texas, the other at Big Springs, Texas. The Marshall engine has been operating a number of years, and judging from reports received from their mechanical engineer, this engine is giving perfect satisfaction, not only in the extreme economy of operation, but wonderful economy in upkeep. They state that their engine consumes 8 gallons of fuel per hour with an output of 90 kw., also that the average upkeep of the engine for the past three years has not been more than $2 a month—their engineer knows his business! The engine in the shops at Big Springs has been operating over two years with perfect success and little upkeep.

Another marvelous example of the reliability of the Diesel engine, both for endurance and upkeep, is at Plant City, Florida. This engine furnishes the lights for the city, in connection with furnishing power for manufacturing ice. The engine is 120 h.p. and was operated almost continuously for three years before any repairs were made. When the engine was overhauled the writer was there to note its condition and found out of eighteen rings, only two piston rings broken on the three pistons. None were stuck, and the cylinders were in perfect condition, as smooth as a looking glass. When the reliability for continuous operation is questioned it is safe to state that the Diesel engine is fully as dependable, if not more so, than the steam plant, when upkeep of boilers, pumps and auxiliaries is considered.

The City of Lyndon, Kansas, was operating a modern steam engine, in excellent condition, in fact when it was sold second hand it brought nearly full price. While operating the steam engine they only ran from dusk to dawn. Their average oil consumption was 1 bbl. of oil per hour; if they ran 10 hours it was 10 bbl.; if 13 hours 13 bbl., etc. The city installed a 120 h.p. Diesel engine three years ago, turned around the generator which had been belted to the steam engine and belted it to the Diesel. The load has been increased by extra street lamps and new users, both residence and stores, but even with the increase of output the Diesel engine does not average a barrel of oil per night, figuring 365 days a year. Naturally they are highly pleased and are now considering the purchase of another Diesel and furnishing lights and power for small surrounding towns.

The longest run the writer can recall was 94 days continuous operation in Jerome, Arizona. The plant consisted of two 225 h.p. Diesel engines connected to a Roots blower with rope drive, ventilating a mine. This we consider "going some" for combustion engines, and they were operated on California fuel oil containing 25 per cent asphaltum.

Another Diesel plant at Coeymans, N. Y., furnishes the light and power for three towns, namely, Coeymans, Ravina and New Baltimore. It has been in operation for the past seven years and the owner stated on several occasions, when asked what he thought of Diesel engines, that if he had his choice of being presented with the best reciprocating steam plant that could be furnished, and he had to buy the fuel to run it, he would much rather pay the price for Diesel engines. This plant, without a doubt, is the cleanest and best kept Diesel plant in the United States. The first two engines installed were 120 h.p. Since that time they have purchased two more, one 120 h.p. and one 225 h.p., all direct connected to a.c. generators operating in parallel. These are simply instances of typical Diesel plants of which there are now over 400 in operation in this country.

CHAPTER VIII

MODERN ENGINES

In present day design, Diesel engines are divided into two classes, the vertical and horizontal. Each of these types has their advocates. In Europe there has been a general adherence to vertical engines and at present the greater number of American builders are following lead. In the vertical engine some manufacturers are using the open "A" frame construction while others have adopted the closed box-frame crank case. The advantages of these types, as claimed by the manufacturers, are accessibility of the "A" frame and cheapness of construction as against the more expensive and more rigid construction of the box type crank case. The matter of cleanliness and absence of vapors being blown from the crank case is also an argument advanced by the latter. Steam engineers in general are advocates of the "A" frame construction, and this type has been operated in America with entire success. On the other hand the operation of the enclosed crank case has also many advocates and has been proven by long experience. It has been adopted by the largest European builders and is preferred there, particularly for high speed engines. This type of construction, however, cannot be carried into extremely large sizes as the capacity of freight cars is limited, both as to the size and the weight of the casting which

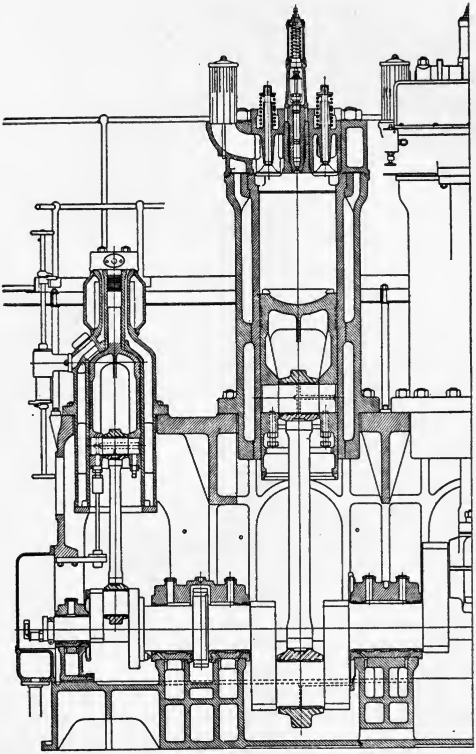


Fig. 11. Section of McIntosh & Seymour Oil Engine.

can be transported. It is usual with builders of "A" frame engines to enclose the working parts with some type of guards of sheet steel with small removable doors for observation.

The McIntosh & Seymour engine is designed with "A" frame as shown in section in Fig. 11. The main bearings are lubricated by chain oilers. The cylinders are lubricated at two different points, one in the front and one in the back, from a mechanically driven sight feed pump. The piston pin is provided with a separate lubricating pipe from the mechanical lubricator, which delivers its oil to a "V" shaped vertical groove in the piston; from this groove the oil is forced through a hole in the center of the wrist pin, whence it is lead to the bearings. The crank pins are lubricated by centrifugal oilers.

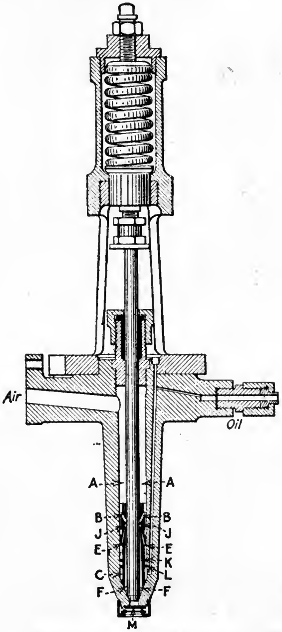


Fig. 12. McIntosh & Seymour Atomizer.

The atomizer is that invented by K. H. E. Hesselmann of the Aktiebolaget Diesels Motorer, (Swedish Diesel Engine Co.) shown in Fig. 12. Its essential feature is that instead of pulverizing the oil by crowding it down through perforated plates it draws it by the injector principle into the current of ingoing injection air, which atomizes and absorbs it as fast as it is drawn up. The charge of oil is deposited in a chamber, which it does not fill, even at an overload. Air is admitted to the chamber **A-A** and passes through the ports **B-B**, while it has also access to the oil chamber through the space **E-E**. When the fuel valve opens, the air, rushing through the port, passes through the expanding passage **F-F**, between the valve stem and the receding wall of the surrounding fitting, induces by injector action a difference of pressure which causes the oil to flow to the space, into which the oil, having been elevated and broken up through slotted plates **K** and **L** is drawn and picked up by the ingoing air. The form of the fuel plate has an important effect upon the efficiency of the atomizer.

The engine is started from a single cylinder. No attempt is made to relieve compression in starting as this is claimed to be unnecessary in engines below 500 h.p. Means are provided, however, for holding the exhaust valve open during the turning or barring of the engine by hand, preparatory to starting.

The cam shaft is located on the level of the heads, the cams not being housed. They are driven by a vertical shaft and screw gears. The rocket arms on these engines are practically alike, the rocker arm shaft being supported by steel pedestals fastened to the cylinder heads.

The variation of the quantity of oil pumped by the fuel oil pump is accomplished by varying the stroke of the pump plunger eccentric operated off the vertical shaft.

The McIntosh-Seymour Corporation are also bringing out an inclosed crank case engine in sizes ranging from 60 h.p. in one cylinder to 1000 h.p. in six cylinders and have constructed several machines of this type. These ratings are claimed to be exceedingly conservative and the engine permits of an overload of 20 per cent. The speeds are suitable for direct connection to 60 or 25 cycle alternating current generators.

The Lyons Atlas engine as built by the Lyons Atlas Engine Co. of Indianapolis, is unique, being truly of American design. It is not connected in anyway with any European concern. The engine is of the "A" frame type, designed by Mr. Norman McCarthy. It is of the vertical, single-acting, enclosed type, with automatic lubrication, ample protection being supplied to the working parts by sheet steel covers. The base contains the housings for the main shaft bearings and also forms a reservoir for lubricating oil. The "A" frame for each crank is cast in one piece with the cylinder. It fits on the base, completely covering the crank pit. The main bearings are in halves, split horizontally. Each bearing is fitted with two ring oilers, the reservoir box being filled with splash in the crank case. The main shaft is a solid forging of open hearth steel, the cranks being fitted with counter-weights to absorb vibration. The connecting rods have solid upper ends, the lower boxes are babbitted. The upper or wrist pin boxes are of phosphor bronze backed by a steel wedge. Adjustments can be conveniently made from the outside through side openings. The cylinder is provided with a liner cast separate from the cylinder proper. The heads are of close grained cast iron and are water jacketed, and can be removed without disturbing the valves. The pistons are of the long trunk type fitted with seven compression rings, no wiper ring being provided. A hardened steel wrist pin is ground to a perfect surface and firmly secured in the piston. The valves are in cages to permit of ready removal for regrinding. The splash system as well as the forced lubrication system is used by this company for lubrication.

The fuel injection pump is of the two-stage type, the first stage being directly controlled by the governor and serving to measure at the last instant before the beginning of each working stroke the exact quantity of oil that is to be admitted. This governing stage operates against pressure not in excess of atmosphere and is sufficiently sensitive in action to perform its important functions with the necessary quickness and accuracy.

The Lyons Atlas Company have built a 600 h.p. engine in four cylinders, this being the largest Diesel engine yet constructed in America. Two engines of this size were shipped to China and one of this size is in operation in the Hawaiian Islands. These engines have cylinders 21 in. by 30 in. stroke, developing 150 h. p. when operating at 164 r.p.m.

The Fulton-Tosi engine built by the Fulton Iron Works of St. Louis, is similar in most respects to the other A frame engines. The cam-shaft is on the front of the engine at the level of the cylinder heads. It is encased in a cast-iron housing for the full length of the shaft and the cams and gears operate in oil. The cam shaft is driven from a vertical shaft which also drives the governor and the fuel oil pump, bronze and steel spiral gears being provided.

The rocker arm slips off the end of the supporting rod without disturbing any other parts of the arm or head.

Variation in the quantity of oil delivered by the fuel oil pump is accomplished by maintaining a constant stroke of the pump plunger with a constant pump cylinder volume during the suction stroke and varying the pump cylinder volume during the delivery stroke. This is shown in Fig. 13. The method is in general use in America.

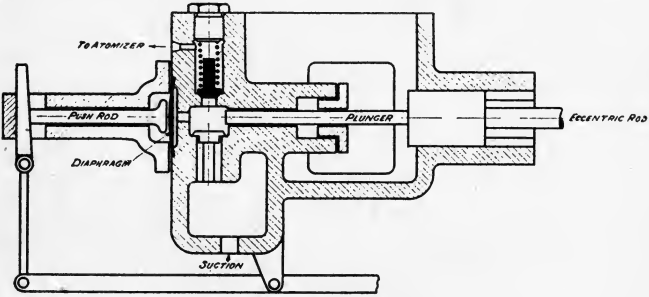


Fig. 13. Fulton Tosi Fuel Oil Pump.

Busch-Sulzer Bros. adhere strictly to the box type of construction up to 500 h.p. The engines (shown in section in Fig. 14) are of the box frame type with all parts under force feed lubrication—the cylinders, main bearings, cranks and wrist pins. The cylinders are lubricated at six different points by a sight feed mechanical lubricator. The main bearings, crank pins and wrist pins are lubricated with a positive displace-

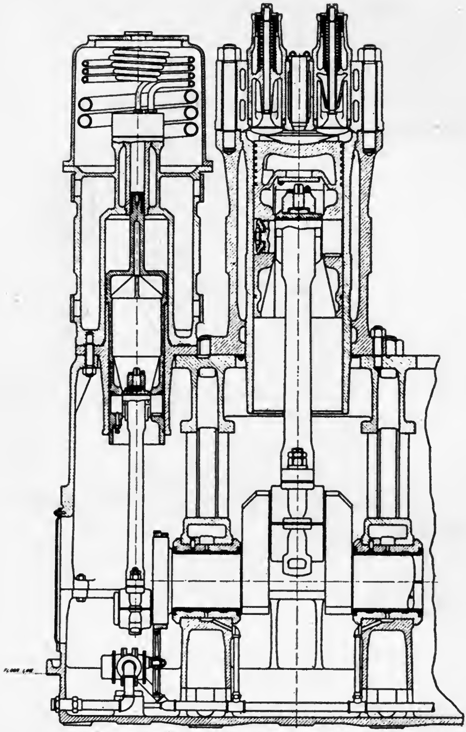


Fig. 14. Section of Busch-Sulzer Bros.-Diesel Engine.

ment rotary pump located in the crank case and driven by gears from the main shaft. It takes its oil from a filter and cooler below the floor line at the end of the engine. The crank shaft (see Fig. 15) and connecting rods are provided with a ⅜ in. hole extending from the main bearing through the web to the center of the crank, the same sized hole extending through the entire length of all connecting rods both for working cylinders and compressor. Fifteen pound pressure is maintained on the lubricating oil by the rotary pump and a gauge in plain sight of the operator indicates the pressure.

