AIR FLOW VISUALIZATION IN THE CYLINDER OF TWO STROKE ENGINE

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF ENGINEERING

in

MECHANICAL ENGINEERING

(Applied Thermoscience)

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled '**AIR FLOW VISUALIZATION IN THE CYLINDER OF TWO STROKE ENGINE**' in partial fulfilment of the requirements for the award of the degree of **Master of Engineering** in **Mechanical Engineering** with specialization in '**Applied Thermoscience**', submitted in the Mechanical & Industrial Engineering Department, University of Roorkee, Roorkee is an authentic record of my own work carried during the period from August 1988 to August 1989, under the supervision of Dr. Pramod S. Mehta of Mechanical & Industrial Engineering Department, University of Roorkee, Roorkee and Dr. B.P. Pundir of Engines Laboratory, Indian Institute of Petroleum , Dehradun.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Dated : Sept. 18, 1989

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

The performance of small two stroke, crankcase scavenged, spark ignition engine depends very largly on the effectiveness of scavenging the cylinder and on the amount of fresh charge retained during the scavenging process. This thesis discusses various techniques for study of air flow in the cylinder of a two stroke engine and analysis of different features of scavenging flow.

A technique was developed for visualization of air flow in the two-stroke engine cylinder. Video Camera has been used to record the air flow pattern. Aluminium foil tracer particles were introduced in a transparent engine cylinder in which dynamic scavenging process is simulated. The effect of piston crown shape and crankcase pressure has been studied on flow pattern.

C O N T E N T S

NOMENCLATURE

V_{del}	Volume delivered
V_{disp}	Volume displaced
V_{ret}	Volume retained or trapped
V_{res}	Volume of residual gas
L	Delivery ratio
η_{sc}	Scavenging efficiency
η_{tr}	Trapping efficiency
η_{i}	Indicated thermal efficiency based on fuel retained
F	Fuel-air ratio
Q_{c}	Heating value of fuel
r	Compression ratio
ρ	Density
ρ_{s}	Density of dry air in inlet mixture at inlet temperature and exhaust pressure

Subscripts

i	Inlet conditions, indicated
NTP	N.T.P. conditions

CHAPTER - I

INTRODUCTION

The two stroke engine is simple in arrangement but its working process is difficult to analyse and improve.The time available for exhaust scavenging and charging the cylinder with fresh fuel-air mixture is relatively short due to high engine speeds.

One of the characteristic features of the two stroke cycle is overlapping of the cylinder filling phase by fresh charge with exhaust phase of burned gases.This situation leads to an inevitable loss of fresh mixture through the exhaust port during scavenging process.Thus, the indicated output and fuel consumption of a two stroke engine is primarily dependent upon the success with which the product of combustion are exhausted and are replaced by fresh charge during the scavenging period.

Fig.1 shows the pressure crank angle diagram for a two stroke engine. After the exhaust port opens,the cylinder pressure falls rapidly in the blow down process. After the blow down, cylinder pressure usually falls below exhaust pressure for a few crank angle degrees because of the inertia of the gases.Soon after the opening of the exhaust port, the transfer port also begin to open.In this period, as soon as cylinder falls below the crankcase (scavenging) pressure, fresh charge flows into the cylinder.The inlet flow continues as long as transfer ports are open and total pressure at intake of cylinder remains higher than cylinder pressure. While gases are flowing out of transfer ports, exhaust gases exit from the exhaust ports. The duration for which both the ports are open is called the scavenging period. The fig.2 is the diagramatic representation of the charging process in a two stroke diesel engine[1].This diagram is also applicable to carburetted engine as instead of air, air fuel mixture is supplied to these engines. The hatched areas represent the combustion gases. The width of the channels represent the quantity of the gases expressed by volume at NTP conditions.

In the analysis of scavenging process in two stroke engines,several terms are used. Some of the important terms are defined below:

Delivery Ratio

It is the ratio of air/mixture quantity supplied to the cylinder to the engine displacement.

$$\text{Delivery Ratio, } L = \frac{V_{del}}{V_{disp}}$$

Trapping Efficiency

It is the ratio of air/mixture trapped in the cylinder to air/mixture delivered . It indicates what portion of the air/mixture delivered , is trapped in the cylinder, the rest being wasted through the exhaust.

