TESTS OF A DIESEL OIL ENGINE PLANT

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Alfred Henry Korndt, Benjamin Salisbury, and Walter Van Turner

ENTITLED Tests of a Diesel Oil Engine Plant

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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Instructor in Charge

APPROVED:

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HEAD OF DEPARTMENT OF Mechanical Engineering
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INTRODUCTION.

In this paper, it is the desire of the writers to trace the development of the Diesel Oil Engine, as far as possible, from its invention to the high development which it has now attained, and to record certain tests of a Diesel engine conducted by them at St. Louis, Missouri.

When this article was first originated it was planned to make extensive tests at the Anheuser - Busch Brewing Association in St. Louis on the Diesel engine, but after encountering numerous difficulties, the idea of very elaborate tests had to be given up. A short review will give the reader an idea of the troubles which were encountered and show why more complete data was not obtained.

Arriving in St. Louis on Thursday, February 1, 1912, we were compelled to wait until the following Sunday for the indicator rigging which had been shipped from the Diesel Company. After getting everything in readiness for the tests, they were started Monday morning. Hardly had the test been started when it was discovered that the indicator cocks, taken from the University of Illinois, were defective, not being strong enough to hold the 600# compression pressure and the high temperature of combustion. Efforts were then made to
secure a new set of indicator cocks in the city. These were
obtained but after trying them out, the same difficulty was
experienced. Finally a telegram was sent to the Crosby Indicator
Company of Chicago ordering the shipment of three indicator
cocks, specifying that they should contain a hole no larger
than 3/8 inch, and the pressure and temperature under which they
would be used. The new cocks arrived in due time but after
putting them on the cylinders it was found that the same trouble
was experienced but not in the same degree as in the previous
trials.

It was decided that any tests which we would make with our
indicators would be worthless. As a last resort we determined
to run fuel tests at no load, one-half load, three-quarter load
and full load. This was done and a few indicator cards were
taken at each load by the Diesel engine people with a Swiss
indicator. This indicator was supposed to be perfect but it
was discovered later that the same trouble arose with it as with
the Crosby indicators. Consequently the results embodied in
this report based on I.h.p. must not be considered as being
accurate to a very high degree, but they will give a close
approximation of the true values which may be obtained from
these engines. Nevertheless, these tests will show the different
fuel consumptions and thermal efficiencies which are obtained
from the Diesel engine at varying loads.
BRIEF HISTORY OF THE DIESEL ENGINE.

The history of the Diesel engine is interesting. It began in 1893 when Rudolph Diesel, in a pamphlet entitled "Theory and Construction of a Rational Heat Motor to Replace the Steam Engine and Other Existing Heat Engines", laid down the following fundamental requirements for a perfect combustion engine:

1. Attainment of the highest temperature in the cycle, not by means of combustion and during the same, but before and independent of it by compression of air alone.

2. Gradual injection of atomized fuel into this highly compressed and heated air so that during combustion no rise of temperature takes place i.e., the combustion shall be isothermal. For this purpose the process of combustion cannot after ignition be left to itself, but must be governed from the outside to maintain proper relations between pressure, volume, and temperature.

3. Correct choice of weight of air with reference to the heating value of the fuel and the desired compression temperature, so that the practical operation of the machine, lubrication, etc., shall be possible without water cooling.

It is interesting to follow out these points and see how nearly they have been attained.

The intended fuel was coal dust, the cycle the Carnot. At the very outset however, a modification was made in the cycle
by omitting the isothermal compression and substituting for it one stage adiabatic compression. But a jacket was not thought necessary and in fact a non-conducting lining for the cylinder was demanded.

As a consequence of the above pamphlet, two firms, Krupp in Essen and Maschinen-fabrik Augsburg, undertook the construction of experimental machines. As was to be expected, further changes from the original idea were necessary, the two most important of which were the substitution of oil for coal dust, and the use of a water jacket.

In 1898 the experimental stage had been so far passed that Schröter could report test figures which more than doubled the thermal efficiency of the then existing Otto engines.

GENERAL DESCRIPTION OF ENGINE.