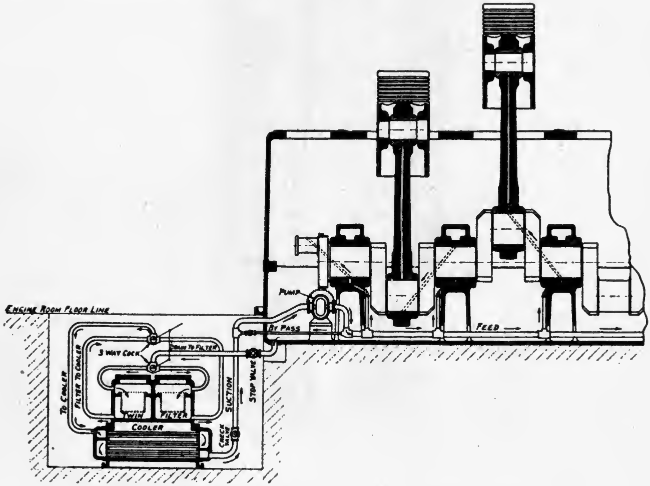


Fig. 15. Lubricating System of Busch-Sulzer Bros. Engine.

The atomizer is that employed by Sulzer, and, in type at least, by most of the Diesel licensees, as shown in Fig. 16. The charge of oil for the coming stroke is delivered to the chamber, which is continuously in connection with the bottle containing the high-pressure injection air. At the bottom of this chamber are disks with perforations which do not register, so that when the fuel valve opens, the oil coming through one of the perforations of the top plate is driven against the solid portion of the next

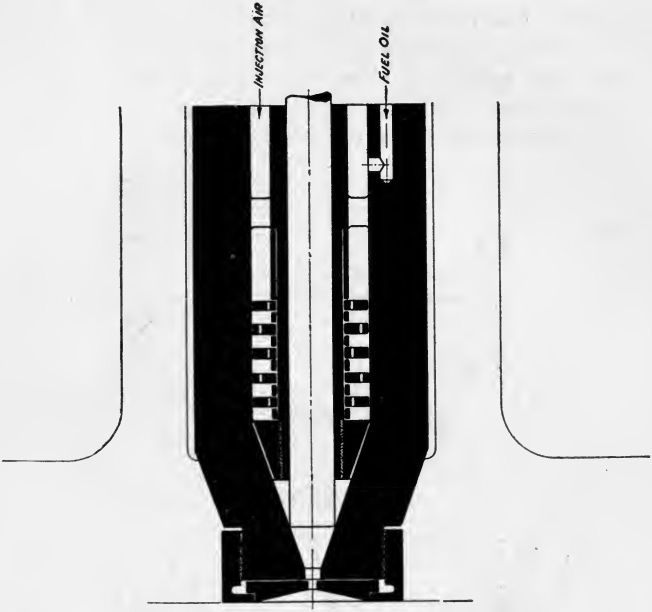


Fig. 16. Sulzer Atomizer.

plate with a velocity induced by a difference of pressure of some 400 lb. at a maximum and it is broken up into a spray, in which form it is swept through the successive places, becoming finally atomized. The truncated cone below these disks is grooved on its outer surface, and the oil-laden air passes through these grooves and is directed against the edges of the opening in the nozzle plate in such a manner that its stream upon entry into the combustion chamber is spread into a saucer-shaper, umbrella like flame all over the surface of the piston. These engines are equipped with removable cylinder liners.

The engine is started from two center cylinders and is furnished with a mechanical device for simultaneously releasing compression on all cylinders by means of an additional cam which opens the exhaust valve on the compression stroke.

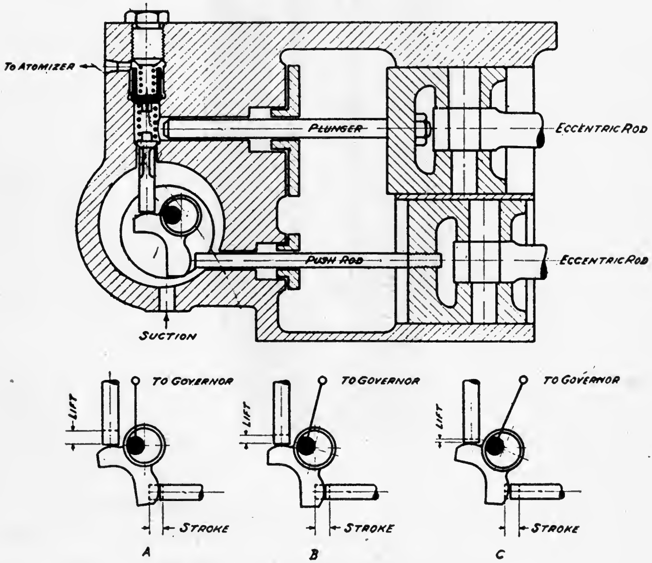


Fig. 17. Busch-Sulzer Fuel Pump.

There are six compression rings and one wiper ring. This latter is a knife edge ring which is very efficient and effects a great saving in lubricating oil.

The cam shaft of the Busch-Sulzer engine is on the front of the engine at the level of the cylinder heads. It is encased in a cast iron housing the full length of the shaft and the cams and gears operate in oil. The cam shaft is driven from a vertical shaft which also drives the governor and fuel oil pump. Bronze and steel spiral gears are provided to drive the vertical shaft and the cam shaft. The rocker arm is in two parts and is claimed to permit of easy removal of the valve cages, particularly the exhaust valve.

The fuel pump is similar to that in general use in Europe and operates by what is known as the "by-pass" method. This by-passing is accomplished by holding open the suction valve of the pump during a portion of the delivery stroke. Both the plunger and the push rod have constant strokes but the action of the bell crank operated by the push rods is varied by its eccentric mounting, which is rotated under governor control; so that the suction valve of the pump is held open during the longer or shorter portion of the delivery stroke of the plunger. This is illustrated by Fig. 17.

Diagram "A" shows the parts in no load position, the suction valve being held open almost throughout the entire delivery stroke. "B" and "C" respectively show the parts in half and full load positions.

The Allis-Chalmers Manufacturing Company of Milwaukee are manufacturing a horizontal oil engine, shown in Fig. 18. This engine is designed under the Lietzenmayer patents, using the open type of fuel nozzle of that name. In this type of nozzle, shown in Fig. 19, the fuel is delivered by the pump into a passage which through a nozzle is at all times in open communication with the cylinder. The compressed injection air is closed off from the passage by the injection valve. When this valve is lifted from its seat the stream of air scours over the surface of the accumulated fuel and atomizes it with an action similar to

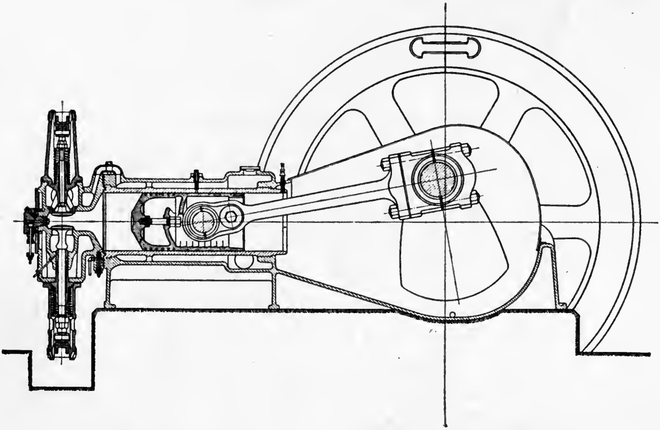


Fig. 18. Section of Allis-Chalmers Engine.

that of a file upon a metal surface. The final atomizing and spreading is performed in the passage through the nozzle as in the case of the Diesel atomizer. The multi-stage air compressor is mounted on the side of the frame and actuated from the crank shaft. Air is delivered directly to the fuel nozzle without the use of the usual storage tank. The regulation is performed by varying the effective stroke of the fuel pump plunger under governor control. A gravity oiling system with filtering arrangement and pump is used for all important bearings. The lubrication of the cylinders, and in special cases that of the exhaust valve stems is performed by a forced feed oil pump. The size of the 115 h.p. cylinder operating at 200 r.p.m is 18 in. in diameter, 27 in. stroke. The weight of a 230 h.p. engine of two cylinders of the above size is 160,000 lb., including a 17,000 lb. fly wheel.

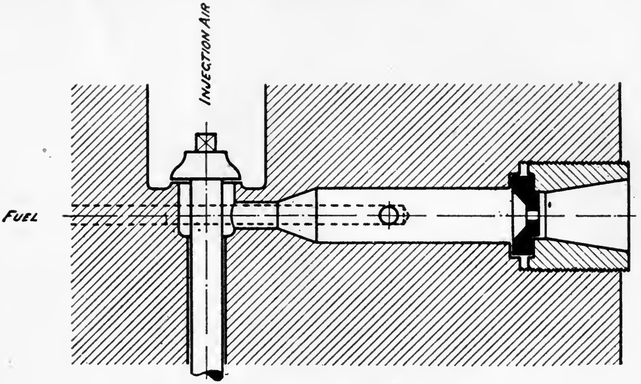


Fig. 19. Lietzenmayer Fuel Nozzle.

The Snow oil engine built by the Snow Steam Pump Works of Buffalo, N. Y., (Fig. 20) is a four-stroke-cycle engine, although this company manufactures engines both of the two-stroke-cycle and four-stroke-cycle. These engines are provided with crossheads. An air compressor is mounted on a pad on the

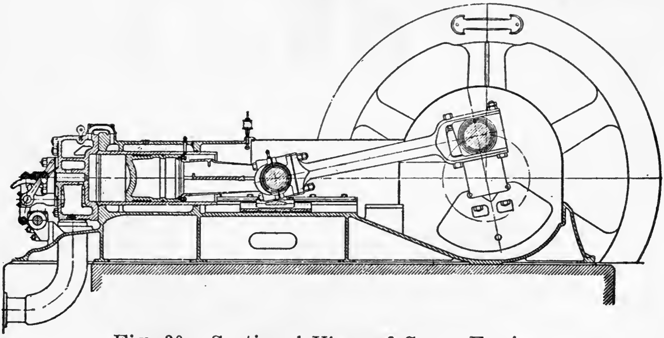


Fig. 20. Sectional View of Snow Engine.

side of frame and is driven by a drag crank on the end of the shaft. The cylinder head, particularly in the two-cycle type, is, of course, free from valves and naturally simple in its construction. The lubrication of the cylinder is effected by a Richardson positive force feed pump. These engines employ a modified type of open nozzle and the regulation is accomplished by varying the stroke of the fuel pump plunger by means of a sliding wedge operated by the governor. The piston head in many of the engines manufactured by this company is removable, being bolted on to the piston proper. In this way the portion of the piston which is subject to the greatest heat is easily removable and renewable.

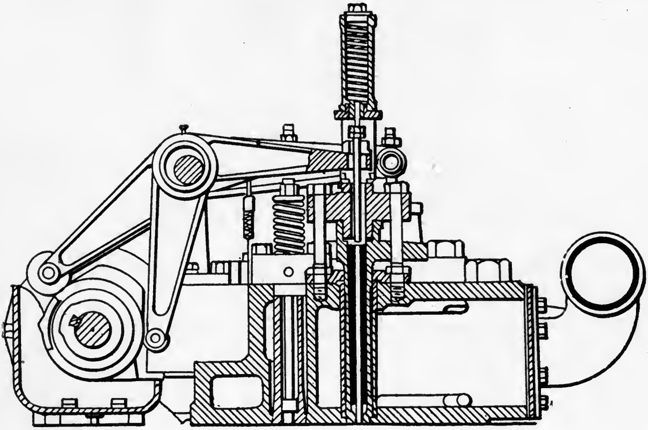


Fig. 21. Section of Willans-Robinson Cylinder Head.

The Dow Willans Diesel type oil engine is built by the Dow Pump and Diesel Engine Company, Alameda, California, under the license of Willans-Robinson of Rugby, England. It naturally follows very closely the design of the engine built in England, which is of the "A" frame type with centrifugal oilers on the crank pins and mechanical lubrication of the pistons pin, the lubrication of the cylinders also being under control of a mechanically operated lubricating pump. The main bearings are ring oiled. This engine is built in 50 h.p. per cylinder, any number of units being combined to make engines of from 150 to 450 h.p. The cam shaft is open type, the valves in the head of the engine being contained in cages shown in section of Fig. 21.) The compressed air for both starting and atomizing is delivered by a Reavell air compressor directly coupled in the end of the crank shaft. This

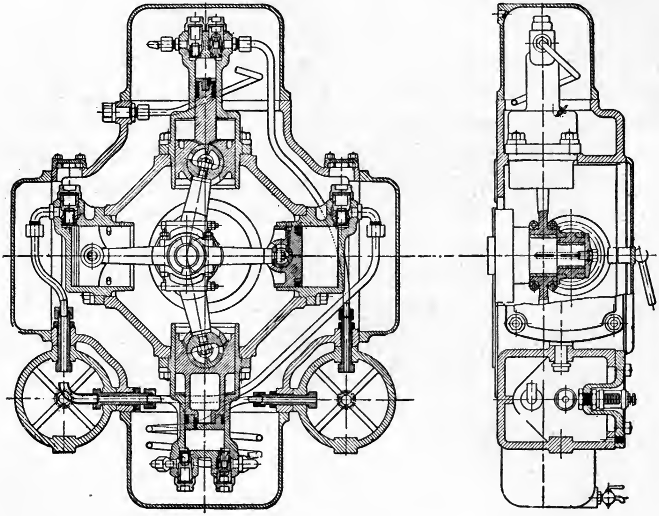


Fig. 22. Willans Compressor.

air compressor is of a type built in England and has the four cylinders set two vertically and two horizontally opposite each other. It is of the three-stage type with two cylinders for the first stage. A cut of this compressor is shown in Fig. 22.

