THE INVESTIGATION OF THE COMBUSTION PROCESS IN AN OIL-FIRED BOILER

AND

THE ANALYSIS OF EXHAUST SMOKE FROM COMMERCIAL DIESEL ENGINES

by

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ABSTRACT

Part A. The combustion in this boiler has never been satisfactory. A flame could not be established at low fire rate. At high fire rates an excessive amount of smoke resulted.

The experimental work was required to give more information on two factors affecting combustion.

1. Photographs showing the nature of the flame under varying fuel metering setting and primary air setting.

2. To measure the velocity profile of the primary air so as to assess its influence on the atomization and combustion.

The results obtained make it possible for the boiler to be used satisfactorily on automatic control and fully modulating.

Part B. In recent years there have been repeated attacks in parliament and in the daily newspapers on the exhausts from the oil-engined vehicles, as being toxicity and cancer encouragement. It would not appear, however, that this admirable act protects the public from the atmospheric pollution resulting from the ever-increasing number of Diesel engines on the roads.

The experimental work was required to study the combustion in commercial diesel engines with emphasis on the exhaust smokes.

The results of the two engines tested are compared relating to incomplete combustion observed in the percentage of the exhaust gases. The importance of a knowledge of the products of incomplete combustion in relation to the combustion process in the Diesel engine. The analysis of the products of incomplete combustion may be a guide toward a better understanding of the Diesel process. From a practical point of view these products hold one of the biggest problems in Diesel development.

Acknowledgement.

The thesis has been written to investigate the combustion in an oil-fired boiler in the Mechanical Engineering Laboratory and to study the combustion in commercial diesel engines with emphasis on the exhaust smoke. The author wishes to acknowledge the suggestions and encouragement of Professor Piset Pattabongse Head of the Department of Engineering. The author also wishes to express his indebtedness to Dr. Vaikun Chalitbhan and Mr.J.F.Howard for helpful supervision, discussions, critism, advice, skill and patience; without their help this thesis would not be in existence.

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INTRODUCTION.

COMBUSTION

Combustion,or burning, is a chemical process in which a substance unites with oxygen, with the evolution of heat and light. At the instant of burning, the fuel must be in the gaseous form, to unite with the oxygen, obtained by supplying air. A rapid combustion, such as that takes place in the cylinder of a gas engine, is called an explosion, an illustration of imperfect combustion is that of a smoldering fire in a peat bog.

Many of the problems associated with the burning of fuels are mechanical problems.

The complete burning of a fuel is accomplished by:-

1. The fuel and air must be properly mixed at all points in the combustion zone.

2. The sufficient of air must be supplied to furnish the required oxygen.

3. The temperature at those points must be adequate to maintain combustion.

4. Enough time must be allowed for the precess to be completed-e.g.,the volume and arrangement of the combustion space in the furnace of a boiler or an industrial furnace should be such that the flame will completely burn out before encountering the dampening effect of relatively cold walls such as the boiler tubes. To insure that oxygen (air) in adequate quantity is in contact with every part of the body of fuel, even though distribution is not uniform, it is usually supplied an amount somewhat in excess of that just sufficient for complete combustion.

The latter amount is commonly called the "Theoretical air" and the additional amount is "excess air"

The quickness of ignition and rate of combustion of liquid fuel depend principally on the following factors.

1. The temperature available.

2. The rapidity with which the air and fuel are brought together.

3. The character of surface of the fuel.

4. The ratio of surface area to volume of substance.

5. The rate of diffusion of air to the fuel surface

The process of burning a liquid fuel and mixing it with air at the proper temperature, is attended with more difficulty, as atomization is required

ATOMIZATION

Atomization,the reduction of liquid to a form of spray, is essential for all industrial and engineering purposes.

Atomizes are special nozzles designed to break up a liquid, and direct a spray where it is wanted. They are used in applying paint, spraying fruit trees, combating insect pests, or to break up fuels for burning. Atomized fuels will burn easily, because they offer a large surface area to the oxygen.