The Diesel engine, as made by the Busch-Selzer Diesel Engine Company, represents the German type and the method of operation as explained before. This engine is made by nearly every country in Europe, and by the above firm in this country. In all cases the engines operate on the same principles, but the mechanical details of the various constructions differ here and there enough to make them distinct from each other. Thus the main point in which the American engine differs from the European types is in the use of the enclosed box frame. The others, to the writers' knowledge all use the open A-frame. There are also the minor differences in the
methods of obtaining compressed air, governor details, valve construction, etc.

The figure on page 28 shows the general assembly of a triple cylinder Diesel engine as built by the American Company. The base of the machine is a single casting completely enclosed, so that splash lubrication may be employed for crankshaft bearings, connecting rods, bearings, cam shaft and cam rollers. The cylinders are cast in one piece with the jackets, the whole being secured to the box pedestal as shown. The cylinder head is a simple casting, containing a relief valve in the center of the head, while admission, exhaust, and fuel valves are of the simple poppet type. The admission valve works downward and the exhaust valve works upward. The latter is water cooled. All of the valves are operated by push rods, the exhaust valve directly, the admission valve through a lever pivoted to the admission valve housing, and the fuel admission valve, which acts horizontally, by means of a bell crank. This is made clearer by a study of the enclosed cut.

Figure on page 28 shows the valve construction in greater detail. The admission valve is held in a separate cage so that the seat may be easily taken care of. It closes against a small dash-pot located in the top of the housing for the purpose of reducing both noise and shock. The exhaust valve has no removable seat, but it is of such dimensions that it may itself be easily removed through the admission valve cage opening, giving opportunity for grinding the seat whenever
necessary. The relief valve in the center of the head is usually set to open at about 800 lbs. per square inch and acts as a safety against undue pressure caused by premature ignition, etc. The former may occur when the fuel valve has accidentally stuck, admitting oil to the cylinder during the compression stroke.

The fuel valve, through which oil is admitted to the cylinder after the charge of air is compressed, is a very important part of the engine, and its construction is shown on a larger scale on page 28. Figure on page 28 shows the location of the oil pump at the right hand side of the crank case and the manner of operating it by means of spur gearing from the cam shaft. From this pump an oil supply pipe leads to the oil valve. From here the oil finds its way into the atomizer in the interior of the bushing held in the cast iron fuel valve cage. Both air and fuel connections are screwed into this steel bushing so that the valve cage is not compelled to stand high pressures. The fuel admission valve itself consists of a nickle steel needle which carries a cast iron spring case on its outer end. Normally the spring forces the needle against its conical seat, but as the fuel-valve cam commences to operate, the bell crank shown pushes the needle to the right against the spring and opens the valve. This happens about the time that the main piston reaches the upper dead center on its compression stroke, and highly compressed air from a storage tank then rushes through
the automizer and forces the oil out into the compressed cylinder charge. In order to keep the needle cool and to keep the oil from carbonizing in the automizer, water is circulated in the space between the steel bushing and the walls of the valve cage.

Diesel engines are governed not by controlling the length of time that the fuel valve is open, but by adjusting the effective delivery stroke of the oil pump, and hence, except in minor variations in the setting of the fuel valve depending upon the kind of oil used, the lift and time of opening of all of the valves once set is always the same. The drawing on page 27 shows the method of setting the valves and the time of opening and closing, the lift being controlled by the fixed cams of the half-time shaft.

The location of the fuel pump with its governor is shown on page 28. It has as many pump cylinders as power cylinders. The pump plunger is actuated by a simple eccentric and strap, and its stroke is therefore constant. By means of a short horizontal arm and nearly vertical rod, the plunger is connected to a "pump suction valve eccentric lever" which, in conjunction with the fly-ball governor, controls the motion of the suction valve. At full load the governor sets the fulcrum about which the eccentric lever turns so that the suction valve opens when the plunger has completed half of its downward stroke. The suction opening increases until the plunger has reached the lower end of its stroke. On the up stroke the
valve is not closed until half the stroke is completed again after which that part of the charge remaining is then forced through the double ball check valve and into the engine cylinder. The reason for keeping the valve open for half stroke each way is to let the oil free itself from air which it is very apt to retain, and thus to deliver solid oil only. Under no load the governor so changes the motion of the eccentric lever that the suction valve is open practically during the entire up and down stroke of the plunger, so that little or no oil is delivered to the fuel injection valves. Between these two extremes the effective delivery stroke of the pump can be made anything to suit the load.