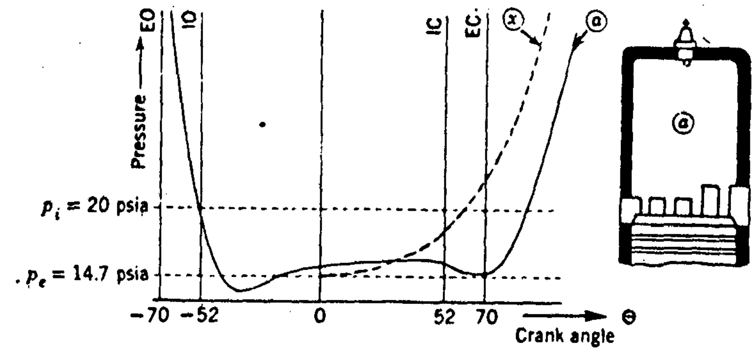


Fig 1— Light-spring indicator diagram for a two-stroke engine: (*a*) 4.5 x 6.0 in loop-scavenged type (*a*) cylinder, piston speed 30 ft/sec, r = 7.0, R_s = 1.4; (*x*) adiabatic compression from p_e at bottom center.

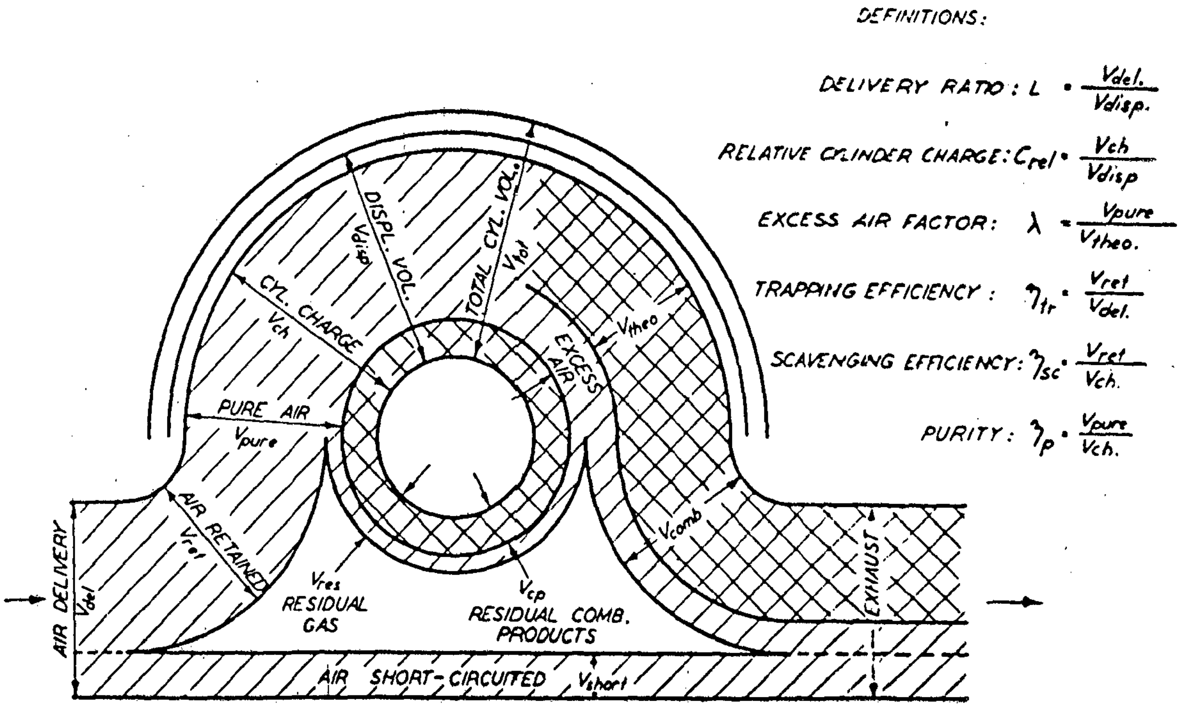


Fig. 2— Diagram Showing the Charging Process of an Internal Combustion Engine. The diagram represents either a two-stroke cycle engine or a four-stroke cycle engine with considerable valve overlap. In a four-stroke cycle engine without valve overlap, the air short-circuited V_{short} is zero, and the area below the dash line is missing. *All volumes refer to N.T.P. conditions.*

$$\eta_{tr} = \frac{V_{ret}}{V_{del}} = \frac{V_{del} - V_{short}}{V_{del}} = 1 - \frac{V_{short}}{V_{del}}$$

Scavenging Efficiency

It is the ratio of air /mixture trapped in the cylinder as defined by Schweitzer (1).

$$\eta_{sc} = \frac{V_{ret}}{V_{charge}} = \frac{V_{ret}}{V_{ret} + V_{res}}$$

It express the measure of the cylinder in clearing the cylinder residual gases.

