Chapter II

EXPERIMENTAL STUDIES

2.1 Description of apparatus

Fig.1 shows schematic diagram of instruments used. The objective was to provide an apparatus for the investigation of performance and exhaust emissions of a diesel engine when running on a combination of diesel fuel and commercial gas. The principal parts were the single cylinder Kubota diesel engine coupled to the dynamometer on the test bed, the nondispersive infrared gas analysers and the smoke meter to evaluate the components of exhaust gas and smoke concentration.

The air drawn in by the engine was passed through an orifice meter(1) and the surge tanks(2) in order to reduce pulsation effect from engine suction. The gaseous fuel was metered by choked nozzle(12), and was added to the inlet air maifold at the mixing tube.

The high pressure gas supply, after passing through a pressure regulator, was led to the engine through a system of control valve. The gas expanded through the choked nozzles where its flow rate was measured. Two metering circuits for high and low gas flow rate were provided.

The exhaust gas temperature was measured by a mercury thermometer (0 - 1200°F) at a point approximately 4 in. from the engine,(9) and was tapped to the nondispersive infrared

Schematic diagram of the general layout of apparatus

1 Orifice meter.
2 Surge tank.
3 Fuel injection pump.
4 Engine.
5 Fuel injector.
6 Electric dynamometer.
7 Brake reading.
8 Tachometer.
9 Exhaust thermometer.
10 Inlet air thermometer.
11 Gas thermometer.
12 Metering choked nozzle.
13 Pressure gauge.
14 Gas control valve.
15 Pressure regulator.
16 Gas supply cylinder.
17 Fuel tank.
18 Fuel oil measuring flask.
19 Exhaust tapped valve.
20 Exhaust muffler.
21 Smokemeter sampling probe.