The high pressure air used for injecting the fuel is usually obtained by independent compressors discharging into steel storage tanks. The air for starting is also obtained from this source. The pressure of the injection air should vary with the load on the engine, for half load or less it should be from 50–60 atmospheres, above that load from 65–70 atmospheres and for overloads 75 atmospheres is safe and permissible.

The use of independent three-stage compressors in place of two-stage compressors driven from the engine is considered a distinct improvement over European practice. In a two-unit plant for instance, two independent compressors, one used as a relay, offer much greater security against a shut-down from lack of air than two belt driven compressors. This advantage is more pronounced as the number of units in the plant
grows. Thus in a plant in Florida, three compressors serve to supply twelve engine units, and the failure of any one of the three cannot possibly effect the operation of the engines. Another important point is that such a system allows a cool air supply to the injection valves, which helps to prevent the carbonizing of the fuel oil in this valve.

To start the engine the fuel-valve cam on one of the cylinders is pulled over so that the fuel valve on that cylinder is closed and cannot be opened. Instead of this the same operation brings into action a cam which controls a special starting valve on the same cylinder. The engine, after the crank shaft has been brought into proper position, is then started by admitting compressed air to that cylinder. After one of the other cylinders is heard to obtain an ignition, the cam lever is returned to its former position, when the starting cylinder will also take up its regular cycle. Previous to starting, the fuel pump must be operated by hand for a few turns by means of the starting wrench and pinion, the pinion meshing with a gear on the pump shaft when the starting pin is pulled out. The oil so pumped is discharged through an overflow, the purpose of this being to work all the air out of the oil and to insure that nothing but solid oil is delivered to the fuel valves.
THE TEST AT ST. LOUIS.

Object.—The purpose of this test was to determine the various efficiencies as shown on table of calculated results under varying conditions of no load, 1/2 load, 3/4 load and full load.

Preliminary Statement.—The apparatus tested consisted of:

One Diesel Oil Engine rated at 225 b.h.p. direct connected to a 160 K.W. direct current three wire generator;

One three stage air compressor;

One centrifugal pump for handling cooling water;

One oil pump and apparatus;

Minor apparatus consisted of two ammeters, one wattmeter and one voltmeter in connection with the main unit and one wattmeter for the compressor. Before starting this series of tests the switchboard instruments were carefully calibrated by means of standard instruments supplied by the University of Illinois, these standard instruments having previously been tested before leaving the University. Data and calibration curves for these instruments are shown on pages 20 and 21-25.

The tank into which the cooling water was discharged was then calibrated in order that this water could be measured. The two tanks containing the oil supply shown on page 26 were then calibrated to one-quarter gallon divisions, the level
of the oil in the tank being visible at any one time through gage glasses.

**Manipulation.** - Four load tests were run, the engine previously being regulated to the load desired. At the instant the test was started the oil supply was switched from one oil tank to one in which the exact quantity of oil was known. A description of the method of handling this oil supply apparatus shown on page 26 can be given briefly. Oil was supplied to the tanks D by the centrifugal pump M, it being possible to fill one tank while the other tank was supplying the engine. When the left hand reservoir was being filled, valve A was closed and valve B opened until the tank was filled, then valve B was closed. While the left hand tank was filling, oil was supplied to the engine from the right hand tank, valves A, C, G and J being closed, while the oil passed through the open valves E, H, F and L to the left hand meter which was used throughout the test. When the right hand tank was empty, the left hand tank was thrown in simply by closing valve F first and then opening valve A which allowed the oil to flow through the open valves A, H and L to the left hand meter. The right hand tank was then refilled so that it could again be used as soon as the other tank was empty. This scheme of reversing from one tank to the other was used throughout the test. Valves P are used only when it is desired to drain the tanks. The index reading on the oil meter was also taken in order to check with
the results from the calibration on the supply tanks. The specific gravity of the oil was obtained whenever a supply of oil was pumped to the tanks. A sample of oil was obtained for analysis by taking 1/2 of the sample at the start of the test and the remainder at the end of the test. These samples were brought back to the University and analyzed by the Department of Applied Chemistry. The following report shows the results of this analysis:

Urbana, Illinois,
March 27, 1912.