The scavenging efficiency defined by Taylor [2] is

$$\eta_{sc} = \frac{\text{Mass of fresh charge retain}}{\text{Mass of fresh charge that will fill the cylinder volume at inlet temperature and exhaust pressure}}$$

Scavenging Ratio

It is the ratio of mass of air/mixture delivered to the mass of air/mixture of displacement volume at inlet density (ρ_i).

$$Rs = \frac{V_{del} \cdot \rho_{NTP}}{V_{disp} \cdot \rho_i} = L \cdot \frac{\rho_{NTP}}{\rho_i}$$

Ideal Scavenging Process

This process assumes that product of combustion are displaced without mixing , by the incoming charge and are completely scavenged.

Perfect MIxing

It assumes that each incremental volume of inflow is completely mix with the cylinder contents and displaces an equal volume of mixture out of exhaust.This assumption results in classical exponential relationship between scavenging efficiency and scavenging ratio:

$$\eta_{sc} = 1.0 - e^{-Rs}$$

Perfect Short-Circuting

It results when the scavenging stream proceeds directly out the exhaust without any fresh charge retained in the cylinder.

Real Scavenging

It consists of some combination of the above idealized process.

Figure 3 shows the variation of scavenging efficiency with change in scavenging ratio with when scavenging follows theabove mention paths i.e.perfect mixing,perfect short-circuiting etc.

The scavenging process is affected by port geometry and timing, piston and cylinder head shape,delivery ratio,exhaust

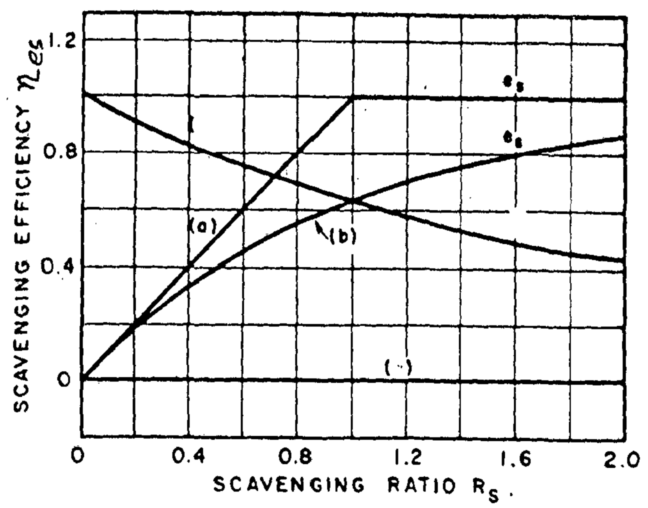


FIG- 3 Theoritical relationship between scavenging efficiency and scavenging ratio.

(a) η_{es} with perfect scavenging (b) η_{es} with mixing $\eta_{es} = I - e^{-R_s}$ (c) η_{es} with complete shortcircuiting.

system etc.Investigation of scavenging process have been carried out on real engine or using dynamic or study flow rigs.

The scavenging analysis on real operating engines using devices such as sampling valve and gas analysis apparatus, though provides answer to the quality of scavenging but gives no clue as to how the air is going through the cylinder or on the mechanism to improve scavenging. In dynamic techniques, hot wire anemometry,laser doppler anemometry, high speed photography etc.is employed to trace the path of inlet air and to study the velocity contours inside the cylinder during scavenging process. The static analysis, however involves mapping the cylinder flow conditions.

This report discusses a technique developed for visualization of flow in two stroke engine. The flow pattern obtained with two designs of piston with different crankcase pressures are also discussed.

CHAPTER - II

REVIEW OF METHODS OF SCAVENGING ANALYSIS

The scavenging analysis of two stroke engine has been done by many diverse experimental methods. Some of the general concepts are summarized below:

The phenomena of scavenging is mainly of a fluid dynamic nature, hence it can be studied with the help of techniques which can provide qualitative or quantitative evaluation of fluid flow pettern in the cylinder.

Selection of a particular technique is dependent on parameters (Ref. Chapter - I) chosen to evaluate the scavenging process. A summary of techniques available from various earlier studies are included in figure 4. A brief description of each is in the following paragraphs.

1. Quantitative Methods

The scavenging efficiency is directly measured on actual and or motored engine operation. It is calculated by sampling and anlyzing cylinder content at pre set crank angle or measuring mean effective pressure.