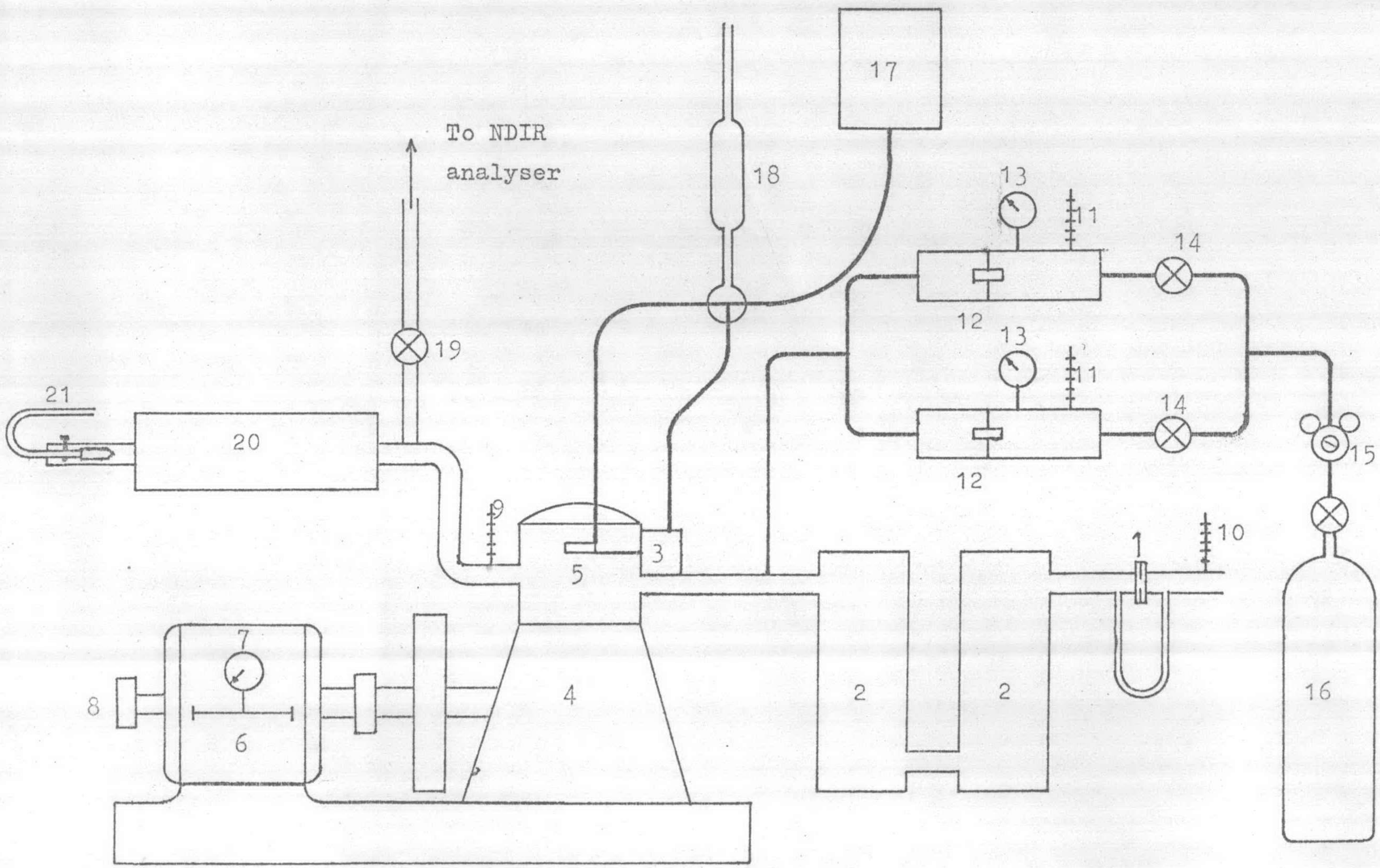

Fig.1. Schematic Diagram of the General Layout of the Apparatus Employed.