The Nordberg Manufacturing Company of Milwaukee, Wis., are to manufacture a Diesel engine under license from Carels Brothers of Belgium. There are at present installed in New Mexico two engines manufactured in Belgium. These are of 1250 b.h.p. in five cylinders and are direct connected to electric generators. These are the largest Diesel engines at present in operation in this country and the report of the purchaser is entirely satisfactory. The Nordberg Company is at present manufacturing a duplicate of the two engines installed under the Carels' license.

Air Compressor.

A typical type of air compressor, see Fig. 14, is of the three-stage type, pyramid piston, capable of compressing to 1200 lb. per sq. in. This compressor is often integral with the engine and driven directly from the main shaft. To avoid lubricating difficulties and the danger of explosion of lubricating oil gases as well as to reduce the dimensions and power consumed in the compressor, it is thoroughly water cooled, being provided with ample inter- and after-coolers. The compressor is provided with automatic valves of very limited lift, closed by springs, the valves being set in cages which can be readily removed for regrinding, and the compressor delivers absolutely cold air at 1000 lb. pressure.

Another type of compressor is a two-stage directly coupled to the engine, the compressor, of course, being thoroughly water-cooled and will deliver air at from 1000 to 1200 lb. per sq. in. All the Diesel engines made in America at the present time supply some type of directly driven compressor. Some manufacturers are directly connecting a separate air compressor by means of a coupling.

The bearings in the vertical Diesel engines are rigid, with ample surface provided for sufficient lubrication so that the wear on them is negligible. The advantage of this rigid construction is obvious in the case of multi-cylinder engines in which there are a number of bearings in line; it is difficult to adjust such bearings without removing the shaft. The lower shells of the rigid bearings are made in a complete circle so that they can be turned out in case of accident by taking off the cap and turning the engine over, bringing the shell on top of the shaft and this can be accomplished without lifting the shaft. The bearing could be then rebabbitted, the bearings scraped in with the mandrel made the size of the shaft and replaced the same way it was turned out. It is necessary in this type of bearing to scrape the cast iron in which the bearing shell rests to a perfect fit to the shell, which requires great care and patience.

The shaft in four-stroke-cycle engines are practically alike; the cranks are set at 180 degrees, the two centers against the two ends; the firing of the cylinders is usually No. 1, 2, 4, 3, No. 1 being toward the fly wheel. The shafts are usually an American product, although some companies were depending on shafts shipped from abroad. The extension shaft of some engines is provided with one outboard bearing, the coupling being inside the crank case. Other engines are provided with two outer bearings, one each side of the generator with a coupling between the inside bearing and engine. The former, with the one outboard bearing, however, has a bearing of extra dimension inside the engine to support the additional weight of the extension shaft, fly wheel and generator, in the case of direct connected electrical equipment. With this arrangement there is less floor room occupied but the two outer bearings prevent a strain on the rigid coupling between the extension shaft and the crank shaft. The fly wheel on the Busch-Sulzer engine is split on the arms, which gives additional strength against bursting over a fly wheel split between the arms, which is, however, the usual practice and the one followed by many manufacturers with good success. The weight of the fly wheel is varied to suit the service performed by the engine, the heaviest fly wheel being provided with engines driving alternating current generators. It is often the case where an engine is belted to design a flywheel that will also be a band wheel and in this way the space occupied is greatly reduced and the expense also lessened.

All Diesel engines are provided with a thorough water cooling system, taking care of the parts of engine which need cooling, such as the cylinders, heads, exhaust valve stems, air compressor and in some cases the exhaust piping. Salt water can be readily used for this purpose; the average cooling water consumption is approximately four to six gallons per horsepower hour.

The connecting rods of practically all Diesel engines are of forged steel. The bearings at the crank end are of the marine type, cast steel and babbitt lined, bolted to the tee-shaped end of the rod. The upper end of the rod is usually closed and contains the bearing of the wrist pin. In the larger sizes the wrist pin bearing boxes are steel castings babbitted; in the smaller, solid bronze. Some manufacturers provide upper end bearings with wrist pin bolts.

The governor in practically all types of Diesel engines is of the inertia type controlling the fuel oil pump by a series of levers. It is customary to operate the governor from the vertical shaft, which in turn drives the cam shaft. Certain manufacturers provide an additional safety device which operates in case of overspeed. This, however, is not supplied on moderate sized units.

CHAPTER IX

SEMI-DIESELS

In the so-called semi-Diesel the entire cylinder volume of pure air is compressed to from 150 to 300 lb. per sq. in., depending upon the type of engine. A small portion of this air being contained in an auxiliary chamber which is in open communication with the interior of the cylinder and which has been heated to a high temperature, resulting from the mechanical compression, is therefore, considerably hotter in this chamber than in the main portion of the cylinder. The fuel is introduced, at or about the completion of this compression, either directly and entirely into this auxiliary chamber, or through the chamber and partially into the cylinder and gasified and ignited by the heat of compression of the air in the chamber, the combustion taking place more suddenly and with a greater increase in pressure than in the Diesel, and being followed by a more rapid drop.

In both this type of engine and the Diesel type the maximum pressure is approximately the same, though the compression pressure in the semi-Diesel type is considerably lower. Fig. 23 shows typical diagrams of a semi-Diesel engine. The fuel consumption of this type of engine is slightly greater than that guaranteed by the Diesel engine, the full load compression being guaranteed in engines from the size 300 h.p. at .5 lb. of fuel oil at full load, .65 lb. at ¾ load and .75 lb. at half load. It will be noted that although the full load consumption corresponds to the Diesel engine that of ¾ and ½ loads are considerable higher than those obtained in the true Diesel engine. These semi-Diesel engines are, therefore, economical on steady loads at or near their full load, but do not show nearly the economy of the true Diesel on fluctuating loads. The oil that these engines will use is practically the same as that used in the true Diesel engine and rigid guarantees from responsible manufacturers of this type of engine will completely cover this point.

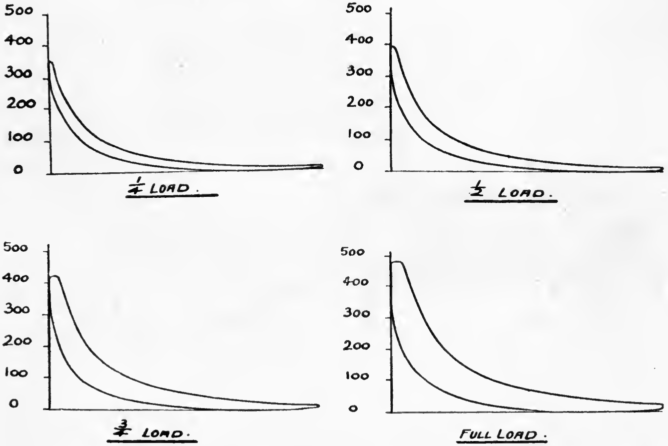


Fig. 23. Typical Semi-Diesel Engine Indicator Cards.

A cut of a De La Vergne engine is shown in Fig. 24. This engine is horizontal single-acting of the four-stroke-cycle type. "A" representing the inlet valve, "D" the combustion chamber and "B" the exhaust valve. These valves are all operated by rocker arms driven from an eccentric shaft. A two-stage air compressor is supplied to maintain air for starting and spraying the oil. This is driven by an eccentric on the engine shaft. Air from the first stage of the compressor, at 150 lb. is stored in a tank and is available for starting the engine, this pressure being sufficient.

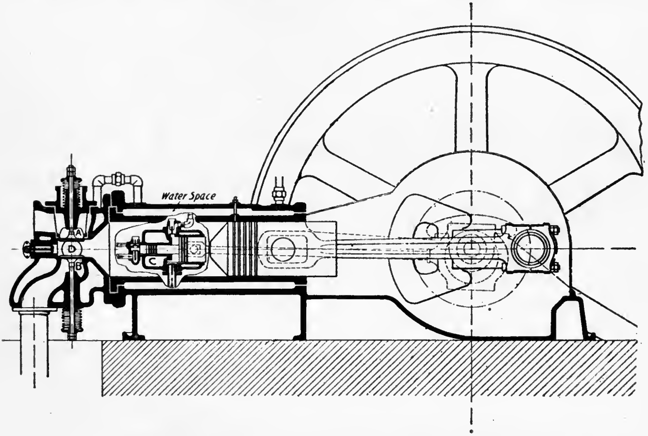


Fig. 24. Longitudinal Section of De La Vergne Engine.

The second stage of the air compressor is quite small in capacity and handles only enough air to spray the oil from stroke to stroke. Speed regulation is guaranteed to be approximately 2 per cent. This company manufacturers engines of from 65 to 200 h.p. in single cylinders and from 130 to 400 h.p. in two cylinders and from 200 to 800 h.p. in four cylinders.

A cross section of a semi-Diesel engine manufactured by The Bessemer Gas Engine Company of

Erie, Pa., is shown in Fig. 25. This engine is horizontal, using a cross head and is double-acting to the extent that 5 lb. per sq. in. pressure is obtained on the forward stroke of the engine, which is used in filling the cylinders with fresh air and sweeping out the products of combustion on the scavenger stroke. This engine operate on the two-stroke-cycle principle. The hot bulb "D" is a hollow projection which is all that requires heating preparatory to putting the engine into operation. A compression pressure of about 180 lb. per sq. in. pressure is used. The water is delivered to a brass cup "E" by a pump under the control of the governor so that the amount of water injected varies with the fuel used in the same time, but the hand adjustment enables the operator to vary the volume at any time, after which it will still remain proportional. The water flows down into a screened trough and is picked up by the air entering at "C." This is not of the crank case compression type as the stuffing box isolates the crank case from the air pump end of the

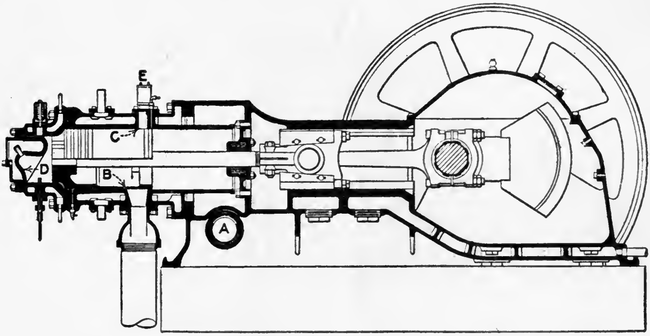


Fig. 25 Section of Bessemer Semi-Diesel Engine

cylinder and in this way it is possible to provide automatic lubrication to all bearings. In the larger size of engine oil coolers are provided to reduce the temperature of the lubricating oil before it is returned to the system. The cross head on this engine elimi-

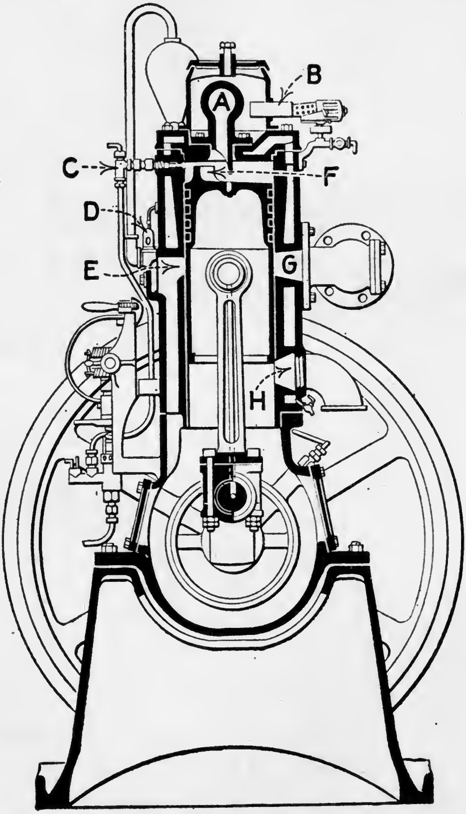


Fig. 26. Metz & Weiss Engine.

nates any side wear on the cylinder. The manufacturer guarantees a fuel economy in engines developing 100 h.p. per cylinder of .65 lb. of fuel oil per brake horsepower hour.

The Mietz & Weiss type of semi-Diesel or heavy oil engine employs steam which is generated from water heated in the jackets for scavenging the cylinder. Fig. 26 shows this engine in section. The bulb "A" is heated by a torch "B" before starting and after the engine is in operation the torch is extinguished and the temperature of the bulb kept by the combustion of the fuel in regular working, which will bring its contents above the ignition point of the fuel at a comparatively low pressure of about 100 lb. per sq. in. The fuel is injected at "C" in quantities measured by the governor which controls the stroke of the feed pump. The incoming air enters the closed crank case through the port "H" when that port is uncovered by the piston on its upward stroke and is compressed after the piston closes the port on the downward stroke at about 3 lb. (gauge), at which pressure it enters the cylinder through the port "E," being deflected upward by the lip "F" and expelling the gases through the exhaust port "G." Vapor from the water jackets is drawn in with it through the pipe "K" and the cock "J" allows enough jacket water to go in with it to prevent pre-ignition. This company manufactures both horizontal and vertical stationary engines and marine engines of the reversible type. The quantity of fuel oil is regulated by the governor, in accordance with the load on the engine, with a fuel consumption between 1 lb. per h.p. hr. in small engines to .65 lb. in large sizes. Mechanical lubrication for all the bearings and pins is provided. These engines are all stroke-cycle.