Mechanical Engineering Department,
University of Illinois.
Gentlemen:-

I have to report on the samples of fuel oils burned in Diesel Oil Engine, Student Thesis, conducted at St. Louis (Anheuser Busch Brewing Association.) as follows:

Laboratory No. 4664-4667

<table>
<thead>
<tr>
<th>Load</th>
<th>B.t.u.</th>
</tr>
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<tbody>
<tr>
<td>No load</td>
<td>19,551</td>
</tr>
<tr>
<td>1/2 load</td>
<td>19,573</td>
</tr>
<tr>
<td>3/4 load</td>
<td>19,703</td>
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<tr>
<td>Full load</td>
<td>19,690</td>
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</table>

Composition made from equal parts of the above

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>88.40</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>10.94</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.31</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.35</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>
B.t.u.-------------------19.629

Low value-----------18,678

Very truly yours,

Professor of Applied Chemistry.

The quantity of cooling water was obtained by measuring its rate of discharge into a tank at ten minute intervals. The cooling water was discharged from three separate pipes, one from each cylinder. Separate thermometers under each discharge pipe gave the temperature of the cooling water at discharge. The r.p.m. of the engine was obtained from the cam shaft this making one-half the number of revolutions of the main shaft. The revolutions of the cam shaft were obtained by a speedometer and checked with a speedcounter. Indicator cards were taken from the three cylinders for each of the loads but owing to the inability of the indicator cocks to withstand the high pressure and temperature of the cylinders, the results which are based on I.h.r. are only approximate and cannot be said to be thoroughly reliable.

It was desired to make a Heat Balance from the data obtained, but this proved impossible for when it was calculated it was found that the heat output of the machine was more than the heat taken in with the oil. This in all probability was due to the method of measuring the circulating water and also the I.h.p. obtained, for it seems impossible that any error
due to the oil consumption could enter as this consumption was measured very accurately.

The method which was to be employed in obtaining a Heat Balance was as follows: (B.t.u. delivered per hour calculated on Low Heating Value) - (Heat equivalent of indicated work per hour + Heat lost to jacket) = Heat used by auxiliaries, lost by radiation, lost to exhaust and not otherwise accounted for.

**Conclusions.**— From the results obtained on mechanical efficiency it would seem that the engine is over rated. The engine does not run at full load in practice but operates continually at approximately 3/4 load. The falling off of the various thermal efficiencies at full load would seem to substantiate the fact further that the engine is over rated since it does not operate as economically at full load. This falling off of thermal efficiency at full load may further be accounted for by the fact that the addition to the area of the indicator diagram at late cut-off does not increase proportionately to the amount of heat added.

These tests compare favorably with a series of tests on a 300 h.p. Diesel engine at the Angsburg Works of the Diesel Company run by Chr. Eberly of Munich and recorded at page 180 of the Zeitschrift des Vereins Deutscher Ingenieure February 1, 1908. The fuel used was Galician crude oil of the following composition:—

- Carbon = 86.41%
- Hydrogen = 12.66
- Sulphur = 0.85
- Oxygen & Nitrogen = 0.08
Low heating value = 18130 B.t.u. per lb.

The following results were obtained at the loads indicated:

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<th>Load</th>
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<th>3/4</th>
<th>1</th>
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<tr>
<td>B.H.P.</td>
<td>156.0</td>
<td>233.0</td>
<td>294.0</td>
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<tr>
<td>Mechanical Efficiency</td>
<td>70.6</td>
<td>80.0</td>
<td>76.2</td>
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<tr>
<td>E_t on I.h.p.</td>
<td>46.4</td>
<td>44.3</td>
<td>45.8</td>
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<tr>
<td>E_t on B.h.p.</td>
<td>29.0</td>
<td>32.9</td>
<td>32.2</td>
</tr>
</tbody>
</table>

These thermal efficiencies are somewhat higher than those obtained in the test at St. Louis but this is probably due to the fact that the unit is larger. It will be noted that the mechanical efficiency on this 300 h.p. engine drops off at full load as in the case of the engine tested at the Anheuser-Busch Plant, St. Louis.
SAMPLE CALCULATIONS.