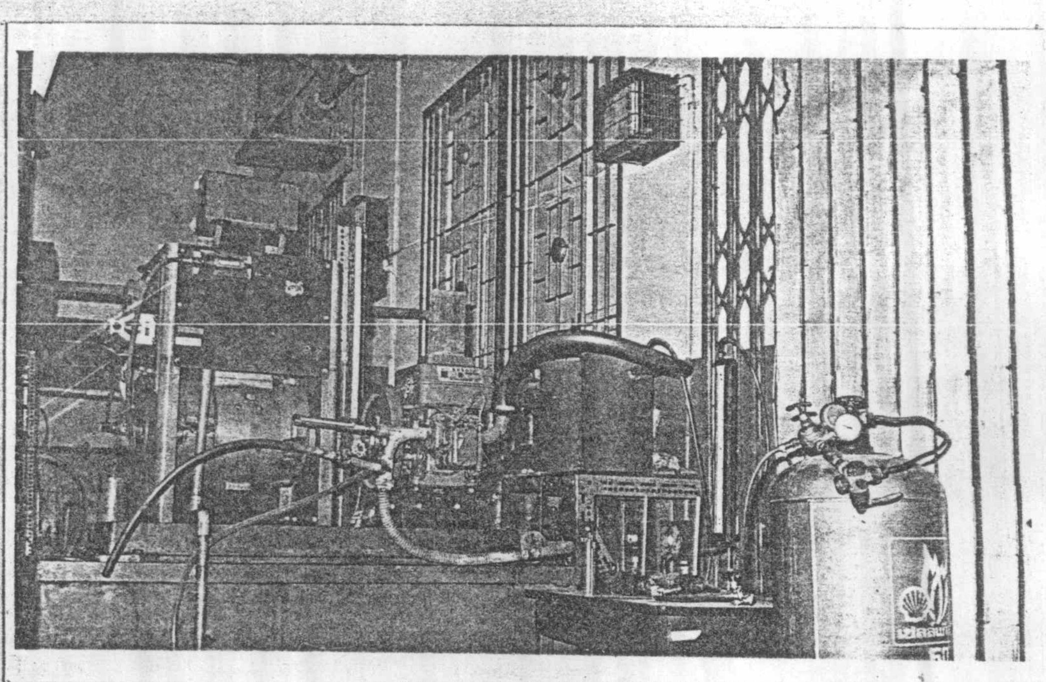

Fig.2. Photograph of the Kubota KND 3 Engine Setup

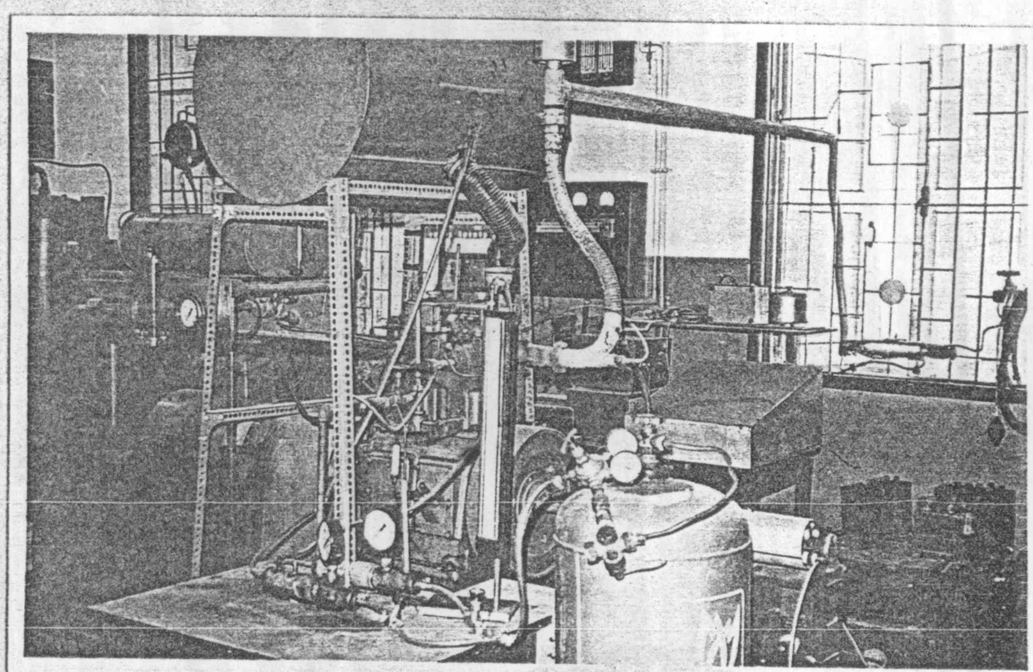

Fig.3. Photograph of the Petter AV 2 Engine Setup

gas analysers for measuring the exhaust gas emissions. At the end of the exhaust pipe a Bosch smoke meter probe(21) was inserted for measuring smoke density of the exhaust gas.

2.1.1 Engine and dynamometer

The engines used in this investigation were four-stroke Kubota KND-3 and Petter AV-2 engines. The Kubota KND-3 is a single cylinder of 2.68 in. bore and 2.95 in. stroke, swirl type with a compression ratio of 22 to 1. The engine cooling water is of a boiling type. In order to maintain the water temperature at 212°F the water level in the cooling water hopper was kept constant. The engine speed was controlled by a speed control adjusting screw for precise adjustment which was inturn connected to the governor spring.

The engine was coupled to a DC electric dynamometer, Plint & Partner, 4 horsepower test bed, which can act as a motor when starting. Also the engine can be started by hand wheel which is more convenient. The engine load was controlled by varying a rheostat in series with the field of dynamometer. A linkage attached to the dynamometer provided measurement of power output of engine by measuring brake load on a spring balance. The brake horse power of engine could be easily obtained from the dynamometer expression:

$$P = WN/6000$$

where, P = Power in horse power; W = Brake reading in lbf
N = Engine speed in rpm.

The Petter AV-2 engine has two cylinders, with 3.15 in. bore and 4.33 in. stroke, direct injection with a compression ratio of 16.5 to 1. The engine was kept running at a constant speed of 1500 rpm by presetting the speed governor. The cooling water was circulated by a water circulating pump, the flowrate was controlled by a gate valve to keep outlet water temperature at 160°F.

The engine was coupled to a DC electric dynamometer of Plint & Partners, 12 horse power test bed. The dynamometer can act as a motor to start the engine by switching the control board switch to start position. The engine load was controlled in the same manner as that of the Kubota's. The dynamometer expression for measuring power output of engine is as follow

$$P = WN/5000$$

where P = Power in horse power

W = Brake reading in lb_f

N = Engine speed in rpm.

2.1.2 Fuel consumption

The fuel supply system to the engine for diesel oil and gaseous fuel was separately controlled. The diesel oil consumption was measured by volume through a measuring flask which have been calibrated in 25,50 and 100 cc. The time used for the amount of fuel to be consumed was recorded by a stop watch. The fuel oil specific gravity was found to be 0.825 at running temperature, this value was used in computing the consumption of fuel in lb_m/min. The gaseous fuel consumption was mixed with the intake air and its measurement was effected by choked-nozzle flow meter, the upstream pressure and temperature of gaseous fuel was recorded and used as a parameter to indicate flowrate in lb_m/min. which can be read directly from calibration curve in Fig.B - 4 of Appendix II.

2.1.3 Surge tanks and orifice meter

Air consumption of engine was measured by using an orifice meter which was fitted to surge tanks before connecting to the intake air manifold. Since orifice is usually used in a steady flow system, therefore surge tanks are employed in order to iron out the pulsation pressure caused by engine suction in inlet piping. The orifice meter must be fitted on the upstream side of surge tanks whereas the other end of the tanks was connected to the intake air manifold, as seen in Fig.4. For single-cylinder engines, two inlet surge tanks are required and each should have volumetric capacity greater than 50 times[1] of engine cylinder volume. In this test surge tanks were constructed to have a magnification of 60.

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[1]Taylor Charles Fayette, The Internal Combustion Engine in Theory and Practice (The M.I.T. Press), II, pp. 611.

The assembly of the square edged orifice used for Kubota engine was shown in Fig.5. Such an orifice design may be found in many fluid meter or fluid mechanics textbooks[2,3] In the present work, the orifice was designed according to the standards of ASME orifices[4] The brass orifice diameter (D_o) is exactly 0.505" with 0.125" thickness. The upstream and downstream pipes are at the same inside diameter (D), being 2.067 in. The pressure taps were provided at two sections across the orifice plate, both at the distance of 1 in. from the orifice plate (flange taps). A U-tube manometer fitting to the orifice meter at the aforementioned pressure taps was provided for registering the differential pressure. This manometer was filled with water(specific gravity is 1 at 60°F) and could be accurately measured within 0.05 in. H_2O. Details for calibrating the orificemeter can be found in Appendix II.