1.1 Methods Based on Sampling of Cylinder Contents

(a) Tracer Gas Method [1,2]

In this method, it is assumed that the amount of

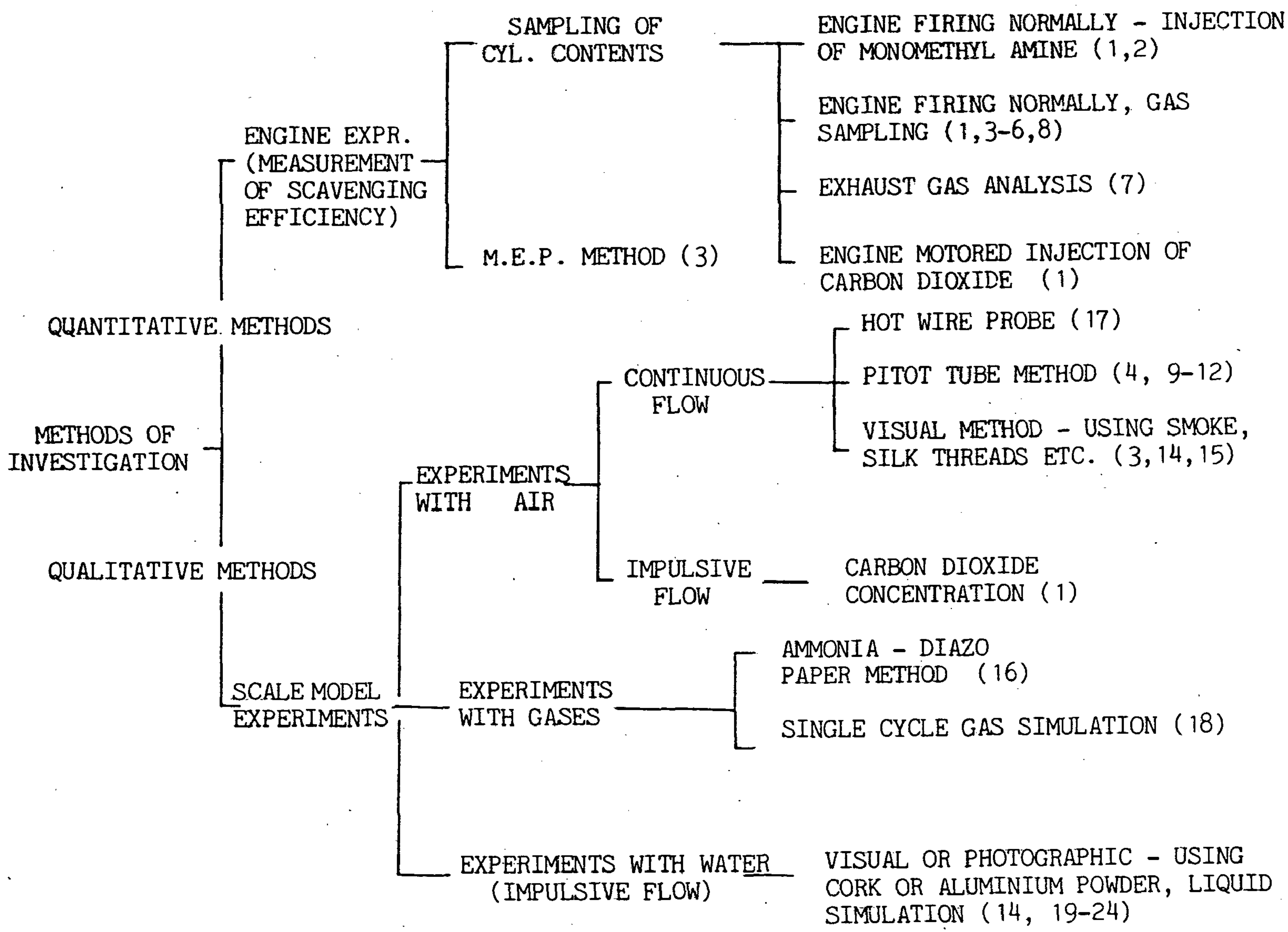


Fig. 4 - METHODS OF INVESTIGATION

trapped fresh charge is equal to the difference between fresh charge delivered and fresh charge short circuited. Trapping efficiency can be calculated if fresh charge short circuited and delivered are known. To determine short circuited amount of charge the tracer gas is continously mixed with the incoming air of a running engine. The division of the gas is directly related to the amount short circuited and the amount retained in the cylinder. Since the tracer gas burns in the cylinder during combustion, the amount of tracer gas in the exhaust measured from the sample allows estimation of the trapping efficiency.

The method consists of introducing 1/2 to 1 percent monomethylamine gas into the intake pipe of the engine operating at three quarter to full load. The samples of the inlet air and exhaust gas through a burette containing 2.5 cc of standardized sulphuric acid solution were taken. A sulphuric acid solution retains the monomethylamine. The known amount of standardized sulphuric acid solution can neutralize a corresponding amount of monomethylamine. After passing through the burette the amine-free gas continues on to a gas meter which measures the amount passed through sulphuric acid. A few drops of mixed indicator solution are added to sulphuric acid solution. The moment the acid solution becomes neutralized by the monomethylamine, the colour changes from purple to green and at this point the gas meter reading is recorded. The quantity of sulphuric acid solution used being known, the percentage of ammonia in the gas mixture can be calculated.