Item 7 = Item 5 X Item 6

Item 9 = \( \frac{\text{Item 8}}{\text{Item 1}} \)

Item 12 = Item 8 X Item 10 X 8.33

Item 13 = \( \frac{\text{Item 12}}{\text{Item 1}} \)

Item 15 = \( \frac{\text{Item 14} \times 3}{2} \)

Item 18 = \( \frac{\text{Item 16} \times \text{Item 17}}{1000} \)

Item 19 = \( \frac{\text{Item 16} \times \text{Item 17}}{746} \)

Item 22 = \( \frac{\text{Item 20} \times \text{Item 21}}{1000} \)

Item 23 = \( \frac{\text{Item 20} \times \text{Item 21}}{746} \)

Item 24 = Item 18 - Item 22

Item 25 = Item 19 - Item 23

Item 27 = \( \frac{\text{LEAP}}{33000} \)

Item 28 = Item 27 - Item 23

Item 29 = \( \frac{\text{Item 25}}{\text{Efficiency of generator}} \)

Item 32 = \( \frac{\text{Item 19} \times 2.545}{\text{Item 13} \times \text{Item 30}} \)

Item 33 = \( \frac{\text{Item 19} \times 2545}{\text{Item 13} \times \text{Item 31}} \)

Item 34 = \( \frac{\text{Item 25} \times 2545}{\text{Item 13} \times \text{Item 30}} \)

Item 35 = \( \frac{\text{Item 25} \times 2545}{\text{Item 13} \times \text{Item 31}} \)

Item 36 = \( \frac{\text{Item 27} \times 2545}{\text{Item 13} \times \text{Item 30}} \)
Item 37 = \frac{Item 27 \times 25}{Item 13 \times Item 31}

Item 38 = \frac{Item 28 \times 25}{Item 13 \times Item 30}

Item 39 = \frac{Item 28 \times 25}{Item 13 \times Item 31}

Item 40 = \frac{Item 29}{Item 28}
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<th>CURRENT</th>
<th>KW.HR</th>
<th>COMPRESSOR EMF CURRENT</th>
<th>WATERS</th>
<th>FUEL OIL</th>
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## OBSERVED DATA.

- **AVERAGE ROOM TEMPERATURE (F):** 71.0
- **AVERAGE WATER FUEL OIL:** 17938.3
- **AVERAGE TEMPERATURE:** 107.5
- **AVERAGE LEAVING:** 104.5
- **AVERAGE LEAVING:** 102.0

**Notes:**
- All measurements are in degrees Fahrenheit.
- The data includes observations of speed, current, and time for various tests.
- Water flow and fuel oil consumption are recorded for each test.
- The average values are calculated across multiple tests.
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## Calibration Data for Correcting Switch Board Instruments

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CALIBRATION CURVES.

**FIGURE 1.**
Fig. 1 - Weston D.C. Voltmeter, No. 4351 (0-300).

**FIGURE 2.**
Fig. 2 - Weston D.C. Voltmeter, No. 4348 (0-600).
CALIBRATION CURVES.

FIG. 1 - WESTON D.C. AMMETER, NO. 7524 (0 - 150).

FIG. 2 - WESTON MILLI-VOLT METER + SHUNT, NO. 11742 (0 - 1000Amps).
CALIBRATION CURVE
SWITCH BOARD D.C. AMMETER - NO. 915.
CALIBRATION CURVE


Switch Board Ammeter No. 9/4 (Ampères)

Ammeter and Shunt—No. 11742 (Ampères)
CALIBRATION CURVE

SWITCH BOARD D.C. VOLTMETER—NO. 1447.

Switch Board Voltmeter No. 1447.

(Volts)

Voltmeter—No. 435% (Volts)
LAY OUT OF OIL FEED
FOR DIESEL ENGINE
ANHEUSER - BUSCH PLANT
ST. LOUIS MO.
Note: Fuel needle valve should be carefully adjusted. If the
passing is too tight, it may cause the valve to close
slowly, and the needle point and other parts are
liable to damage.

Fuel valve settings: Open admission valve with easing
year. Turn air on in injection air pipe at set valve rod so
the air is heard to escape through cylinder at the
time given for opening of valve.
A TYPICAL DIESEL OIL ENGINE PLANT

Two 225 B. H. P. Triple Cylinder Diesel Oil Engines, each direct connected to a 160 K. W.-D. C. Generator, installed by

DEUTSCH-SÜDDEUTSCHER BROS.-DIESEL ENGINE CO.

ST. LOUIS