For the Petter AV-2 engine, the air flow consumption was also calculated from an orifice meter. The standard thin plate orifice of diameter 0.996 in. and coefficient of discharge 0.6 was fitted on a surge tank of about 480 times cylinder volume. The pressure differential or the pressure

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[2]R.L. Daugherty, and J.B. Franzini, Fluid Mechanics with Engineering Applications (6th ed., New York: McGraw-Hill, Inc., 1965), pp. 356-59.

[3]V.L. Streeter, Fluid Mechanics, (4th ed., New York: McGraw-Hill, Inc., 1966), p. 431.

[4]Bean S. Howard, "Fluid Meters Their Theory and Application" ASME (6th ed. 1971), pp. 198-209.

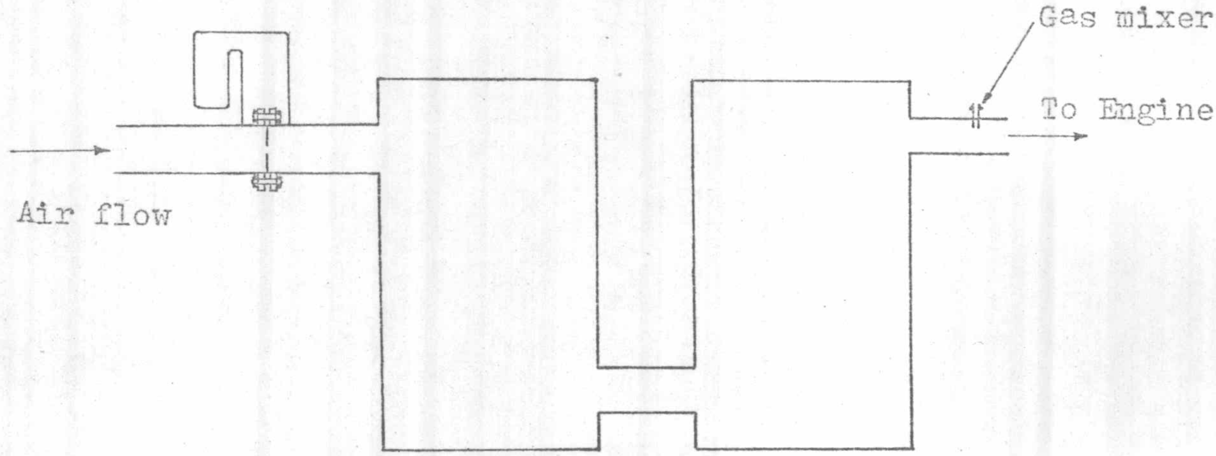

Fig.4. Surge Tanks and Orifice

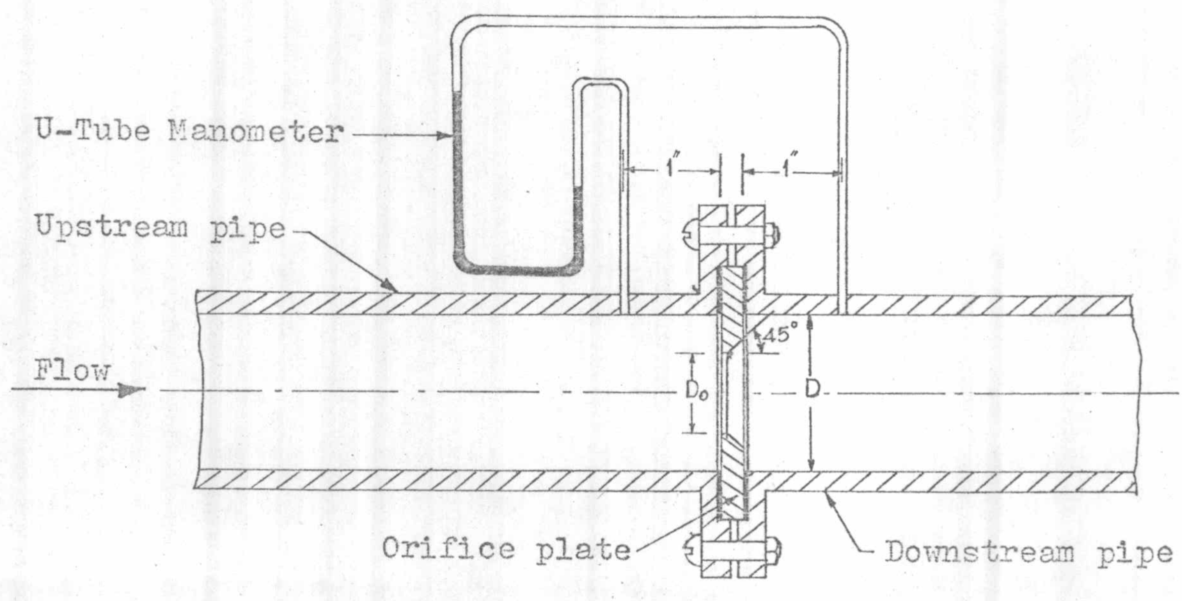

Fig.5. Orifice Meter Assembly

D - Inside pipe diameter

D_O- Orifice diameter

drop across the orifice was measured by an inclined manometer with a range of 0-5 in.H_2O. This manometer is filled with water and can measure within 0.05 in. accurately.

2.1.4 Choked nozzle flowmeter