In the marine engine the reversing is accomplished by an air distributing rotating valve driven by bevel gears from the engine shaft. Air is allowed to enter through a two-way valve into one or the other side of the distributing valve, depending upon the desired direction of rotation of the engine. The same handle that operates the air also admits the fuel, so that operating one lever starts, stops and reverses the engine. The air for starting is supplied by an air tank supplied by air directly from the engine or by a separately driven compressor, depending on the size of the installation. These engines are not provided with a flywheel, being coupled directly to the propeller shaft. The engine ranges in price from $60 per h.p. in small sizes to $45 in larger units.

CHAPTER X

COMMERCIAL SITUATION

The commercial situation of the Diesel Engine is unique, for economical and reliable as the engine is it will not answer, economically, for all possible needs. The matter of first cost and interest on this fixed charge, together with the retirement of the principal by depreciation or placing a certain sum aside to retire the whole cost of the installation in a given number of years all must be given their full consideration. To call the Diesel Engine a "cure-all" is a mistake and it hurts the entire Diesel situation. If after making an extravagant statement the facts prove otherwise the engine and engines as a whole are discredited. Fuel economy is not the whole story in the economical generation of power, for the matter of fixed charges and the relative cost of coal and oil must be weighed impartially. It is questionable if the Diesel is suitable to a territory served by an electric transmission system having a diversified load factor composed of many different industries with maximum demands for power at different times of the day and at different times of the year. Such a system can offer inducements of low rates to the character of load to which the Diesel is most suited that need careful consideration. In certain industries where the load factor is high or the ratio of the average load to the maximum demand is high, such as with ice plants where the ice machines are operated 24 hours per day over the large part of the year, the Diesel engine shows its superiority and can compete with any type of power and show a saving.

A simple example can be cited. Suppose an ice plant having a capacity of 50 tons of ice in 24 hours is considered and the cost of power only is analyzed, the engine of approximately 150 or 160 h.p. will cost about $12,000 set up ready to operate. Let interest and depreciation be figured at 13 per cent per annum which is enough to retire the whole cost in ten years. This 13 per cent amounts to $1560 per annum or $4.33 per day. To this must be added the cost of fuel, considering that the engine is of the four-stroke-cycle type and is delivering its full 160 h.p. for 24 hr. each day. The fuel consumption is .41 lb. per b.h.p., or .41 × 160 h.p. × 24 hours = 1574 lb. Assuming that a barrel of oil costs $1 and weighs 315 lb. the number of barrels will be 1574/315 or approximately five barrels, or $5 per day for fuel. Lubricating oil may be guaranteed to be 1/10 of a gallon per hour, at a price ranging from 30 to 40 cents per gal. This will amount to 24×.40/10=96 cents per day. In an ice plant it would be difficult to justly apply the cost of labor exactly where it belongs. If the ice machine were operated by electric motors the cost of labor would be as great as if the plant were operated by the Diesel engine and less with the Diesel engine than with steam driven ice machinery. For convenience let us divide the cost of labor in half, charging half to the power and half to the actual manufacture of ice. There would be required in such a plant as we are considering a chief engineer and two assistants, the chief taking at least a part of the 24 hour operation for his watch, salary of the chief engineer $1500 per year or $125 per month, and two engineers at $100 per month, or a total labor charge of $325 per month, or $10.83 per day, a half of which, or $5.42 to charge against the cost of power. A charge must also be made for engine room repairs, such as new valve packing, gaskets, springs, emery, etc., of $150 per year or approximately 50 cents per day.

To recapitulate: Cost per day of 24 hours,

Interest and depreciation	$4.33
Fuel	5.00
Lubricating oil	.96
Labor	5.42
Sundries	.50
Total	$16.21

The output of this plant is 50 tons of ice per 24 hours, making a cost per ton of ice for power 32 cents, including all charges.

Comparing this with an electric motor driven plant using the same size ice machine it would require a 160 h.p. motor with an imput of 133 kw., assuming 90 per cent motor efficiency, or 3200 kw.-hr. per day of 24 hours. At 1 cent per kw.-hr. this would amount to $32.00; at ½ cent per kw.-hr. $16 per day. To this must be added $5.42 per day for labor, making $37.42 and $21.42 respectively, the total cost of power per day. This shows the saving by using a Diesel engine with this type of service amount to $21.20 per day with current at 1 cent per kw.hr. and $5.20 with electricity at the ½ cent rate.

If, however, the yearly load factor should be only 50 per cent, or in other words the plant should be run for only six months and shut down completely for the balance of the year the apparent Diesel saving would be materially reduced, for \$16.21 × 182 days of operation = \$2950 cost during the time the plant is in operation, but during the balance of the year the interest and depreciation continue and there must be in addition a charge of \$4.33 × 182 days or \$790 fixed charges, making a total of \$3740 per year. While with electric power the cost would be entirely proportionate to the number of days' operation, the fixed charges on the electrical apparatus, which would cost approximately \$1000, being wholly inconsiderable. With power at 1 cent and ½ cent per kw.-hr. the cost of power would be \$37.42 × 182 = \$6810.00 and \$21.42 × 182 days = \$3900 respectively.

The above gives a clear conception of the great effect of load factor on the total cost of power. In other words, fixed charges, interest, depreciation, insurance and taxes go on day and night regardless of whether the plant is being operated or not. A far more marked example may be assumed where labor joins fixed charges and must be retained whether or not the apparatus is doing the full useful work, for instance, in an electric light plant where 24 hr. service is maintained and during part of this time but an exceedingly small load is carried.

In comparison with a steam turbine the Diesel engine will cost considerable more to install, but the total cost of operation, including fixed charges labor, fuel, lubricating oil and maintenance may be considerably less with the Diesel if the load factor is between 25 per cent and 50 per cent.

The following comparison is interesting: Assume a plant consisting of one 200 kw. unit and one 400 kw. unit, a total capacity of 600 kw., having a load factor of 25 per cent, oil to cost $1 per barrel. The steam turbine plant erected would cost approximately $50,000 while the Diesel engine would cost $73,000. These costs would include building and all necessary apparatus in connection with each of the installations. Operating at 25% load factor the average load per hour would be equivalent to 125 kw. or the load per year would be 125 kw. × 365 days × 24 hours, or 1,100,000 kw.-hr. A steam turbine plant of this size may be assumed to develop 190 kw.-hr per barrel of oil, while a Diesel engine plant will develop 100 kw.-hr. for every 9 gal. of oil, or 466 kw. hr. per barrel. The number of barrels per year for the steam turbine will be 1,100,000/190, or 5800 barrels; for the Diesel engine the consumption per year will be 2360 barrels. The fixed charges of 14 per cent on the installation cost on both Diesel and turbine plant, including the boilers the life of the turbine plant being equal to the life of the Diesel. This will amount to $7000 per annum on the steam turbine plant and $10,220 per annum for the Diesel engine, the total of fuel and fixed charges in the case of the turbine being $5800 and $7000 = $12,800 per annum. With the Diesel engine fuel cost $2360 in addition to $10,220 = $12,580. The wages in the Diesel engine plant will be less than those in the steam turbine plant but the lubrication of the Diesel engine will be slightly in excess of that of the steam turbine. The maintenance, including boiler and turbine will be greater on the steam plant than on the Diesel engine. The cost for water on the steam plant will be in excess of that of the Diesel engine and it would be difficult in any ideal case as we have assumed, to compare any of these figures, as they so greatly depend upon the locality of the plant, but neither type of prime mover will have any distinct advantage over the other in these regards.

From the above comparison of the cost of fuel and fixed charges the Diesel has so slight an advantage over the steam turbine at 25 per cent load factor that the case alone would not indicate the choice of prime mover. However, as the load factor increases the advantage of the Diesel becomes more apparent and with 50 per cent load factor the following is the result:

The fuel cost of the steam turbine	$11,600
Fixed charges	7,000
Total	$18,600
With the Diesel, fuel charge	$ 4,720
Fixed charges	10,220
Total	$14,940

This is a saving of approximately $4000 per year over the cost of operation of the steam turbine plant. It will be noted that the fixed charges remain constant and the fuel charges increase, making the Diesel continue to show an economy as the load factor increases and even as it decreases between from 50 per cent toward 25 per cent the advantage will still be with the Diesel. At the 50 per cent load factor it will be noted that the $3600 per year saving represents almost 5 per cent on the total cost of the Diesel installation or the saving on the Diesel would return the difference in cost over a steam turbine plant in approximately six and one-half years.

It will also be noted from this analysis that the advantage of the Diesel increases with an increase of price of oil for the item of fuel consumption would increase in each case for both the steam turbine and the Diesel, but more so with the steam turbine where the fuel consumption is at a greater rate.

But there enters here the consideration of the consumption of coal, so again the situation must be looked into for the special locality of the proposed installation. All problems of the installation of a Diesel engine revert to fixed charges or the value of the money invested, and in each case must be analyzed on its merits. Where oil is expensive and coal cheap another problem presents itself and again the load factor will undoubtedly be the determining issue. In a comparison with a steam plant using Corliss engines the Diesel can show a saving at lower load factor than when compared with steam turbines, although the fuel consumption for a steam engine plant may be slightly better.

Plant Load.

	Time.	Average Load.	Total load.	
A.	1 a.m. to 5 a.m.	90 kw.	360 kw.-hr.	
B.	5 a.m. to 7 a.m.	110 kw.	220 kw.-hr.	
C.	7 a.m. to 8 a.m.	220 kw.	220 kw.-hr.	
D.	8 a.m. to noon	170 kw.	680 kw.-hr.	
E.	noon to 1 p.m.	50 kw.	50 kw.-hr.	
F.	1 p.m. to 5 p.m.	170 kw.	680 kw.-hr.	Av. load, 141 kw.
G.	5 p.m. to 6 p.m.	300 kw.	300 kw.-hr.	
H.	6 p.m. to 9 p.m.	150 kw.	450 kw.-hr.	
I.	9 p.m. to 11 p.m.	110 kw.	220 kw.-hr.	
J.	11 p.m. to 1 p.m.	100 kw.	200 kw.-hr.	
			3380 kw.-hr.	Per av. day, 24 hr.

Peak load say 315 kw.

Diesel Plant.

Diesel Engine Plant, consisting of 2-240 b.h.p. Diesels, each with a 160 kw. direct coupled generator.

Period.	Engines running.	Load on each kw.	Fuel per kw.-hr. lb.	Fuel Gal., per 100 kw.-hr.	Total fuel gal.	Engine hr.
A.	1	90	.64	8.9	32.0	4
B.	1	110	.62	8.6	18.9	2
C.	2	110	.62	8.6	18.9	2
D.	2	85	.65	9.1	61.8	8
E.	1	50	.83	11.6	5.8	1
F.	2	85	.65	9.1	61.8	8
G.	2	150	.62	8.6	25.8	2
H.	2	75	.68	9.5	42.7	6
I.	1	110	.62	8.6	18.9	2
J.	1	100	.63	8.8	17.6	2
					304.2	37
Add 8 per cent for ordinary conditions......					24.3	2.5
					328.5 (Gal. fuel per day.)	39.5 (Call 40 hr).

Fuel oil at $1.50 per bbl. delivered, $150/42 3.67c gals., or $12 per day.

Labor—1 man at $100 mo.; 1 at $80; 1 at $60 = $240 mo. = $8.00 per day.

Lubrication—1¼ pints per engine hr. (40 eng. hr.) = 6¼ gal. per day. At 32c per gal, delivered = $2.00 per day.

Water—At 65° to 75° F. = 1500 gal. per eng. hr. = 60,000 gal. per day. Cost of pumping—2c per 1000 gal. = $1.20 per day.

Maintenance—$300 per annum per engine.
25 per annum per generator.

$325 × 2 = $650, all running 24 hr. day (48 eng. hr. day). Actual only 40 hr. per day.

$$\frac{650}{365} \times \frac{40}{48} = \$1.50 \text{ per day.}$$

Operating Expenses—Diesel Plant.

	Per day.
Lubricating oil	$ 2.00
Labor	8.00
Fuel	12.00
Water (pumping cost)	1.20
Supplies	.50
	$23.70 or .702c per kw.-hr.
Maintenance	1.50
	$25.20 or .746c per kw.-hr.

Total operating expense per annum, $25.20 × 365 = $9200.

Plant Cost—2 Diesels and standard equipment; Piping and Sundry; 1 Oil Storage Tank—12,000 gal.; 2 Generators; 1 Switchboard; Station Wiring; Foundations, 120 yd.; Erection. Approximately, $41,400.

Interest, depreciation, 13 per cent = $5382 per annum = $14.77 per day.

Operating	$25.20
Fixed charges	14.77
Total cost per day	$39.97

Or, $39.97/3380 = 1.18 cents per kw.-hr total expense.

Steam Plant.

Consisting of 2-200 I.H.P. compound condensing Corliss engines, each with 140 k.v.a. generator; 100 r.p.m.; 3-100 h.p. boilers.

Total constant loss, 45 I.H.P. each engine due to mechanical efficiency of engine, generating efficiency, including friction and windage losses.