Oil Burners for use in Furnaces.

a. The function of an oil burner is not to burn the oil but to prepare it far rapid and complete combustion and to project it into the furnace. The best way to insure complete burning with low excess air is to break up the oil into very minute particles.

Oil burners are therefore designed to atomize, and in some instances to vaporize fuel.

The main requirements of an oil burner are :-

1. To atomize and vaporize the oil completely, and to be free from clogging or "drooling";

2. To produce a jet of such shape that all parts can be readily mixed with adequate air for combustion;

3. To give complete combustion with minimum excess air over the entire range of loading;

and 4. To provide accessibility and require a minimum of attention and cost of maintenance.

OIL BURNERS.

The primary purposes of an oil burner are to atomize the oil thoroughly and to prepare it for intimate mixing with air. The combustion of the plant, the furnace design, the cost of the installation, and the type of oil used should govern the choice of burner. Burners should be simple in design, difficult to clog, easy to clean, and should require but little expenditure for maintenance. The efficiency of a burner may be considered from either of two viewpoints.

First, the amount of steam or power required to atomize a given quantity of oil, and

Second, the degree of subdivision produced in the oil. Increased subdivision or atomization usually permits the use of less excess air which in addition, usually results in lower stack temperatures.

Oil burners may be divided into four main groups:

1. The spray type, in which the oil is divided into a fine spray by the action of an atomizing agent, steam or air;

2. The rotary type, in which the oil drops into the inner section of a revolving hollowcone or plate and is atomized by the action of centrifugal force.

3. The mechanical type, in which the oil under high pressure is atomized by being forced through small slots; and

4. The vapor type, in which the oil is vaporized by heat.

1. Spray-Type Burners.- The spray-type burners, in which the oil is sheared by the action of an atomizing agent, may be further subdivided into inside-mixing and outside-mixing types. Either of these types may use high or low-pressure air or dry steam. Also in either case the shape of the spray may be either flat or conical, depending on the design of the burner. Conical sprays are to be preferred, as they permit, to a greater extent, the intermixing of the oil and the air required for combustion. in a given burner, increasing the amount of steam or air used for atomization improves atomization, shortens the flame, and decreases the tendency to smoke.

A burner of the inside-mixing type is shown in Fig. I. The air or steam for atomization enters through the nozzle A and mixes with the oil in the chamber C. The resulting mixture passes out of the orifice D. in the form of a fine spray, due to the expansion of the steam or air. This type of burner gives best results with the atomization agent at pressures of 40 lb. per sq.in.

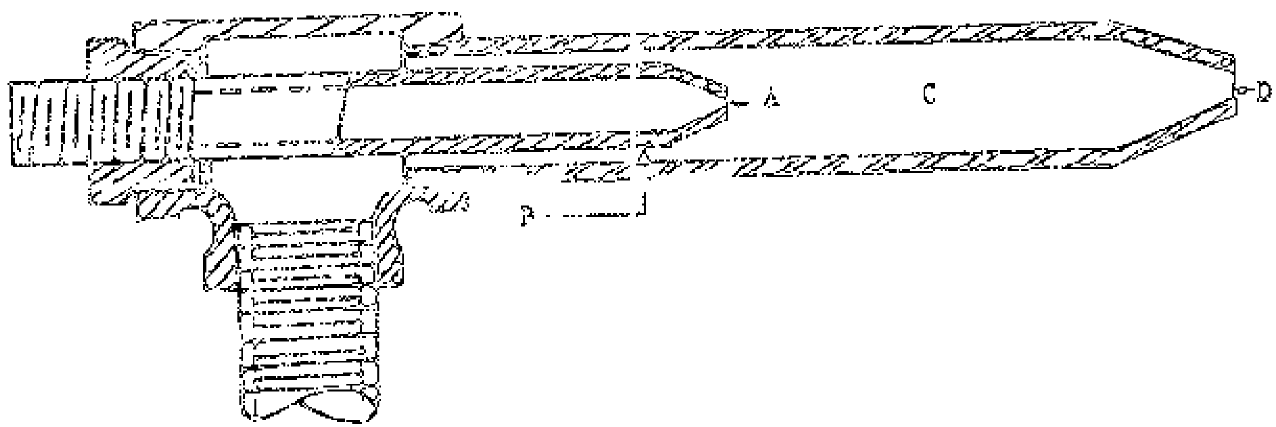


Fig. 3 Inside-mixing type of oil burner.