The choked nozzle flowmeters were selected for measuring gaseous fuel flowrate, as they can not be disturbed by pulsation effect due to engine suction, they are also cheap and convenient to use in laboratory work. The nozzles used for these meters were selected from various sizes of Nissan M3 and Zenith carburettor jets, the Nissan M3 no. 70 and Zenith no. 45 were found to be suitable for the consumption of engines, however, it was necessary to construct a smaller size of nozzle, say no.30, which could not be found in the market.

Fig. 6 shows the assembly of the choked nozzle flow meter, which consists of upstream part (A) and downstream part (B). The nozzle (C) was fastened centrally to the upstream part inside face. The upstream gas pressure and temperature were measured by a Bourdon type pressure gauge, 0-60 lb_f/in^2(D) and a thermometer 0-120°F at bulb (E). The pipe connector to manometer (F) and thermometer bulb (G) were used for measuring the downstream pressure and temperature respectively during calibration. The upstream and downstream parts were designed to have 5 in. long and the same inside diameter of 1.5 in. which is much larger than the throat diameter of nozzle, in order to ensure negligible entry velocity. The downstream part were connected to the upstream part by turning the

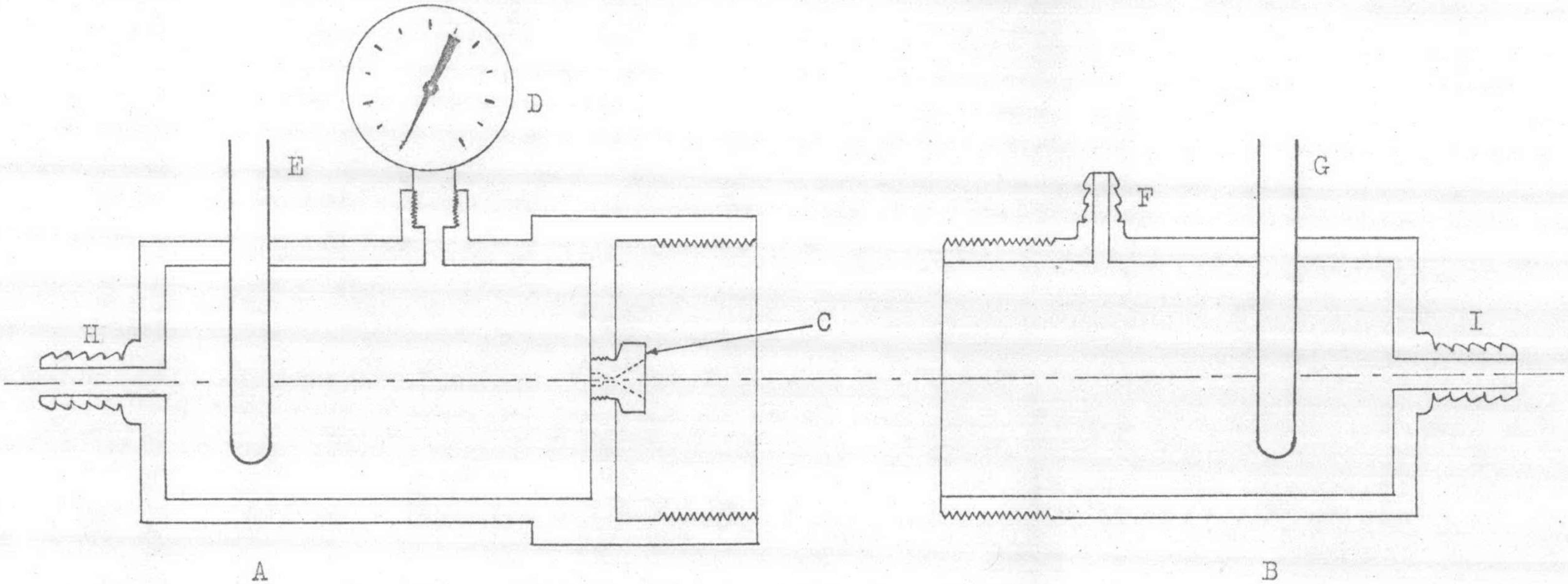

Fig.6. Choked Nozzle Flowmeter Assembly.