Period.	Engines running.	Load in elec. h.p.	I.H.P. (El. H. P. and 45 h.p. loss).	Engine hr.	H.P. hr.	Total dry steam to engines.
A.	1	120	165	4	660	9510
B.	1	147	192	2	384	5530
C.	2	295	385	1	385	5540
D.	2	227	317	4	1268	18250
E.	2	67	157	1	157	2720
F.	2	227	317	4	1268	18250
G.	2	402	492	1	492	7330
H.	1	201	246	3	738	11000
I.	1	147	192	2	384	5530
J.	1	134	179	2	358	5160
Test conditions					6094	88820
Add 8 per cent for ordinary conditions						7100
						95920 = 15.75 per hp. hr.

Add 3 per cent leakage and condensation, 10 per cent auxiliaries and oil burners	12480
Total steam for boiler	108400 (Per day)

Fuel—Actual evaporation, 121 lb. water per. lb. fuel oil.

Fuel per day—108000 ÷ 121 = 9000 lb. = 1250 gal. (3.85 times as much as Diesels).

Fuel at $1.20 per bbl.—2.86c per gal. = $35.75 per day.

Labor—2 licensed engineers at $125 mo. each; 2 oilers at $2.00 day each; 2 firemen at $2.00 day each—$490 mo. = $16.33 per day.

Water—Boiler feed taken from condenser.

Condensers taking 25 to 1 condensing water.

$$\frac{95920 \times 25}{8.3} = 288{,}000 \text{ gal. per day.}$$

At 2c per 1000 gal. pumping cost = $5.76 day.

Maintenance—Boilers 200 h.p. running at $1.50 per h.p.	$300 per annum.
Auxiliaries	125 per annum.
Engines and generators	175 per annum.
	$700 = $1.92 per day

Operating Expenses—Steam Plant—

Labor	$16.33	per day.
Fuel	35.75	
Lubricating oil	1.37	
Water	5.75	(pumping cost)
Supplies	.75	
	$59.96	÷ 3380 = 1.77c per kw.-hr.
Maintenance	1.92	
	$61.88	÷ 3380 = 1.83c per kw.-hr.

Total operating expense per annum $61.88 × 365 = $22,600.00

Comparison—Annual operating expenses, Diesel	$ 9,200.00
Annual operating expenses, steam	22,600.00

Difference in favor of Diesel $13,400.00 per annum or 2½ times the total interest and depreciation on Diesel plant.

Or, the cost of current with steam engine for operation alone exceeds the total cost of current with the Diesel.

Steam Plant Equipment.

2-200 h.p. Cross compound condensing Corliss Engines for direct connection to alternator; 100 r.p.m.; for 150 lb. ga. pressure and 24 vacuum ref'd to 30 Barometer.
2-140 k.v.a, 80 per cent P.F., 60-cycle, 3-phase, 2300-volt, 100 r.p.m., Eng. type generator.
2 belted exciters for same.
2 jet condensing equipments, complete for above engines suitable for 24 in. vacuum ref'd to 30 Barometer, with water at 70° F.
3-100 h.p. (1000 sq. ft. heating surface) boilers, complete with all trimmings.
1 oil burning equipment complete for above boilers.
2-200 sq. ft. closed heater.
2-50 g.p.m. feed pumps .
All station piping.
2-12000 gal. oil storage tanks.

This comparison is a most rigid one, showing a lighting and power load, the Diesel plant consisting of two engines direct connected to generators, price per barrel for oil being placed at a high figure—in the case of the Diesel $1.50 per barrel, the cost of the steam plant $1.20 per barrel. It is interesting to note the difference in favor of the Diesel and its comparison with the total interest and depreciation on the Diesel plant.

Another interesting comparison between the cost of power as produced by the Diesel engine compared with the cost of purchased electricity is illustrated in the following example: Assume a plant to consist of two 500 h.p. engines, generators, exciters and all necessary equipment, delivered and erected for $78,000, interest figured at 7 per cent per annum, a sinking fund of 7 per cent fixed charges, including taxes and insurance, to amount of 15 per cent per annum on the total investment. The operating cost is shown on the basis of 8 hours, 16 hours and 24 hours' operation, with oil as noted at $1 per barrel. The cost of power, including fuel oil, lubricating oil, maintenance, labor and fixed charges show a total cost per horsepower year varying from $18 to $27 as against the cost of purchased electricity at 1 cent per kw.-hr. of $16 to $38 per h.p. per year. The result of this comparison is plotted in Fig. 24 and shows that as the number of hours of operation increases the cost of purchased electricity increases at a more rapid rate than electricity produced by the Diesel engine and that if the plant is operated for over 10½ hr. the Diesel is the most economical type of prime mover. This emphasizes plainly the bearing of load factor to the cost of power compared with the purchase of electricity. If the proposed plant operates more than 10½ hr. it would be more economical to install the Diesel engine than to purchase electricity at the low rate of 1c per kw.-hr.

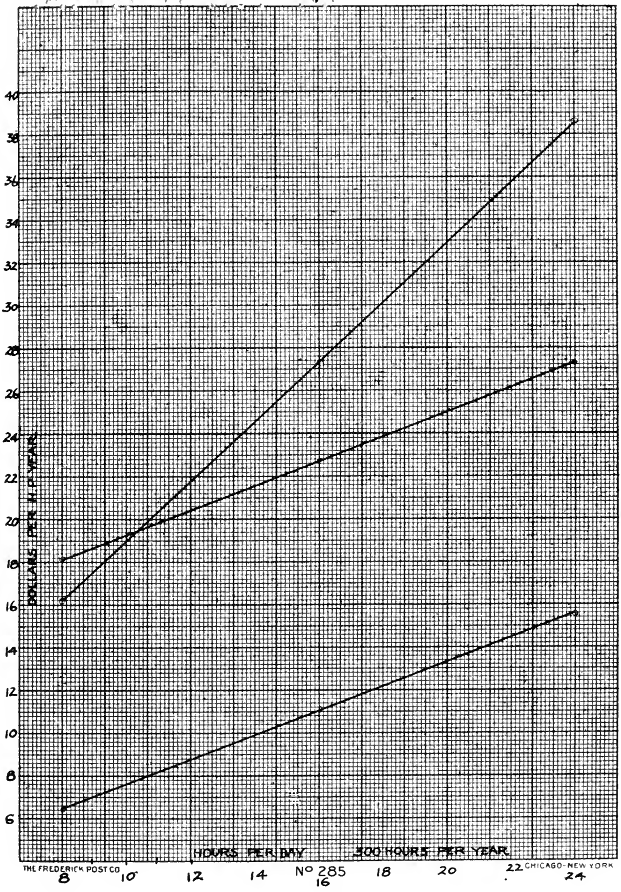

DOLLARS PER H.P. YEAR
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
HOURS PER DAY
300 HOURS PER YEAR
THE FREDERICK POST CO
8
10
12
14
Nº 285
16
18
20
22
CHICAGO-NEW YORK
24

Fig. 27.

First Cost.

A plant to consist of 2 engines, 500 h.p. each; 2 generators, 336 kw.; switchboard, exciters, piping and connections, erected in a suitable building, including an oil tank, for $78,000 or $116 per kw.

Fixed Charges—

Interest, depreciation, taxes and insurance at 15 per cent per annum, $11,700.

Operating expense operating 300 days per year at 8 hr. per day, 16 hr. per day and 24 hr. per day.

	8 hr. per day.	16 hr.	24 hr.
Fuel consumption oil (at $1 bbl).	3270	6540	9810
Lubricating oil at 32c per gal.....	256	512	768
Maintenance	300	300	300
Labor, 8 hr., 1 at $1500 per yr., 1 at $1100 per yr..................	2600		
16 hr., 1 at $1500 per yr., 2 at $1100 per yr..................		3700	
24 hr., 1 at $1500 per yr., 3 at $1100 per yr..................			4800
Total	$6,426	$11,052	$15,678
	$18,126	$22,752	$27,378
Or cost per h.p. yr. for power....	$ 18.12$	$ 22.75	$ 27.37
Electric power at 1c per kw.-hr. based on 672 kw. capacity......	$ 16.12	$ 27.25	$ 38.60

CHAPTER XI

DIESEL APPLIED TO MARINE PURPOSES

The beginning of the application of Diesel engines for mercantile ships was made in Russia on the river Volga and the Caspian Sea. They were designed for ships owned by the firm of Nobel Bros. in Petrograd and were partly built in their own shops and partly at the Kolonna Works in Moscow and at the Swedish Diesel Engine Company in Stockholm.

These new marine engines were first built in Russia for two reasons: First, because there are large oil wells at the Caspian Sea, whereas other fuels are expensive in that vicinity. This brought, therefore, the first stationary engines from the Maschinenfabrik Augsburg-Nurnberg at an early time to these countries. But, that cheap oil and expensive coal does not necessarily lead to the early adoption of marine Diesel engines is demonstrated on the Pacific Coast of the United States in regard to stationary engines, where circumstances are similar in this respect.

The second factor was the progressiveness of Nobel Bros., who, being owners of oil fields, as well as of ships and engine works, had everything in their possession necessary for the realization of their plans in this line.

In this way there existed in Russia several marine Diesel engines long before the rest of the world earnestly considered the manufacture of such engines. The construction, however, was mainly the same as of the standard stationary engines of the Nurnberg type with slight changes. But, when observing the present day big Diesel engines for sea-going ships, it is noticed that the valves and valve gear are copied from the original stationary engines; otherwise they are different in many ways. After the engines of Nobel Bros. a few small marine Diesel engines were turned out in 1910 by Sulzer Bros. of Winterthur, and the Machinenfabrik Augsburg-Nurnberg, known in their country as the Nurnberg Company. These engines were high-speed, box frame engines of comparatively low power. They did not yield much satisfaction in continued service, being much of the type of light weight submarine engines.

Up to 1910 all marine Diesel engines were designed with the long trunk piston in which the wrist pin was fixed, to which the connecting rod was fastened. In 1910 for the first time, a box-shaped piston with piston rod, cross-head and guide was introduced in place of trunk pistons and are now used in almost all types of marine Diesel engines. At this time there was also applied the four tie-rods around each cylinder coupling most directly the upward forces due to the pressure on the cylinder heads and the downward forces on the main bearings due to the pressure on the pistons. By these means it became possible to keep the cast iron frame in which the connecting rods move, very light and to provide for big apertures, as this box-shaped frame had to carry the weight of the cylinder only, no forces being transmitted through it.

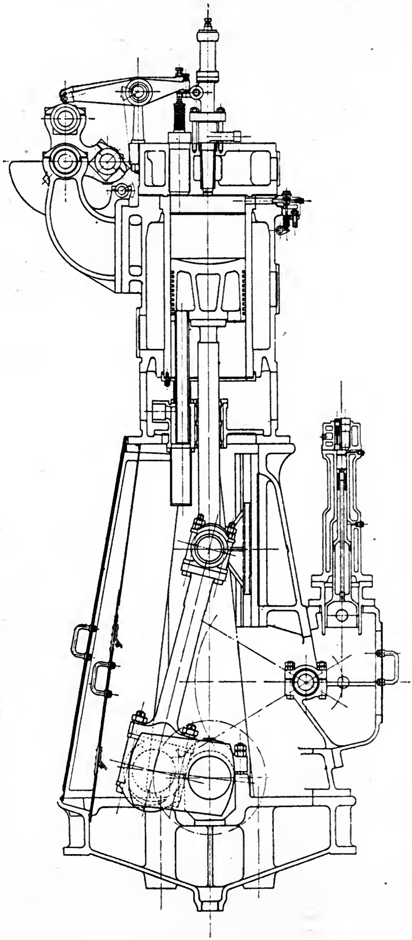


Fig. 28. Six-Cylinder Werkspoor Marine Diesel Engine of the "Vulcanus," 450 b.h.p.

After the small Diesel marine engines, the six-cylinder engine of the "Vulcanus" was the first full-powered reversible Diesel engine, shown in section in Fig. 28. This engine had a capacity of 450 b.h.p. at 180 r.p.m. The cylinder was 15.7 in. in diameter and 31.5 in. stroke. The ship is of 1000 tons, owned in Holland. The hull and engine was built in Amsterdam; it was ordered in 1910 and in December of the same year the trial trip took place.

In the beginning trouble was encountered with the air compressors and also through the lack of experience of the engine attendants. The ship has, however, completed successfully every voyage undertaken, among others a trip from France to Singapore without an extra stoppage at sea, and it is in permanent service in India at present, to the full satisfaction of the owners.

The engine of the "Vulcanus" is directly reversible, there being two cam-shafts, one with cams set for forward motion, the other for backward motion. The hand-wheel for the reversing is mounted on a handle case, where all the operations necessary for starting, reversing, regulating and stopping can be controlled. The valves and levers in the cylinder heads do not differ from what is ordinary practice for four-stroke-cycle stationary Diesel engines.

The fuel pump shows an interesting feature. There is only one pump and one spare pump for the whole engine. The oil is pumped into an accumulator, which stops the pump when full by keeping the suction valve open. The "Vulcanus" is now plying between the East Indian Islands, making short trips.