or above. Although simple to construct and operate, this type is suitable for thin (or high Baumé),clean oils only, due to a tendency for the orifice to clog. The oil supply is regulated by needle-valve adjustment on the oil-feed line. With burners of the steam-atomization, inside-mixing type, the oil does not have to be heated to such an extent as with either the outside-mixing type or the mechanical burner, since a large amount of heat in the steam for atomization is available for heating the oil before the oil-steam mixture leaves the burner.

In the outside-mixing type of burner, shown in Fig.2,oil flowing out through the wide slot B. is sheared by the action of the atomizing agent from the slot A. These burners operate best with steam pressures (2 to 5 lb. per sq.in.) This type is well adapted for use with heavy-residue oils as well as with light distillates.

Choice of atomizing agent.

a. Air atomizing burners are frequently used where a short, intense flame, is required or where ease of regulation is essential. In steam-atomization systems, on account of the high steam pressures required, a small change in the setting of a regulating valve makes a large change in the amount of atomizing agent admitted. With air, or the other hend, particularly with low pressures, a small change in a valve adjustment brings about a relatively small change in the amount of air admitted and close adjustment of the burner is, therefore, possible.

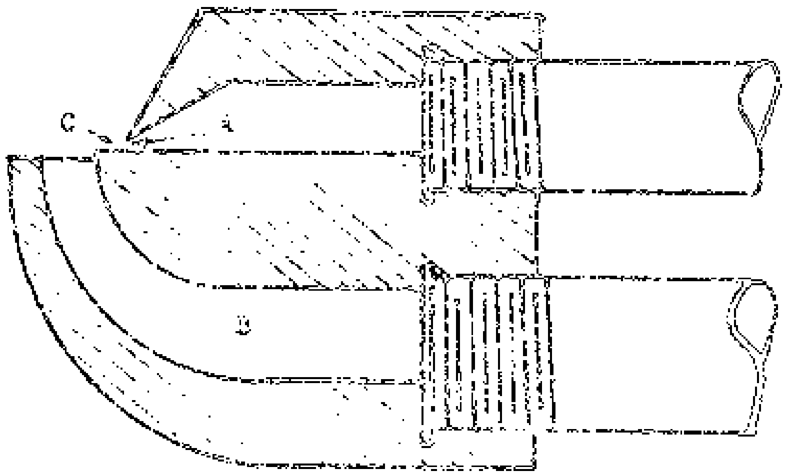


Fig. 2 Outside-mixing type of oil burner.

Air atomization.

Air-atomizing burners may be divided into low-pressure burners, in which air from a fan or positive blower is supplied at pressures from 8 oz. per sq. in. up to 2 lb. per sq. in.;and high-pressure burners using air under pressures from 50 to 80 lb. per sq. in. the low-pressure burners have the advantage that a large proportion of the air for combustion is supplied by the atomization air.

The big field of usefulness for burners using low-pressure atomizing air is in small industrial furnaces where the oil consumption is low, where a short flame is required and close control is necessary.

High-pressure air atomizers (40 to 50 lb. per sq.in.) are very efficient, though the compressors are expensive and have high operating costs. High-pressure air is usually used for atomization of oil only when air is already available, due to other requirements of the plant.

b. Steam Atomization.- Steam-atomizing burners are generally used in medium-sized installations where steam is available. The steam must be dry, since slugs of condensed water from wet steam interfere with the continuous operation of the burner. Steam atomizers have the advantages of simplicity, low first cost, and ease of operation.

The disadvantages of burners using steam atomization are:

1. They cannot be used small flames (which are liable to be put out by the steam);

2. with wet steam, slugs of water cause a sputtering flame;

3. there is an extra loss of sensible heat up the stack, carried by the uncondensed steam used in atomizing;

4. too much steam is often used, since the extra steam reduces the tendency of the flame to smoke;.