The figure 5 shows the set up for the test. The monomethylamine is fed from the steel flask through flow control valve into the engine intake. Air delivery is measured by an orifice type flowmeter. The inlet sample is withdrawn from the intake pipe for analysis. Exhaust samples is bled from several points in the exhaust pipe and then analyzed.

It is reported that tracer was readily absorbed by condensate in the surge tank. Dissociation of tracer gas take place in the exhaust stream at high exhaust gas temperatures prevailing in the two stroke engine.

(b) Gas Sampling Method [1,3-6,8]

In this method gas samples are taken from the charge, burned or exhaust gases and analysed for CO, CO_2 and O_2 contents quantitatively.

The scavenging and trapping efficiency are determined from several samples taken at different instants and expressed interms of composition of desired constituents as:

$$\eta_{es} = \frac{X1 - X2}{X0 - X2} \qquad \text{------------(1)}$$

and

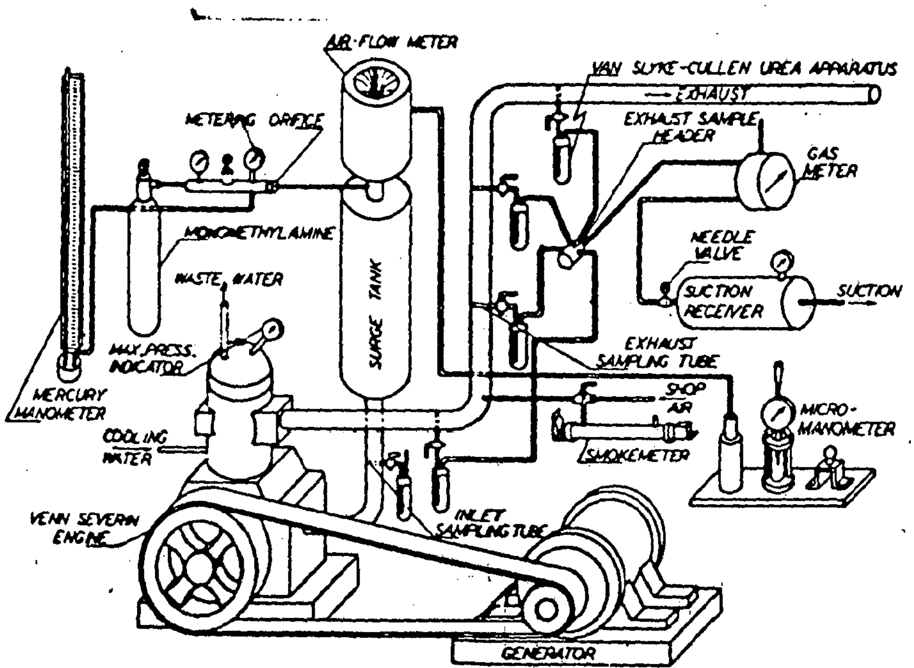


Fig. 5 – Setup for Testing Engine Scavenge with the Tracer Gas Method.

$$\eta_{tr} = \frac{X0 - X3}{X0 - X2} \qquad \text{-------------(2)}$$

where: X0; mass percent of gas composition in fresh air, X1; mass percent of gas composition in charged gas after gas scavenging, X2; mass percent of gas composition in burned gas before scavenging, X3; mass percent of gas composition in exhaust gas.

The composition of the sampled gas may be evaluated on the basis of mass balance of any product element or their combinations e.g. CO_2 or O_2 or sum of CO_2 and CO.

The schematic diagram of electromagnetic gas sampling valve and test set up arrangement is shown in Fig. 6 & 7.

To obtain true representative sample of the cylinder charge, it is necessary that the unburned gas sampling duration for which the valve remains open is large enough while the burned gas sampling is extracted in small amount after the completion of the combustion process.

The operation of gas sampling should be carried out at an interval of about 100 or 200 engine revolutions, because running conditions of the engine are disturbed intensively by such a gas extraction.