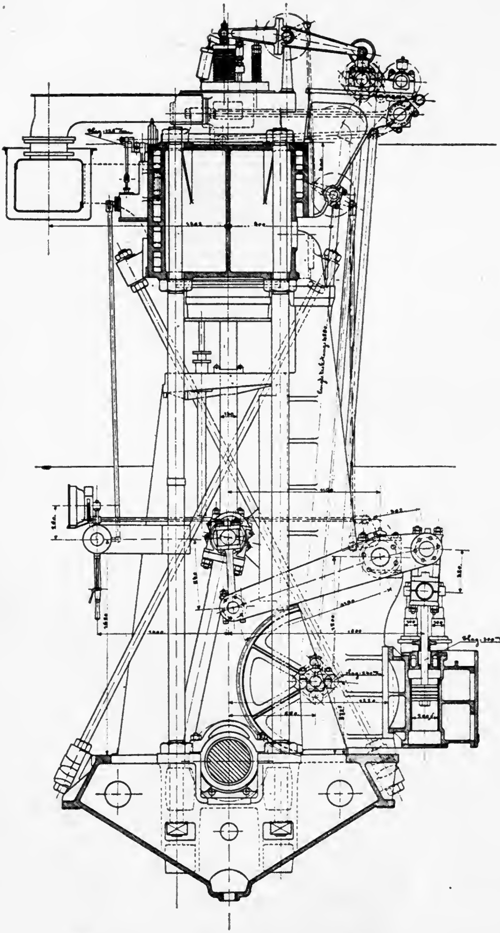


Fig. 29. Werkspoor Marine Diesel Engine, 1100 b.h.p.

There is inserted here a comparison made by the marine superintendent of the Anglo Saxon Petroleum Company, the following comparison showing the result of two years' actual working with the Diesel Ship "Vulcanus" and the S. S. "Sabine Rickmers" using coal:

	"Vulcanus"	S. S "Sabine Rickmers"
Length	196 ft. 0 in.	200 ft. 0 in.
Breadth	37 ft. 9 in.	30 ft. 6 in.
Draught	12 ft. 4½ in.	16 ft. 9 in.
Deadweight—		
Carrying capacity	1235 tons	1269 tons
Displacement	2080 tons	2290 tons
Engines	6 cylinder reversible	Triple expansion

The following economic results have been shown in service:

	"Vulcanus."	S. S. "Sabine Rickmers."
Total running time on voyage	8.26 days	7.04 days
Total distance	1530 miles	1473 miles
Mean speed	7.7 knots	8.7 knots
Average oil consumption per day of 24 hr.	2.06 tons	13.4 tons
Cargo	976 tons	1013 tons
Dead weight	1112 tons	1225 tons

A striking example of the advantages associated with low fuel consumption is to be found in the fact that the "Vulcanus" recently completed a voyage of eighty-eight days without bunkering at any intermediate port. On this particular run she left Europe in August with 140 tons of fuel oil in her bunkers and returned in November, covering a distance of some 10,750 miles. Nevertheless, six tons of liquid fuel remained on board after the completion of the voyage. Thus the total consumption was 134 tons in 65.7 operating days or 2.03 tons per diem.

The "Vulcanus" held for the full year the place of being the only full-powered Diesel ship afloat, from the end of 1910 to 1911, when the "Sembilan" was constructed. This vessel had a comparatively small engine of 200 h.p. in three cylinders, the engine being reversible. This vessel proved very successful and is at present running to the East Indies, the owners having since ordered five engines for larger vessels.

In February, 1912, the "Selandia," the first marine Diesel engine installation built by Burmeister & Wain of Copenhagen, was completed. She is a twin-screw vessel with engines of 1000 b.h.p. each, four-cycle.

It may be interesting to note the results obtained with one of the latter Burmeister & Wain engines, by comparing the Diesel ship "Siam" with two steamships "Kina" and "Arabien." The ships belong to the same owners and the voyages are the first made by each ship.

S. S. "Kina" and "Arabien" are single-screw ships of the following dimensions:

Length	385 ft. 0 in.
Beam	53 ft. 0 in.
Draught	26 ft. 10¾ in.
Deadweight	8720 tons
Bunker capacity (coal)	770 tons

They were built in 1911 by Swan Hunter & Wigham Richardson and driven by triple expansion steam engines. They are the most economical and latest type of steamships in every respect.

The Diesel-engine ship "Siam" was built and engined by Burmeister & Wain of Copenhagen. The dimensions are:

Length	410 ft. 0 in.
Beam	55 ft. 0 in.
Draught	30 ft. 6 in.
Deadweight	9700 tons
Bunker capacity (oil)	1250 tons

The voyages made by these ships are the same, so that the results are well suited for comparison.

S. S. "Kina." first voyage June 16, 1911, to November 25, 1911:

Full outbound load in Antwerp—
8720 tons — 1162 tons = 7558 tons cargo.
Full homebound load from Sabang—
8720 tons — 932 tons = 7788 tons cargo
Mean Cargo—7673 tons.

Diesel-engine ship "Siam," first voyage, April 9, 1913, to October 4, 1913:

Full outbound load in Antwerp—
9500 tons — 493 tons = 9007 tons
Full home load in Hankow—
9500 tons — 1168 tons = 8332 tons
Mean cargo—8670 tons.

From the engine room report of these two ships, the following data are of interest:

	S. S. "Kina." 1st Voyage.	D. S. "Siam." 1st Voyage.
Duration of trip	163 days	182 days
Time passed at sea, engine working	109 days	107.5 days
Time passed in harbor	54 days	74.5 days
Distance in miles	27,808.0	27,818.0
Numbers of hours regular running	2,517	2,497
Manoeuvering	92	82
Mean speed, knots	11.0	11.14
Number of hours auxiliary engine running starboard		2,127.5
Number of hours auxiliary engine running port		1,666.5
Fuel consumption per mile	174.5 kg. coal (384.6 lb.)	40.25 kg. oil (88.7 lb.)
Lubricating oil consumption per I.H.P. per hr.	0.206 gr. (.0072 oz.)	1.64 gr. (.0577 oz.)
Fuel consumption for firing up	49.6 tons	0
Stand-by losses	31.6 tons	0
For full steam no propulsion	7.8 tons	0
Regular propulsion	4,415.0 tons	1,061.98 tons
Manoeuvering	71.9 tons	14.74 tons
Electric light	59.6 tons	19.04 tons
Heating	10.7 tons	0.6 tons
Winches and pumps	179.6 tons	23.84 tons
Fuel for main engine	4,576.3 tons	1,076.72 tons
Fuel for auxiliaries	282.3 tons	43.48 tons
Total fuel consumption	4,858.6 tons	1,120.2 tons

Economic results for one round trip, Europe, East Asia and back:

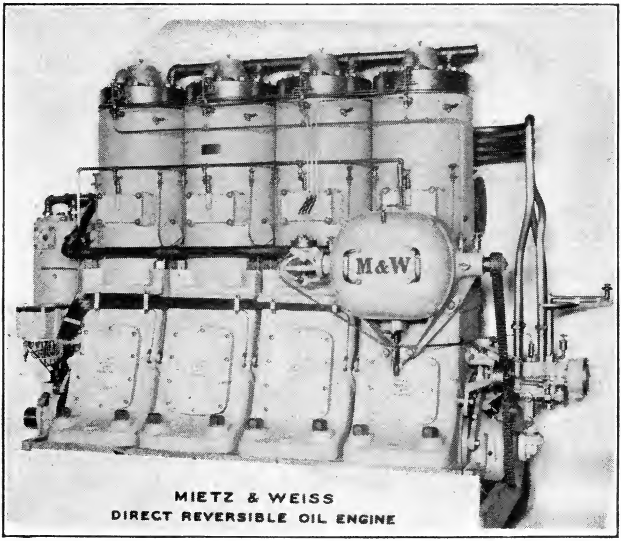
Cargo	7,673	8,670
1000 tons of cargo carried one mile at a speed of about 11 knots at fuel consumption	22.8 kg. coal (50.3 lb.)	4.65 kg. oil (10.25 lb.)
Price of fuel per ton	$5.40 (coal)	$8.60 (oil)
1000 tons of cargo carried one mile at a speed of 11 knots at fuel expense of	12.3 cts.	4.0 cts.
Total fuel expense for a cargo load of 8500 tons for transportation from Copenhagen to East Asia and back (27,818 miles) at a speed of 11 knots	$30.300	$9,900
Outgoing cargo	8720 — 1555 tons = 7165 tons	
Cargo when plying between the West Coast and Japan	8870 — 1085 tons = 7635 tons	
Homebound cargo	8720 — 1120 tons = 7600 tons	
Average cargo for the whole voy-voyage about		7500 tons

From the engine log book of these two ships the following items are of interest:

	S. S. "Arabien" 5th voyage.	D. S. "Siam" 2d voyage.
Duration of voyage	300 days	236 days
Time spent at sea engines working	183 days	140 days
Time spent in port	117 days	96 days
Distance in miles	45,676	34,819
Number of hours regular running	4,278	3,279
Number of hours manoeuvering	109	88
Average speed, knots	10.7	10.6
Number of hours auxiliary engine running port		2,539
Number of hours auxiliary engine running port		2,665
Fuel consumption per mile	186.4 kg. coal (410.8 lb.)	41.5 kg. oil (91.5 lb.)
Lubricating oil consumption per I.H.P. hour		0.866 gr. (.03 oz.)
Fuel consumption for firing up	66 tons	0
Stand-by losses	77.5 tons	0
Fur full steam no propulsion	16.95 tons	0
Regular propulsion	7,600.75 tons	1,357.9 tons
Manoeuvering	102.5 tons	18.3 tons
Electric light	149.75 tons	23.4 tons
Heating	49.25 tons	27.5 tons
Winches and pumps	396.25 tons	18.9 tons
Fuel for main engine	7,863.7 tons	1,376.2 tons
Fuel for auxiliaries	670 tons	69.8 tons
Total fuel consumption	8,533.7 tons	1,446 tons

Economic results for trip around the world:

1000 tons of cargo carried one mile at a speed of 10.6 knots at fuel consumption of	25 kg. (55.1 lb.)	4.9 kg. (10.8 lb.)
Price of fuel per ton	$5.40 (coal)	$8.60 (oil)
1000 tons of cargo carried one mile at a speed of 10.6 knots at fuel expense of	13.5 cts.	4.2 cts.
Total fuel expense for a voyage round the world covering 35,000 miles, which coincides with Diesel engine ship "Siam's case of 8500 tons at a speed of 10.8 knots amounts to	$40,000	$12,600



Typical American Marine Engine.

Attention is drawn to the following. The engine room attendance in S. S. "Kina" consists of 3 engineers, 2 assistant engineers and 14 firemen, a total of

19 men. In the Diesel ship "Siam" it consists of 4 engineers, 5 assistant engineers and 4 oil men, a total of 13 men.

S. S. "Kina" bunkered coal 10 times on the voyage. D. S. "Siam" bunkered oil twice on the voyage; the last time so much that the ship on the next trip over the same route only needed bunkering once.

Diesel ship "Siam": Second voyage; trip around the world. From Europe, South America to west coast of the U. S. A., from thence to Japan, China, Vladivostok and back through the Suez Canal:

Outgoing cargo	9500 — 780 tons = 8720 tons
Cargo when plying between the West Coast and Japan	9500 — 1056 tons = 8440 tons
Homebound cargo	9500 — 1215 tons = 8285 tons
Average cargo for the whole voyage about	8500 tons

S. S. "Arabien"; Fifth Voyage:

The steamship "Arabien" bunkered 14 times during the voyage. The Diesel-engine ship "Siam" bunkered only three times during the voyage, and of these one was caused by a mistake in the execution of the order.

At the end of the trip the remaining oil was sufficient to carry the ship back to the oil-supplying port without bunkering under way. A saving of about 68 per cent in fuel expense is the practical result obtained with the use of the Diesel-engined ship on the voyage. This included all consumption needed for loading and unloading, lighting, heating, etc. The extra saving by smaller crew, bigger cargo-carrying capacity of the Diesel-engined ship were not even taken into account.

The longer the voyages are without stopping, the more economical the Diesel-engined ships are.

The only condition in the choice of route to be taken for the Diesel-engined ship is that it should be such that the ship may enter ports where oil is available.

In 1912 Messrs. Sulzer Bros. installed engines in the "Monte Penedo." The two engines are two cycle, single-acting with four cylinders of 18.5 in. bore and 26.9 in. stroke, having a speed of 160 r.p.m. The data of the ship are:

Length	351 feet
Beam	50 feet
Depth	26.9 feet
Speed	10 knots
Deadweight	4000 tons
Bunker capacity	700 tons
Weight of engines and auxiliaries	160 tons
Power	1700 h.p.

The "Monte Penedo" engines are remarkable for the absence of inlet and exhaust valves. The only valves in the cylinder heads are those for fuel injection and starting air. It makes a simple cylinder head but involves complications in the cylinder wall. The exhaust takes place through openings in the cylinder wall forming one-half circle, whereas the other half of the periphery is taken by openings for scavenging air. Of those there are two rows, one above the other, and the communication between the air main and the top row of openings can be blocked by a double-seated valve. This arrangement serves to keep the scavenging air pipe closed at the beginning of the exhaust and then to keep it open after the exhaust is closed, thus preventing the exhaust gases from entering in the air line first and afterward securing an abundancy of fresh air at the start of the compression.

The "Monte Penedo" is probably the most successful two-cycle marine motor at present in service. After some trouble with the pistons on the first voyage (the extension required to shut the exhaust and inlet ports worked loose) the construction was altered, and since then the motors have given full satisfaction. It must not be forgotten, however, that these engines were of the best workmanship that can probably be found and were operated by trained engineers.

In 1913 the "Hagen," built by Messrs. Krupp started on her first trip. She is equipped with two single-acting two-cycle engines, each composed of 6 cylinders 18.9 in. bore and 31.5 in. stroke, running 140 r.p.m. The ship's dimensions are: 400 ft. long, 53 ft. beam and 32.3 ft. depth; carrying capacity, 8350 tons, speed, 11 knots; weight of machinery, 580 tons.