2. Rotary Burners.- In rotary-type burners the oil drops into the inner section of a revolving hollow cone or at the center of a revolving saucer-shaped disc. This cone sometimes forms one end of a hollow shaft on which a fan may be mounted. Oil passes from the pump through the hollow shaft to the revolving saucer or cup shown in the Fig 3. When the shaft rotates rapidly the oil flies out radially in small droplets and is further atomized by a blast of air from the fan. A direct-connected fan is commonly used, and the whole apparatus, including pump, fan, motor and burner, is often mounted as a single unit. These burners are adapted for use under low-pressure boilers (where the steam pressure is to low for steam atomization) or where cleanliness and compactness are more important than economy. The efficiency of the rotary-type burner frequently is low, due to the large excess of air required to keep the flame free from smoke (200 to 300 per-cent) but the ease of operation and their ability to handle small loads, and a low first cost sometimes make their installation advisable. However, some rotary burners are more efficient than just indicated; is fact, their efficiency may be made equal to that of any other type.

3. Mechanical Spray Burners.- In the mechanical spray type of burner the atomization is due to the motion imparted to the oil

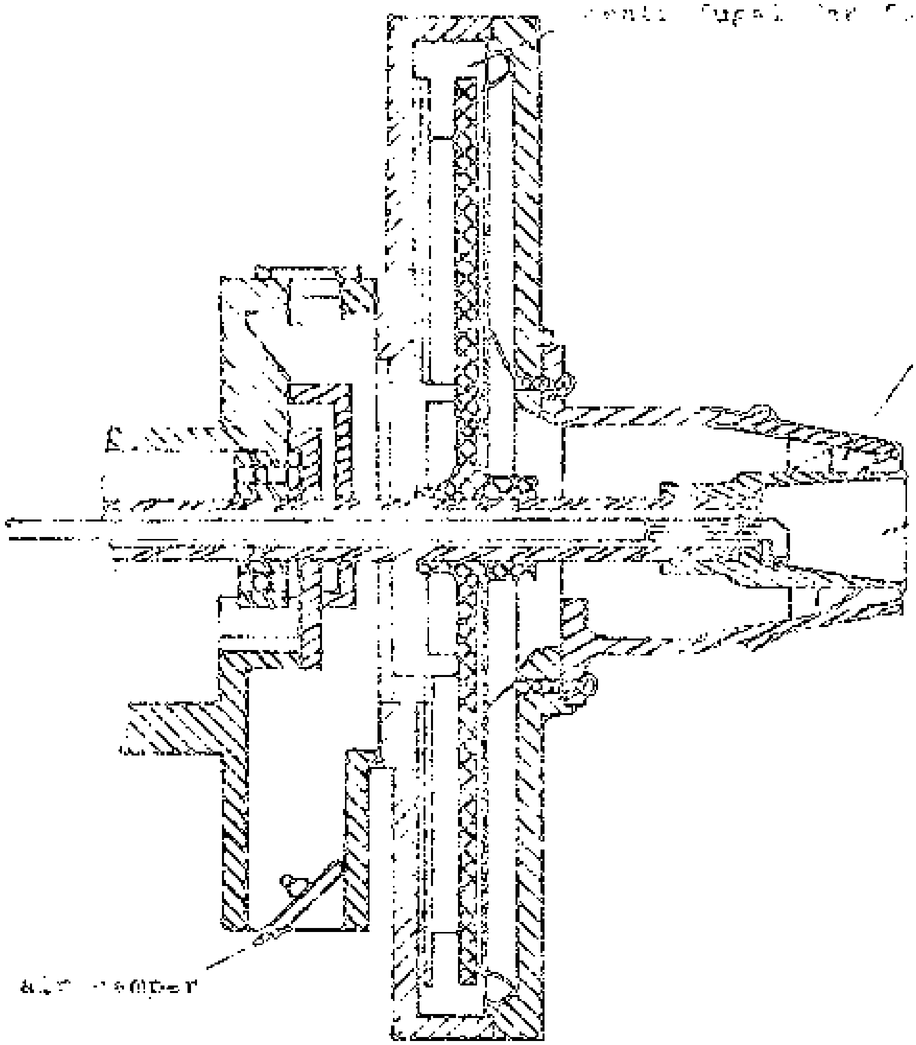


Fig.3 Rotary type oil burner

in passing tangentially through small orifices at high pressures and temperatures. The atomization is the result of a series of actions;

a. atomization by the friction as the oil comes out the small orifice.