(c) Exhaust Gas Analysis

This method help to evalute short circuited mass. The following two approaches are described to explain the

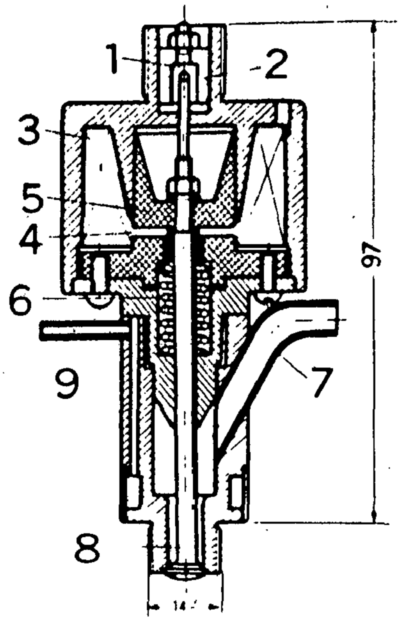


Fig. 6 — Poppet-type gas-sampling valve, (1) condenser pickup, (2) insulator, (3) coil (solenoid), (4) air gap, (5) pure iron piston, (6) spring, (7) gas outlet, (8) valve, (9) cooling water pipe

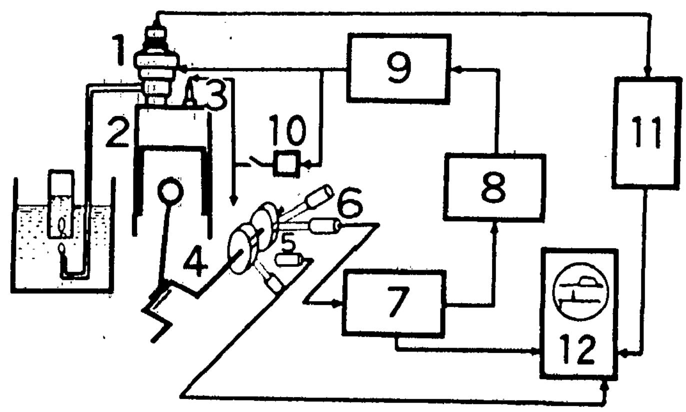


Fig. 7 — Arrangement of apparatus, (1) gas sampling valve, (2) engine, (3) spark plug, (4) crankshaft, (5) signal pickup (to sweep), (6) signal pickup (to open valve), (7) delay circuit, (8) electronic counter, (9) impulse current circuit, (10) relay, (11) transducer, (12) oscilloscope

methodology.

(i) Measurement of intake air flow, fuel consumption, exhaust HC emission and pressure and temperature in the exhaust.

The method consist of measurement of volumetric intake air, flow referred to the ambient conditions of the exhaust gases. The mass flow of HC is then calculated from the HC concentration and density values. The mass flow divided by the flow of the fuel entering the engine is the measure of short circuit ratio.

The method assumes that the exhaust HC are generated by short circuiting of the fresh mixture alone. This hypothesis is quite acceptable as it was shown [7] that exhaust HC are about ten times the combustion generated HC.

(ii) Measurement of CO, CO_2 and HC emissions

It needs exhaust gas analyzers for CO, CO_2 and HC, and takes its basis on some considerations of combustion chemistry to evaluate the incoming HC.

If the combustion equation is written as

$$(N_f)\, CH_y + (0.21 Na)\, O_2 + (0.79\ Na)\, N_2 = (X1) CO + (X2)\, CO_2 + (X3)\, CmHn + (X4) O_2 + (X5)\, H_2 + (NW)\, H_2O + (0.79\ Na)\, N_2$$

Then, the indicated short circuiting ratio

$$Z = \frac{m X3}{X1 + X2 + m X3}$$

In terms of volume concentration of CO, CO_2 and the HC expression becomes

$$Z = \frac{m (HC)}{CO + CO2 + m (HC)}$$

(d) Motoring Test [1]

Scavenging efficiency was determined by motoring tests by artificially introducing carbon dioxide before scavenging and withdrawing samples before and after scavenging as in the firing engine. The uneven distribution of carbon dioxide after scavenging affects the accuracy of the results. The composition of the combustion gas is fairly homogeneous near the bottom end of the piston stroke.

In this method, it is difficult to obtain a sample representing the average composition of the charge after scavenging.

1.2 Indicated Mean Effective Pressure Method [3]

This method applies only to spark ignition engines, scavenged with a homogeneous, gaseous, fuel-air mixture of known composition. In using this method following expression is employed.

$$IMEP = \eta_{es} \rho_s F Q_c \eta_i \frac{r}{r - 1}$$

For a given test ρ_s F and Q_c are known, IMEP is measured from indicator diagram. The remaining unknowns are η_{es} and η_i.