In 1914 the increase of ships with motors is quite remarkable.

Burmeister & Wain of Copenhagen delivered in 1914:

Name	Size of Ship Length x Beam x Depth.	I.H.P.	No. of Screws
Pacific	362 ft. x 51 ft. 3 in. x 25 ft. 6 in.	2000	2
Kronprince Gustaf Adolf	362 ft. x 51 ft. 3 in. x 25 ft. 6 in.	2000	2
Fionia	410 ft. x 53 ft. x 38 ft.	4000	2
Kronprincessin Margarete	362 ft. x 51 ft. 3 in. x 25 ft. 6 in.	2000	2
Malakka	410 ft. x 55 ft. x 30 ft. 6 in.	3000	2
Tonking	410 ft. x 55 ft. x 30 ft. 6 in.	3000	2

Werkspoor of Amsterdam has delivered the engines for:

Name.	Size of Ship Length x Beam x Depth.	I.H.P.	No. of Screws
Elbruz	375 ft. x 40 ft. x 29 ft.	2900	2
Ares	345 ft. x 46 ft. 6 in. x 27 ft. 5 in.	2300	2
Artemis	346 ft. x 46 ft. 6 in. x 27 ft. 5 in.	2300	2
Selene	346 ft. x 46 ft. 6 in. x 27 ft. 5 in.	2300	2
Hermes	346 ft. x 46 ft. 6 in. x 27 ft. 5 in.	2300	2
Jules Henry	305 ft. x 40 ft. x 23 ft	1350	2
Poseidon	185 ft. x 30 ft. 6 in. x 13 ft. 3 in.	450	1

The Southwark Foundry and Machine Co. are building the Southwark Harriss Valveless Engine. It is of the verticle two-cycle type operating on the full Diesel principle. This engine, though it is made for both stationary and marine application is used most extensively aboard ship.

In the marine engine a step piston is used, the lower portion of which acts as a scavenger air compressor and also for starting the engine. The starting air of relative low pressure, 175 lb. per in., is allowed to enter the lower cylinder, in this way avoiding the necessity of this cold aid entering the working cylinder and causing violent temperature changes. This lower piston also acts as a crosshead, taking the side thrust of the connecting rod. In manoeuvering a vessel the air cylinder is said to assist the working cylinder by using compressed air if it is desirable. The engine is reversible and as the engine operates on the two-stroke-cycle principle this is comparatively simple, due to the absence of valves. The engine is made two to eight cylinders from 120 to 2000 h.p. This engine is installed in many vessels on the Pacific Coast and many more on the Atlantic.

The Bolinder, a semi-Diesel engine, made in Sweden, has been successfully operated in a number of vessels in this country.

The Polar Diesel Engine Company of Stockholm, delivered the twin-screw two-cycle engines of about 800 h.p. each for the "Sebastian," built at Dundee, but they did not give satisfaction.

In May, 1914, the "Arum," with English-built Polar type engines made her trial. The engines are of the sigle-acting, two-cycle type. Each of the two engines has 4 cylinders, bore 16.2 in., stroke 3.9 in., speed

135 r.p.m., power rated at 650 b.h.p. each The principal dimensions of the ship are 360 ft. by 47 ft. by 27 ft. depth, 22 ft. draft, carrying 550 tons. After performing various short trips, the "Arum" was sent on her first long voyage to the Persian Gulf, which was perfectly successful according to reports obtained.

The German motorship "Secundus" started her career likewise in 1914. The owner, Hamburg-American line, now possesses two motor motor vessels, "Christian X" and "Secundus." The former has four-cycle Burmeister Wain engines, the latter has two-cycle engines built by Blohm & Voss of Hamburg. Each of these two engines has four cylinders of 23.6 in. bore, the stroke is 36.2 in., speed 120 r.p.m., power 1850 h.p. per engine.

The scavenging air is produced by a pump worked by levers off one of the cross heads. The air enters the cylinders through 4 poppet valves in each cylinder head.

The exhaust gases leave the cylinders through openings in the cylinder walls, and a water-cooled pipe. The lower part of the engine resembles a steam engine, but forced lubrication is employed; the crankshaft bearings are water cooled. The pistons are cooled with fresh water, which may be considered an unnecessary complication.

The "Secundus" made one complete voyage from Hamburg to New York and back. At the outbreak of the war she had not started her second voyage and is now therefore presumably at Hamburg.

The results obtained with a few non-reversible engines of 350 b.h.p., driving propellers with reversible blades promise a great future for such engines for medium size crafts. The reversing of the blades is performed with aid of the engine power. The advantage of this is the excellent security of manoeuvering, which is controlled directly from the bridge. The installation is of course far simpler than one with reversible engines. The manoeuvering air reservoirs are cut out and the auxiliaries are of a far simpler nature.

In designing a motor ship an important question is, how to drive the deck-machinery and the auxiliaries in the engine room. When plenty of money and good personnel is available, the best system is to generate electricity by Diesel engines and drive everything electrically. Where fuel to heat a boiler is expensive, this system is also the most economical in the long run. In first cost it is, however, the greatest, and a staff of engineers is required to undertake many novelties at once. To save first cost and to keep the novelties in the ship within the smallest limits, the best plan is to have two donkey boilers. Fire them either by coal or oil, depending on the price, and drive everything by steam, including the air compressor required to manoeuvre the main motor. When the ship runs several days continuously and the motor is four-cycle, the waste gases can heat the donkey boiler, giving plenty of steam for steering and for the whistle. The gain is about 1 ton of oil per day for ships of about 6000 tons. In short runs, or when the motor has to slow down often, this system cannot be applied. To drive the auxiliaries by compressed air has not proved a success; the air compressors must be too large. In tank ships it is good practice to make the main cargo-discharging pump centrifugal and drive it by a Diesel engine. The same engine can then drive the air compressor for manoeuvering. This system is slightly more expensive in first cost, but, when the ship has to unload often, it is cheaper in service than steam pumps. It also permits the ship to unload the cargo when it would be dangerous to fire a steam boiler.

The New London Ship & Engine Company, which started operation in 1910 have built a large number of the marine Diesel engines produced in the United States, a typical type is shown in section in Fig. 30. Although it has been in operation only a comparatively short time, its record to date is as follows:

Engines built and building	107
No. of cylinders, approximately	600
Total horsepower, approximately	40,000
Smallest engine	60 h.p.
Largest engine	1,000 h.p.

Their efforts have been directed largely toward engines for sub-marines. The engines being applied to merchant service are of the four-stroke-cycle type with the cam shaft on both sides of the cylinder for the operation of the admission and exhaust valve, the fuel valve being verticle in the center of the head.

There has always been a difference between the European and American point of view, due to conditions. It may be stated, in general terms, that, in Europe, capital was scarce, consequently, the European shipowner considered ultimate saving, and was willing to pay a greater first cost for his propelling plant, if the operating economy would show on ultimate gain. In the United States, the shipping business has never been given much encouragement, and those who have gone into the business have had to seriously consider first cost. Fur-

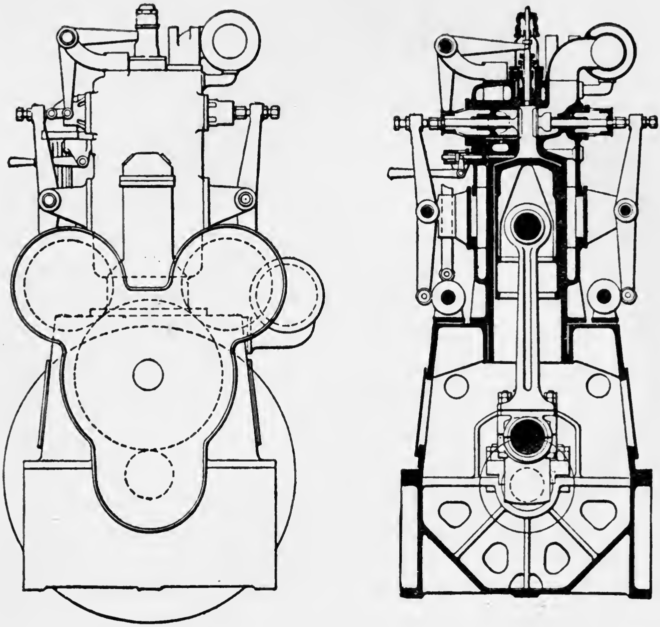


Fig. 30. New London Ship & Engine Co. Engine.

thermore, both coal and oil are comparatively cheap in this country. Finally, information in regard to Diesel engines has been obtained principally from the technical description of foreign vessels. It is only comparatively recently that Diesel-engined ships have visited American ports, so that first-hand information from actual observation has been scarce. A further drawback to American development has been the lack of trained operators. In the course of time, the basic advantages will be realized in the United States and the necessary trained operators will be developed.

Many ships intended for trade between the Atlantic and Pacific Coast, through the Panama Canal. are being fitted with to burn oil under their boilers. To one acquainted with the operation of a Diesel engine, this seems to be almost a wicked waste. The same amount of the same fuel used in a Diesel engine would run four ships instead of one, or would carry one ship four times as far.

Probably the two-cycle motor will eventually become cheaper to manufacture than the four-cycle for the same power. The running economy of the four-stroke-cycle is the greater, especially when the waste gases are passed through a steam donkey-boiler.

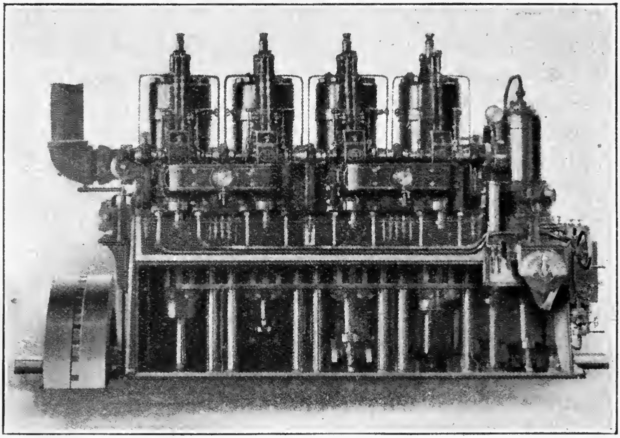
The cost to make a good marine engine is, and will remain probably, about 1/3 higher than to make a good reciprocating steam-engine and boilers of the same power, but this higher proce is partly compensated by the cheaper ship, because the Diesel engine takes up less room and weight than the steam installations, as the boilers are omitted and the bunkers can be made much smaller. This latter saving depends on the distance or intervals between the places where it is economical to replenish the bunkers.

The large motor ship requires fewer men to run than the large steamship; the quality of the men must, however, be higher. Difficulties with the troublesome firemen are eliminated; but the motor ship if not well attended to, is apt to require more repair in harbor than the steamship.

Balancing these good and bad qualities of motors and steamships, the fuel price in the parts of the world where the ship has to run will generally decide to which the balance will incline. In special cases, however, the fuel price will not be the main factor to be considered, but the following properties of the motor-driven ship are of greater value. That it does not require any warming up of boilers or engines, even if nobody has been on board in advance, the motor ship can start at full speed as soon as the oil tanks are filled. That it is possible for a motor ship to bunker only at very long intervals, three or four times longer than a steamship. And last, but not least, that motor ships can be made in which the part of the ship where the engines are placed is of absolutely the same temperature as the other parts of the ship. In hot climates this quality will go far to turn the balance when the engineers have a say in the decision.

Probably the worst enemies of the marine Diesel engine, during the past ten years, have been the over-enthusiastic advocates. Many have made promises they could not fulfill. Others have built and installed engines which were experiments. New firms are continually entering the field, little realizing that the design and construction of these engines are highly developed specialties. The first engines produced in this way are generally failures; and, unfortunately the good and the bad suffer as a result. The experienced builders approach perfection only by close application, and naturally do not publish all of the practical points which they develop in the course of their work. The individual or firm with small resources is taking a desperate chance when plunging into this line of work. So, also, are the customers who buy the first engines turned out.

The Diesel engine as applied to merchant ships to the present time has proved that this engine, if well designed, well made and well attended to, is reliable enough for the longest voyages and is at least four times more economical in fuel consumption, weight for weight, than a coal-fired steamship, or nearly 3 times more economical than an oil-fired steamship.



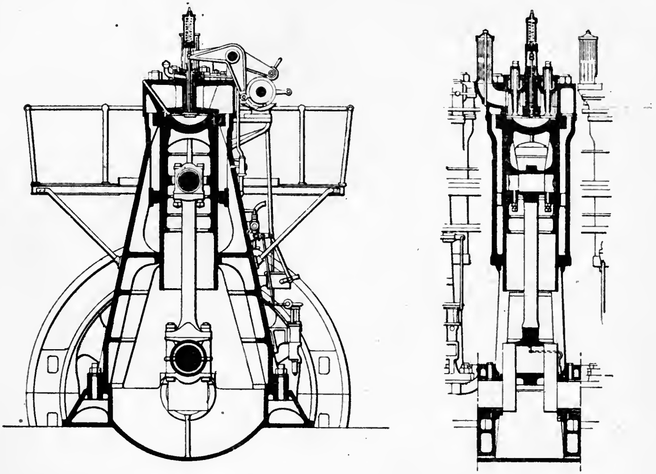
240 I. H. P. Southwark-Harris Valveless Engine,
Diesel Principle, Marine Type.

CHAPTER XII

INTERNAL COMBUSTION ENGINES AT P.P.I.E.