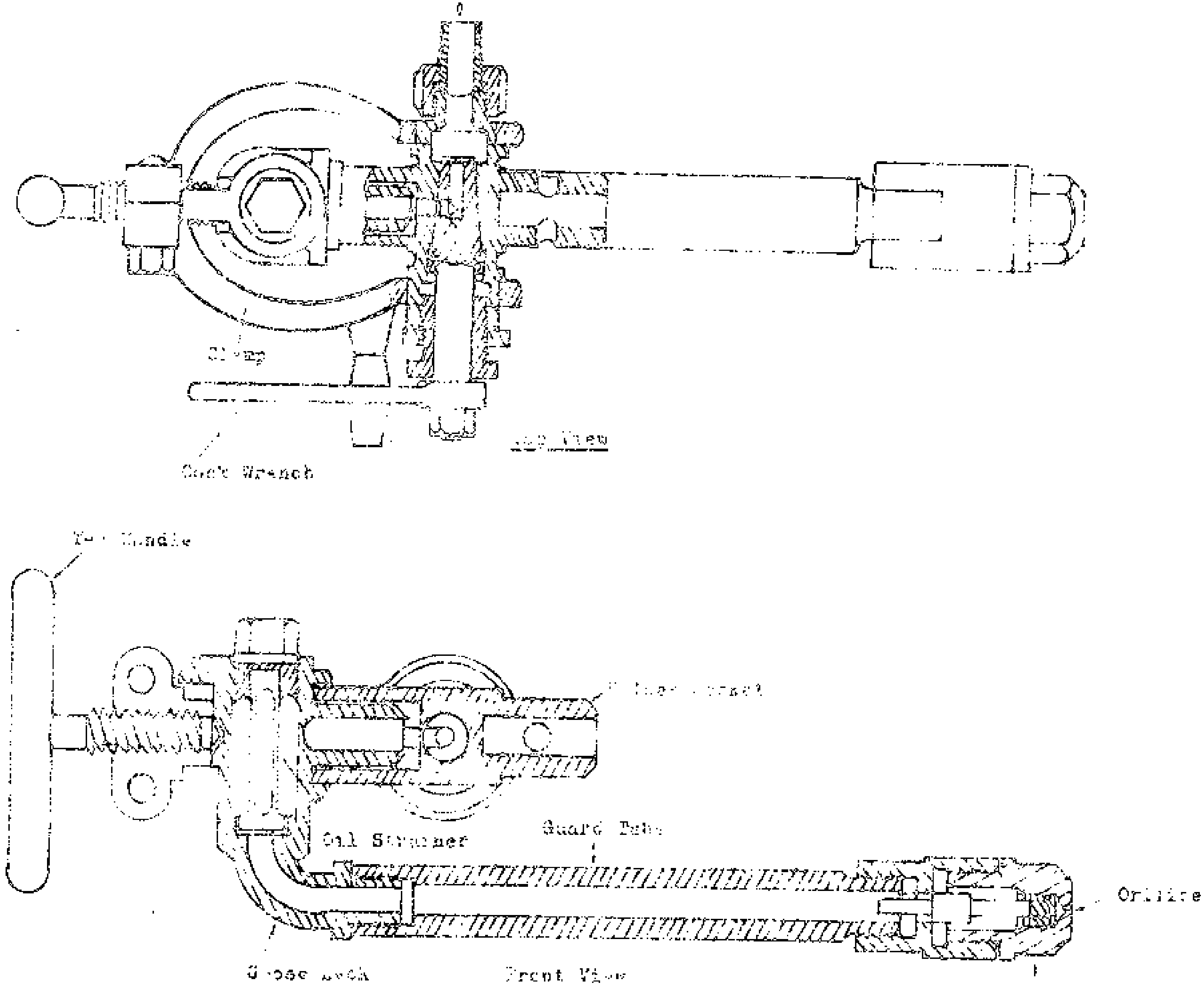
b. the "flashing" into vapor of a part of the heated oil as the pressure is suddenly reduced, and

c. atomization due to a centrifugal motion imparted to the oil, usually obtained by passing it through tangential slots inside the burner.