A -	Upstream part	D -	Pressure gauge
B -	Downstream part	E,G -	Thermometer bulb
C -	Nozzle	F,H,I -	Pipe connector

thread together, the thread was wound with sealing tape to prevent leakage.

2.1.5 Bosch smokemeter

Smokiness of exhaust gas was measured by Bosch filter type EFAW 65A smokemeter[5](Fig.7). This type of smokemeter is well known for its versatility to measure the exhaust smoke of diesel engines. It consists of two main functional parts, the sampling pump complete with sampling probe and hose which draws off a cirtain amount of exhaust gas from the exhaust pipe. The sampling gas was sucked through a filter paper disk which, inturn, darkens during this process thus giving the measure of the soot content in the exhaust gases. The other part, the evaluating instrument, employs the associated photoelectric reflectometer for assesing the smoke density of the filter paper disk. Reading of the smoke density is done by a microammeter, scaling 0-10 smoke numbers. Rough guide to determine the smoke number[6] is as follows.

No. 1 Invisible.

No. 2 Barely visible smoke.

No. 3 Readily acceptable level.

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[5]A.E. Dodd, and J. Spiers, "Smoke Measurement Instrument and Comparison of Method" Motor Vehicle Air Pollution Control. (I. Mech. E., Proc. 1968-69), vol. 183, pp. 158-60.

[6]"Diesel Exhaust Emissions Reduction by L.P.G. Supplementary Fuelling" Clean Air. (Vol. 3, No. 10, Summer 1973), p. 46.