Naturally internal combustion engines occupied a prominent position at the Panama-Pacific Internationa Exposition and were the feature of the Palace of Machinery.

The McIntosh Seymour Corporation of Auburn, N. Y., Busch-Sulzer Bros.-Diesel Engine Company of St. Louis, Mo., both exhibited engines of 500 h.p. capacity direct connected to electric generators. The latter company supplied direct current to the Exposition for various purposes and operated throughout the times that the palace was open to the public. The McIntosh Seymour Corporation operated in connection with a water rheostat. They were unfortunate in not having their engine ready for operation during the earlier periods of the Exposition. This gave the Busch-Sulzer Bros.-Diesel Engine Company an opportunity to participate in the opening ceremonies. The exposition was opened by wireless from Washington, a receiving station being established on the grounds and the wireless impulse closed a metallic circuit which was connected to a trip on the Busch-Sulzer engine. A large weight attached to an extension of the starting lever started the engine when President Wilson pressed the button 3000 miles away. Both of these engines demonstrated their ability to operate on all kinds of load and their reliability was tested out to a large degree. The accompanying table gives the principal dimensions of these machines.



Section of McIntosh & Seymour "A" Frame Engine.

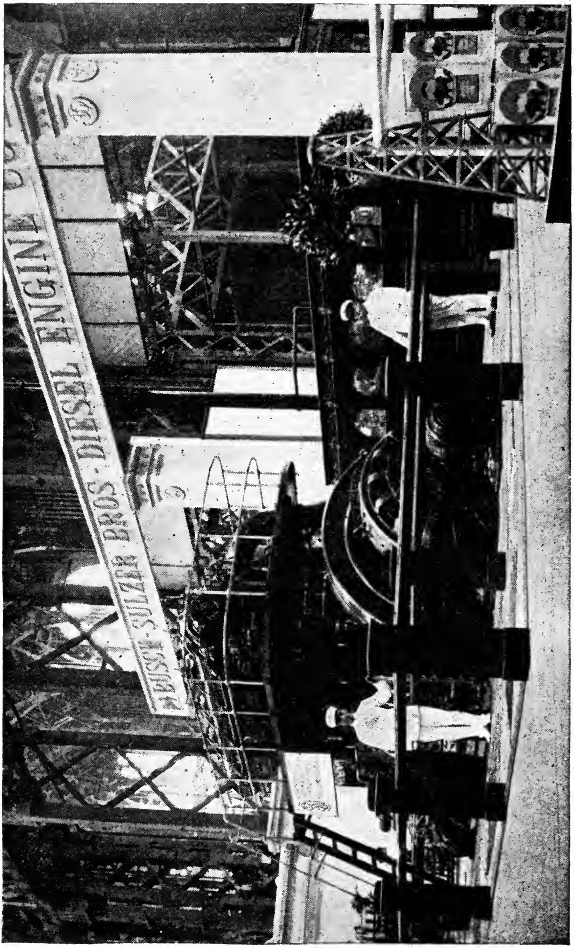
	Busch-Sulzer Bros.	McIntosh & Seymour	New London S. & E. Co.	Fulton.
Rating	500	500	180	50
No. cylinders	4	4	6	3
Diameter in inches.....	19	18⅞	8	8
Stroke	24½	28⅜	12½	9
R.p.m.	200	164	350	400
Compressor	3-stage	2-stage	2-stage	2-stage
Compression in lb.......	500	500	450	500
Injector pressire, lb.....	600-800	600-800	800	825-975
Weight per h.p., lb......	375	324	100	100
Governs by	Control of suction	Control of stroke	Control of suction	Control of by-pass
Air starting	2 cyl.	1 cyl.	3 cyl.	2 cyl.
Piston water-cooled.....	Yes	No	No	No
Air starting pressure, lb..	800-850	800	750	700-1000
Piston speed	816 2/3	780	875	600

The New London Ship & Engine Company of Groton, Conn., exhibited a vertical marine engine, the power from which was utilized to drive a pump in the exhibit of the Pelton Water Wheel Company. This engine is of the type manufactured in America for marine purposes and is somewhat similar to the large number of engines supplied by this company to the United States Navy for submarines. The engine was operated at frequent intervals and it typifies one of the best types of marine Diesel engines in this country.

The Fulton Engine Company of Erie, Pa., had a small engine on exhibit. The engine, however, was not erected so that it could operate so it was unable to demonstrate its ability in this regard. The details of the machine seem to be carefully worked out and the workmanship and finish show care and precision.

These constitute the four examples of high compression engines, two stationary, and two marine, and although the American Diesel Engine Company had its engines on exhibition and in operation at St. Louis in 1904, this Exposition was the first opportunity for any number of Diesel manufacturers to exhibit their product. Many manufacturers were handicapped by the great distance from their factories and the consequent expensive freight, but those who did exhibit had the opportunity of showing their product to a most appreciative and receptive public and were fully repaid for their expense.

The low compression, or semi-Diesels, were represented by The Bessemer Engine Company of Grove City. Pa., Mietz & Weiss Company of New York. The first of these exhibitors showed a number of engines, one being direct connected to electric generator sup-



Typical Diesel Engine Installation with Westinghouse Direct Current Generator.

plying electricity to the Exposition, another engine of the stationary type drove a centrifugal pump through a rope drive. These engines operated on California fuel oil similar to that burned in Diesels and operated entirely satisfactorily. There were also exhibited by this company several smaller engines of different types, principally for operation on natural gas.

The August Mietz Company showed a three-cylinder, vertical engine connected to electric generator and a reversible marine engine of three cylinders, both of these engines being in operation, the former carrying considerable electrical load. This company also showed a horizontal stationary engine and a vertical engine direct connected to an air compressor. These latter, however, were seldom in operation.

In all there were six companies exhibiting in the Diesel and semi-Diesel class, three of whom are exclusive manufacturers of stationary engines and two exclusive manufacturers of marine engines, one making both stationary and marine types.

It is interesting to note that on account of the fire hazard the Diesels and semi-Diesels were the only internal combustion engines to operate on their regular type of fuel. The carburetted type of engines having to rely upon compressed air, city gas or motors for driving power within the Exposition Palaces.

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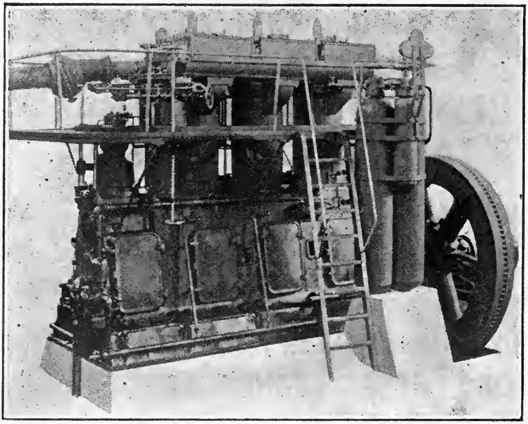

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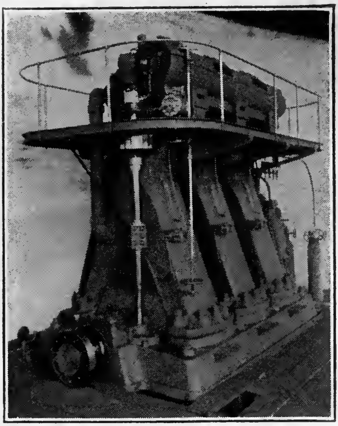

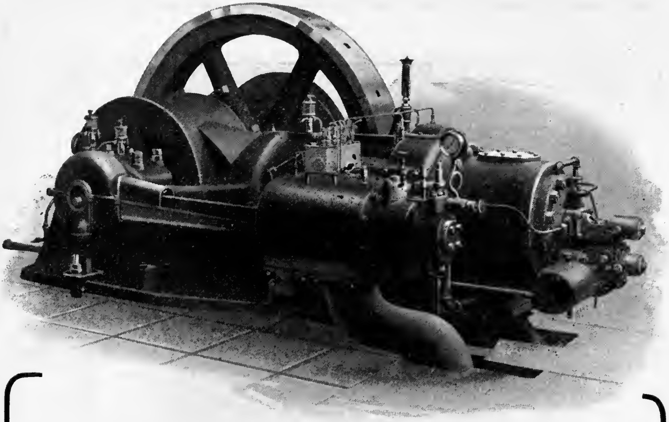

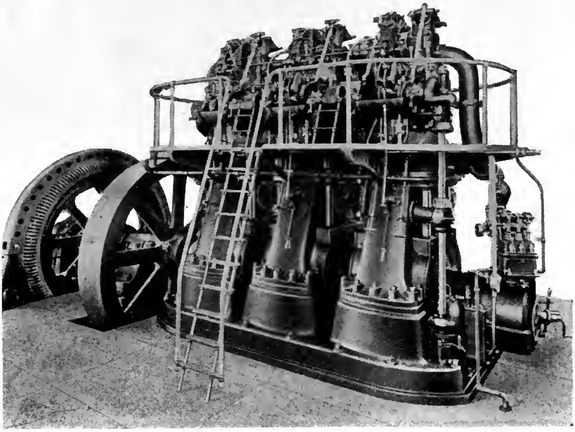

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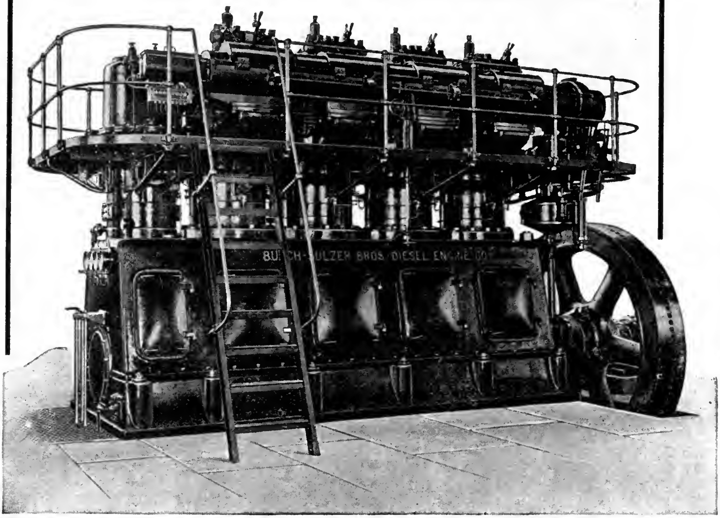

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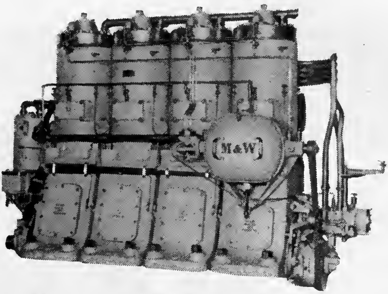
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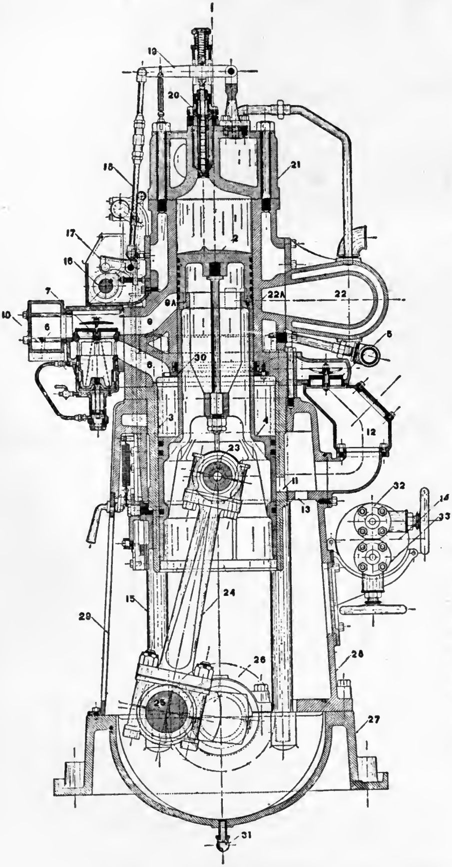

1. Main or Working Cylinder.
2. Main or Working Piston.
3. Scavenging and Air Starting Cylinder.
4. Scavenging and Air Starting Piston.
5. Scavenging Air Inlet Valve.
6. Scavenging Air Outlet Passage, Starting Air Inlet Passage.
7. Scavenging Air Delivery Valve.
8. Scavenging Air Manifold between Adjacent Cylinders.
9. Scavenging Air Inlet to Working Cylinder.
9A. Scavenging Air Inlet Ports.
10. Air-operated Intercepting Valve for Air Starting.
11. Outlet for Starting Air.
12. Silencer for Starting Air Exhaust and Scavenging Air Inlet.
13. Vents for Housing Fumes.
14. Injection Air Storage Bottle.
15. Removable Front Columns.
16. Cam Shaft.
17. Atomizer Actuating Rockers (one Ahead, one Astern).
18. Radius or Atomizer Push Rods (one Ahead, one Astern).
19. Atomizer Levers (one Ahead, one Astern).
20. Atomizer Spindle.
21. Cylinder Head.
22. Exhaust Pipe.
22A. Exhaust Outlet Ports.
23. Wrist Pin.
24. Connecting Rod.
25. Crank Pin.
26. Crank Shaft.
27. Bed Plate.
28. Housing.
29. Light Sheet Steel Removable Fronts.
30. Floating Packing Rings.
31. Crank Pit Drains to Filter.
32. Injection Air from Compressor.
33. By-pass to Starting Bottles.

Section of Southwark-Harris Marine Engine