Because no air is used for atomization, and since good mixing of the oil spray and air is essential, the air necessary for combustion is blow through an air pipe or register surrounding the burner. These registers are used both to control the amount of air admitted and to give the oil a whirling motion.

A mechanical burner with a given size of orifice opening usually has a rather limited capacity range. With a fixed orifice the only method of changing the rate of oil flow is the oil pressure, shown in Fig. 4. A substantial drop in oil pressure decreases the output only to a small extent; for example, with a burner having an orifice 1.75 mm. in diameter, decreasing the oil pressure from 200 to 100 lb. per sq. in. only decreases the burner capacity from 385 to 300 lb. oil per hr. Therefore, the usual method of regulating the flow of oil is either to turn on or to turn off individual burners or to change to an orifice of different diameter.

Mechanical atomization was formerly used only in marine work


Cock Wrench
Oil Strainer
Guard Tube
Orifice
Front View

where the distilled water used for making steam had to be condensed andrecovered. This method is now being used quite widely in land boiler furnaces and high efficiencies are being obtained.

The advantages of the mechanical spray type of burner are:

a. No high pressure air or steam lines are required for atomization,

b. high efficiencies at high capacities are possible (due to a large extent to proper admission of air through air registers),

c. the flame is shorter than with steam-atomized burners and therefore the combustion space may be smaller.

d. mechanical atomization requires less work than atomization by either steam or air,

e. there is less maintenance cost for the burners.

Against these must be balanced the following disadvantages:

a. the installation of mechanical atomizing equipment is more expensive than for other types, due to the extra strength of piping, pumps, etc. required to withstand the high pressure,

b. they are not as flexible as other types, and

c. clogging of the burner tip, due to carbonization of the oil or to the small size of the orifice, is liable to make frequent cleaning necessary. To help overcome this last difficulty extra-heavy strainers with small opening should be installed. The burner tips may be cleaned by blowing steam through them.

4. Vapor-Type Burners.- In the vapor-type oil burners the oil is vaporized (not atomized) in a stream of preheated air these burners have been used with forging, annealing, and tempering

furnaces, or in general, where the stack temperatures are high and air recuperation (in order to preheat the air sufficiently for vaporization of the oil) is possible. This type of burner is not suited for boiler or large furnace work.

The Burning of Oil in High-Speed Engines.

High-speed engines are required in airplanes, automobiles, trucks, speed boats and other forms of transportation, because high speeds reduce the weight per unit of power and ,furthermore the cost is also reduced when the weight is kept reasonably low, provided large numbers of the same size and type of engine are manufactured.

The carburetor type of engine has been developed to a very satisfactory standard today and is the one used for the great majority of automotive engines. The high speed, ease of control, high mean effective pressure, fuel economy and general reliability of this engine afford remarkable evidence of the excellent development work that has been done, especially within the past twenty years. One the other hand, the carburetor type of engine cannot use heavy oils nor can it employ as high a compression ratio as the engine that injects the fuel into the cylinder at or near the end of the compression stroke.

Since the compression ratio is always a factor in the thermal economy of any internal combustion engine, regardless of what cycle is employed, engineers naturally try to develop the high speed engine having sufficient compression to produce auto-ignition of the fuel very soon after its injection,. If this type of engine is to run at high speed many new problems regarding the injection of the fuel and its combustion are involved, because the time available for these processes becomes so very short.

The name that should be given to the internal combustion engine using auto-ignition of the fuel sprayed into the cylinder by means of a high-pressure pump is somewhat debatable at the present time. Such terms as "solid-injection," "compression-ignition" (C.I.) and "Diesel" are applied by various engineers. The objections to designating such an engine as a "Diesel" are:

1. Auto-ignition or oil fuel injected into a hot chamber by a pump at the end of the compression stroke was first used in an engine developed by Ackroyd Stuart in 1890, several years ahead of Diesel's engine.