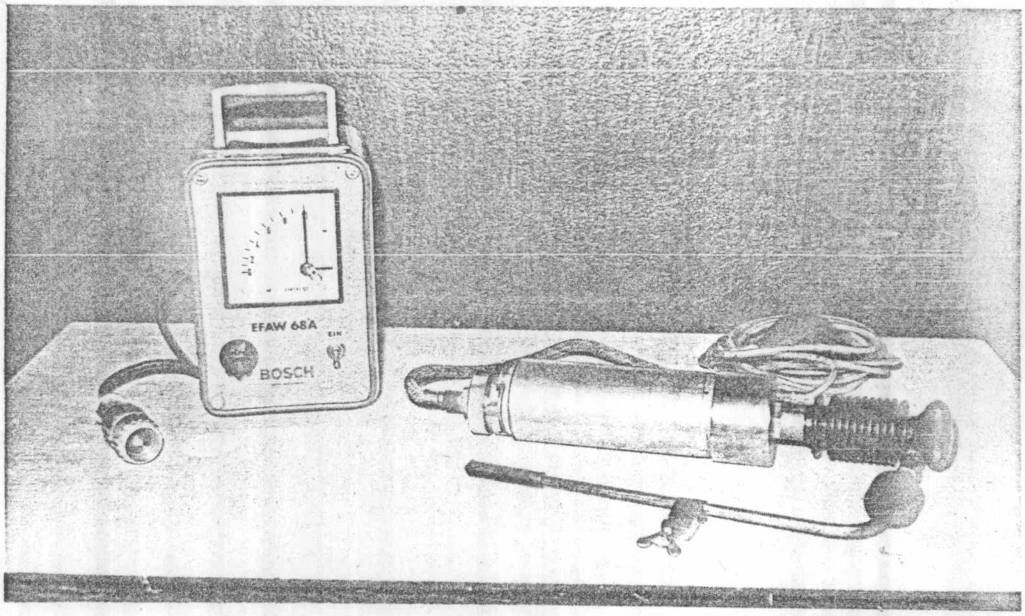

Fig.7. Bosch Smoke Meter Type EFAW 65 A

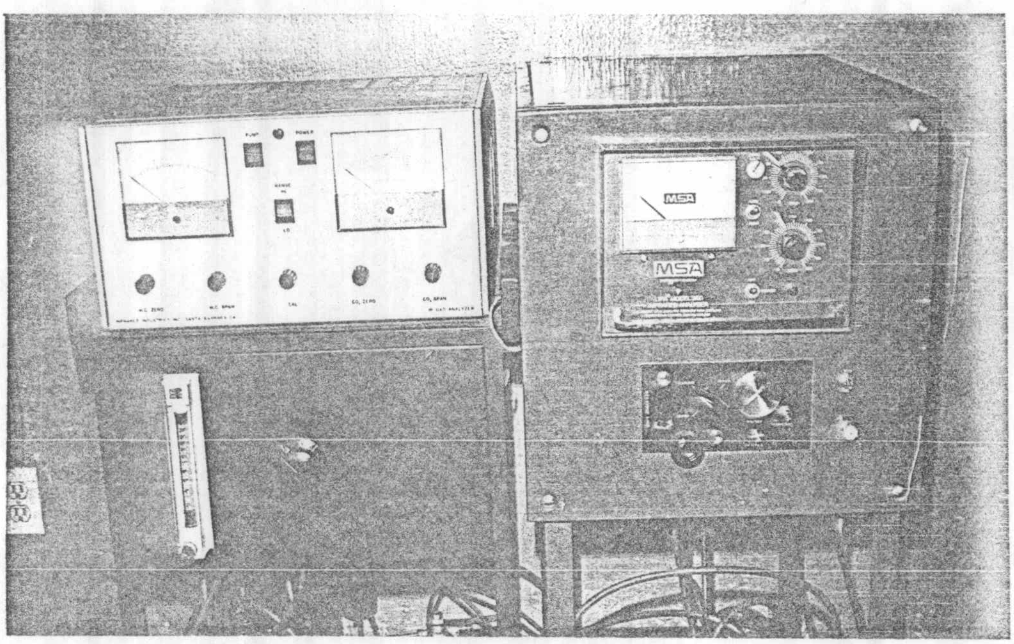

Fig.8. Nondispersive Infrared Analyser for HC,CO_2 and CO

No. 4 Maximum acceptable level.

No. 5 Above acceptable level.

No. 6 Dense black smoke.

No. 7 Choking black smoke.

2.1.6 Nondispersive infrared analyser

Many methods of exhaust gas analysis are available[7] but the choice of method need to be determined depend on conditions and concentrations to be considered. The standard instrument presently used for the testing of the engine exhaust gas emissions are nondispersive infrared analyser. The operating principle of NDIR is shown schematically in Fig.9. The infrared radiation is passed simultaneously through a beam chopper to two cells containing, in one cell the reference gas, and the other, the exhaust gas. Emerging from the cells, the radiation passed into a single detector unit that contains a sealed-in gas. As the gas in the detector absorbs infrared radiation emerging from the exhaust gas has had some of the infrared radiation absorbed by the presence of the gas to be measured, the detector gas is heated resulting in pressure and temperature increases. The increased pressure moves a diaphrem in the detector unit and results in a capacitance change in the detector which is converted to an output signal, providing a

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[7] D.J. Pattersan, and N.A. Henein, Emissions from Combustion Engines and Their Control. (Ann Arber Science, Inc., 1972), pp. 305-12.