The most reliable method of estimating η_i *is to operate a* four stroke engine of nearly the same cylinder size, with the same compression ratio, fuel air ratio and other operating conditions. This measures the indicated thermal efficiency based on compression and expansion stroke only. It is then assume that η_i for two stroke engine will be equal to x times the indicated efficiency of four stroke engine, where x is the correction factor,accounting for the smaller area of the toe of two stroke diagrams. Its value usually ranges between Ø.85 and Ø.95.

2. Qualitative Methods

In a firing engine it is very difficult to analyze the fluid flow patterns. The quantitative methods though most desirable but are time consuming. Reseachers therefore, have developed some semi-quantitative techniques for simulating the scavenging process for quick investigation, particularly for prototype engine development.

The experiments on models can be classified in following three groups:

Experiments with air

Experiments with gases

Experiments with water.

2.1 Experiments with air

To analyse the flow pattern in the model, air is fed continuously or impulsively to the model by disregarding dynamic and other aspects of actual operation. The following measuring techniques have been employed.

2.1.1 Continuous Flow Method

(A) Hot-Wire Anemometer

The hot wire anemometer is a device that utilizes the variation of a metals electrical properties with temperature to measure the rate of heat transfer from an electrically heated wire to a surrounding fluid. This heat transfer rate depends on the properties of the fluid and its fluid velocity relative to sensor. So it can be used to measure one of these quantities when others are known.

The hot wire anemometer is composed of a fine wire sensor and electronics necessary to operate that sensor. The sensor is heated by passing an electric current through it. The temperature of the sensor rises until the heat transfer rate from the sensor to its sorrounding is equal to the heat generated with in the sensor. Since the electrical senstivity of a metal is a function of its temperature. If the sensor is placed in a fluid, changes in the fluid properties or velocity will cause changes in the heat transfer rate from the fluid to the sorroundings, disturbing the thermal equilibrium. Two things are then possible. If the current to the sensor remains constant, the temperature will change to a new equilibrium value, changing the resistance of the wire. If current to sensor is adjusted to compensate for the change in the heat transfer rate, the temperature and resistance of the wire remain constant, and its power dissipation varies. These two modes of operation are known as constant current and constant temperature method.

E.Sher [17] has developed a experimental rig to study the flow field characteristics inside a cylinder under steady state conditions. Measurement of three orthogonal components of the average velocity at some preselected points were taken using hot wire anemometer technique. The effect of design factors were investigated; the effect of mass flow rate and angular momentum of introduced air, the effect of scavenge port height and effect of the exhaust port diameter.

(B) Pitot Tube Method [4,9-12]

The pitot tubes are used to measure the velocity in a flowing stream. Jante [9] proposed a technique to construct scavenging picture in the externally motored engine. In this system crankcase is performing as a pump. The pitot tubes are fitted at the cylinder head level and the pressure reading are recorded by using water manometers. The actual cylinder head is removed. These total pressure records are converted to mean velocity values. Reference static pressure for each pitot tube is atmospheric pressure. The matrix of velocity values is obtained over the bore area and results are plotted as an equivelocity contour picture at a particular motoring speed. Similar tests were carried out by Blair [12] on steady rig to develop transfer port lay out.

The details of the set up are shown in Fig.8. Jante has defind !good! and !bad! scavenging diagrams by shape and position of the zero velocity line with respect to the plane of symmetry of scavenging flow. The basic definitions are presented in Fig.9 where type (a) shows the perfect scavenging diagram. The arrow at the top of the diagram shows the axis of symmetry of the scavenge flow and inherently, for most engine, the direction of exhaust flow from cylinder. The perfect scavenge velocity contour map has the zero velocity line across the bore diameter with lines of increasing velocity extending smoothly towards the scavenge flow side the highest velocity being at the opposite side of the cylinder from the exhaust port. The negative !velocity! in the exhaust half of the bore area shows the entrained flow caused by piston motion.

The bad scavenging diagrams are (i) Unsymmetrical Fig.9(b), (ii) having a !tongue! pattern, Fig.9(c) (iii) forming a !wall! pattern, Fig.9(d).

(C) Visual Methods [14,15]