2. Compressed air was the only successful means of fuel-injection developed by Diesel.

3. The cycle used in high speed injection engines is the dual-combustion one instead of the Diesel.

4. Confusion is caused by employing the term "Diesel" to cover a much wider field than appears justifiable.

The modern high-speed oil engines are largely employing "airless injection" of the fuel, first used by Ackroyd-Stuart. Furthermore, many of the late engines employ and auxiliary bulb or chamber into which the fuel is injected, as was done in the Ackroyd-Stuart engine. Thus, there seems to be small justification for using the term "Diesel" to apply to all modern oil-injection engines.

The injection nozzles are designed to form the fuel into a very fine spray and distribute this spray throughout a definite portion of the combustion chamber. The nozzle requirements are naturally somewhat different for various cases. These nozzles are often called injection valves, also spray valves or nozzles, and sometimes simply injectors. They are divided into two general classes designated as the open and closed types.

The open nozzle has no means provided within it to stop the flow oil into the cylinder, but it should contain a check valve, as shown in Fig. 5, to prevent the entrance of gases from the cylinder; in other words, it is always open to the cylinder except when the check valve is closed, and the flow of oil through and open nozzle must be therefore entirely controlled by the pump, or by special mechanically operated timing valves in a common-rail system.

The closed nozzle contains a spring loaded valve that may be opened either mechanically of automatically, the latter by the fuel pressure when sufficiently high. The principle of operating a closed nozzle automatically shown in Fig. 6. The spring is adjusted so that the desired pressure of oil will just suffice to open the valve. After the valve has started to open, the area on which the oil acts is then increased slightly; hence a pressure wave coming through the pipe line from the pump or from a common-rail system will open the valve very quickly. When the closed automatic nozzle is used with the common- rail system, one or two mechanically operated valves are essential to control the time during which the high-pressure oil is acting on the nozzle. If only one mechanically operated valve is employed the injection

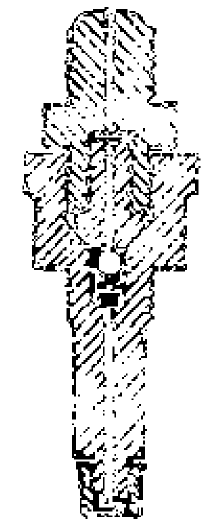


Fig 5 An Open Nozzle.

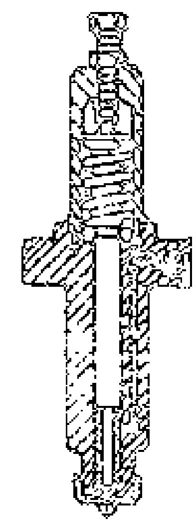


Fig.6 A Closed Nozzle.

nozzle will open when this valve admits the high-pressure oil and will remain open after the valve has closed until the spring pressure overcome the oil pressure remaining in the tube. Sometimes a second mechanically operated valve is employed to release the oil pressure on the nozzle which is then sure to have a sharp cut-off.

The great advantage of the closed type of nozzle is the prevention of dribbling or dripping of the oil after the injection is supposed to stop. Thus a more definite control of the injection period is obtained than is possible with the open type of nozzle which permits dribbling as long as the pressure in the oil line is greater than that in the combustion chamber.

The closed nozzle also has the advantage of giving more nearly a uniform spray during the entire injection period, because the oil pressure on the nozzle is high during this entire period. On the other hand, the open nozzle generally has its flow controlled entirely by the pump, and the start and finish of each injection are at lower pressure and the resultant spray at these times may be poor. Furthermore, when the engine is running at low speeds the spray from the open nozzle is much coarser than it is at full speed.

The open nozzle has the advantage of extreme simplicity and generally greater freedom from trouble due to air in the pipe line than the closed nozzle. The closed nozzle must be very carefully designed and manufactured; it must also be maintained in excellent condition, otherwise the high-pressure oil will leak past the valve, and this will soon prove to be a very serious trouble.