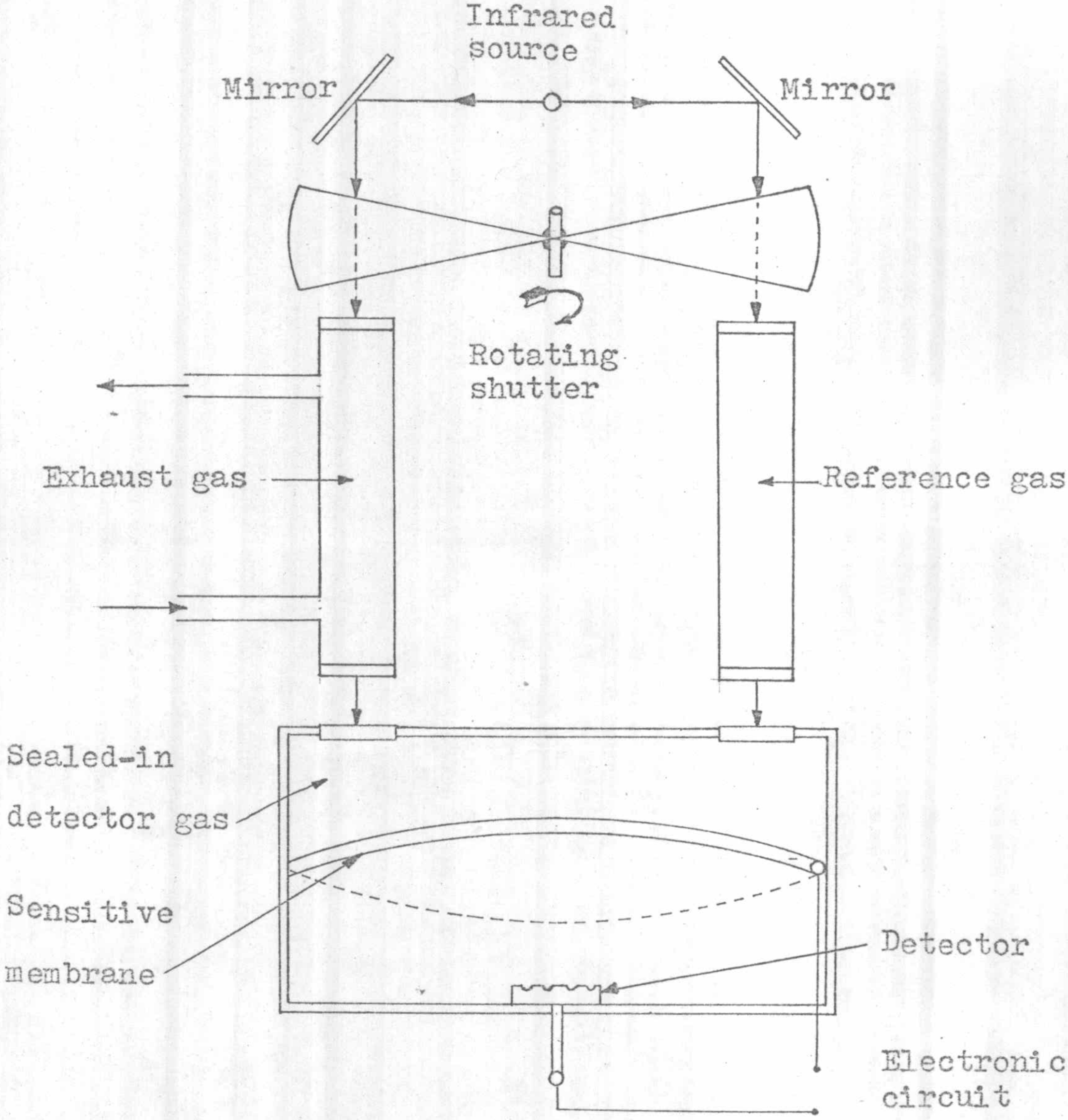

Fig.9. Schematic Diagram of Nondispersive Infrared Analyser.

means of calibrating the amount of the required gas present in the exhaust.

In this investigation, the MSA LIRA infrared analyser model 300, was used for measuring the concentration of CO, and for the concentrations of HC and CO_2 the Infrared Industry analyser model 700 was used, as shown in Fig. 8.

2.2 Experimental procedure

In this experiment the procedure employed could be separated into two parts, namely (1) for Kubota KND-3 engine which was tested at four speed settings: 1200,1400,1800 and 2000 rpm, (2) for Petter AV-2 engine which was tested at 1500 rpm only.

Part 1 In order to compare the performance of pure diesel oil running to dual fuel running, the assembly of test equipments were shown in Fig.2.

Before commencing the experiment, the nondispersive infrared analysers have to be warmed up to reach thermal stability, where drifting is unnoticeable. For the LIRA model 300, CO analyser, it takes about three hours or more to attain thermal steady condition, for HC and CO_2 analyser, stability can be reached within an hour. After steady condition the analysers were checked for zero reading with zero gas (N_2). Also the sampling probe and hose of Bosch smokemeter have to be blown out with compressed air to remove soot particles of previous test which might influence the measuring results. A check can be made by pumping freshair through a filter disk, which must not be darken.

The engine was started by means of the starting handwheel. After warming up the engine to avoid the possibility of a buildup of lubrication oil on the cylinder walls, the cooling water temperature was kept at 212°F constant for all the tests. The test was conducted by first running with pure diesel oil and keeping the speed constant at 1200 rpm, this was done by adjusting the speed control adjusting screw. A 2 lb_f brake load was first applied and varied to a maximum of 10 lb_f with an increment of about 2 lb_f. During the change of loads the speed was found to vary, therefore, it was necessary to readjust speed for every load setting. After the engine steady conditions were maintained, the following reading were recorded:

(1) Inlet air temperature.

(2) Pressure drop across orifice meter.

(3) Engine brake load.

(4) Time in consuming 25 cc. of fuel oil.

(5) Exhaust gas temperature.

(6) Exhaust emissions HC, CO and CO_2.

(7) Sampling the exhaust gas through filter paper disk by sampling pump, the smoke number reading was taken at the end of test.

The exhaust gas temperature and emissions were last recorded in order to allow more time for temperature and emissions to stabilize.

Next the engine was run in combination with gaseous fuel which was added into the inlet air stream. By keeping the choked nozzle (No.30) gas pressure at 12,15 and 20 psig, the amount of gas was constant for each setting of gas pressure. The test was proceeded the same manner as that of pure diesel for each gas pressure setting.

In order to investigate the effect of varying the concentration of gaseous fuel mixing at maximum load, the test was done by keeping the engine load at maximum brake load, 10 lb_f, with speed being kept constant also. Gaseous fuel was gradually increased until the engine started knocking. At each gas pressure setting, all readings were recorded as mentioned above.

The engine was investigated at constant speeds of 1200,1400,1800 and 2000 rpm, respectively.

Part 2 For Petter AV-2 engine the test equipments were shown in Fig.3. The gaseous fuel consumption was much larger than in Part 1, therefore, two nozzles of the three sizes namely No. 30,45 and 70 were used in combination giving higher flowrate of gaseous fuel. Again, the procedure were successively performed like in Part 1.