The simplest and quickest way to analyze air flow

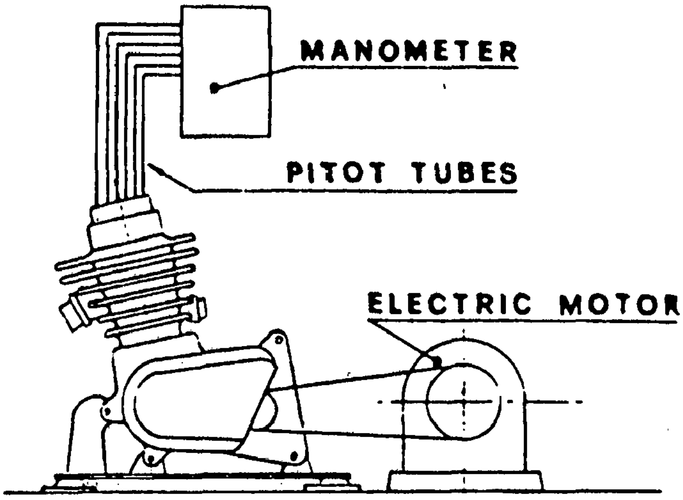
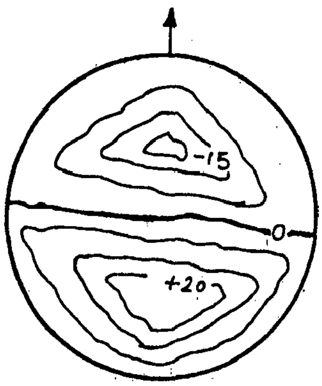
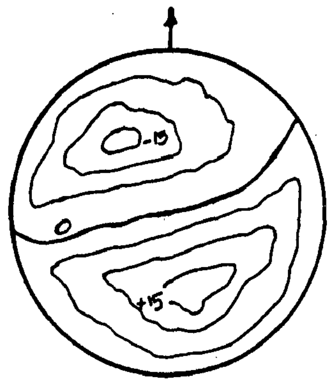


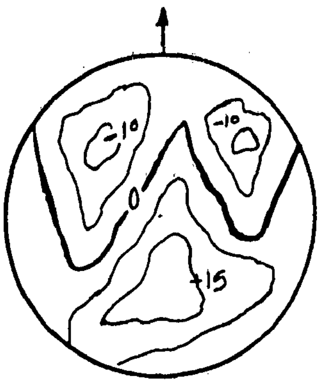
Fig. 8 - Pitot tubes fitting



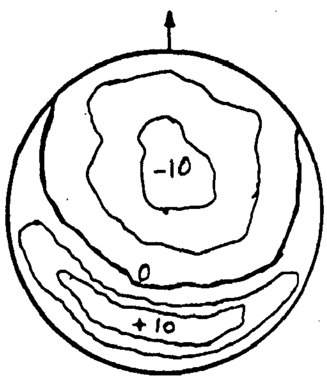
A : Perfect pattern



B : Unsymmetrical pattern



C : Tongue pattern



D : Wall pattern

Fig. 9 Fundamental Jante or scavenge patterns.

pattern, is still the qualitative method of visualization by wool tufts or tracers of various types. It is a form of investigation, which though having provided valuable information in the past, is used presently only for an overall idea about a given system to enable selecting other paramters which need a more exhaustive quantitative analysis.

These tests use transparent models of cylinder and determine the nature and direction of fluid flow through the smoke [14] or light flages of thread located at a number of points in the cylinder. A preliminary study of the flow using smoke revealed substantial changes of direction, at any apparent regularity. Owing to the highly turbulent nature of the flow, the smoke diffuses very rapidly and observation of details of the flow configuration is not possible. A new method of smoke generation by heating the wire electrically at particular location and time has been tried in compression ignited engine [15].

Rogowski and Taylor [3]) have used this method in a modified form on a small sized engine. Magnesium powder and ammonia fog made by mixing silicon tetracloride with ammonia have been used in transparent model for indicating the air flow.

2.1.2 Impulsive Flow Test

!Curtis! Test of Scavenging Efficiency

Curtis [1] measured the scavenging efficiency of various porting arrangements on model cylinder. He used full scale wooden models complete with pistons. The piston did not move during the test but was either at bottom dead center or at any another preselected position, partly covering the ports. Cylinder is filled with atmospheric air contaminated with a small percentage of carbon dioxide. The scavenging process is simulated by allowing sudden admission of a known amount of fresh air that purges the some part of the cylinder contaminated air. By comparing the CO2 concentration before and after the scavenging, the scavenging efficiency is determined with various amount of air supplied and also in various piston positions.

Fig.10 shows the Curtis apparatus consisting of an air reservoir of considerable capacity to feed scavenging air to the model cylinder through a quick acting piston valve. A small pipe was provided for introducing carbon dioxide from an ordinary carbonic gas flask. The carbon dioxide was introduced shortly before and was well distributed by the time the scavenging was set in motion. To determine the initial CO2 concentration, a sample was drawn through a sampling tube to CO2 analyzer.

The scavenging process was set in motion by tripping the spring loaded toggle joint of the air valve which allowed a certain amount of air of known pressure to enter through the inlet ports and exit through the exhaust. A second sample was then drawn from the cylinder through a second sampling tube

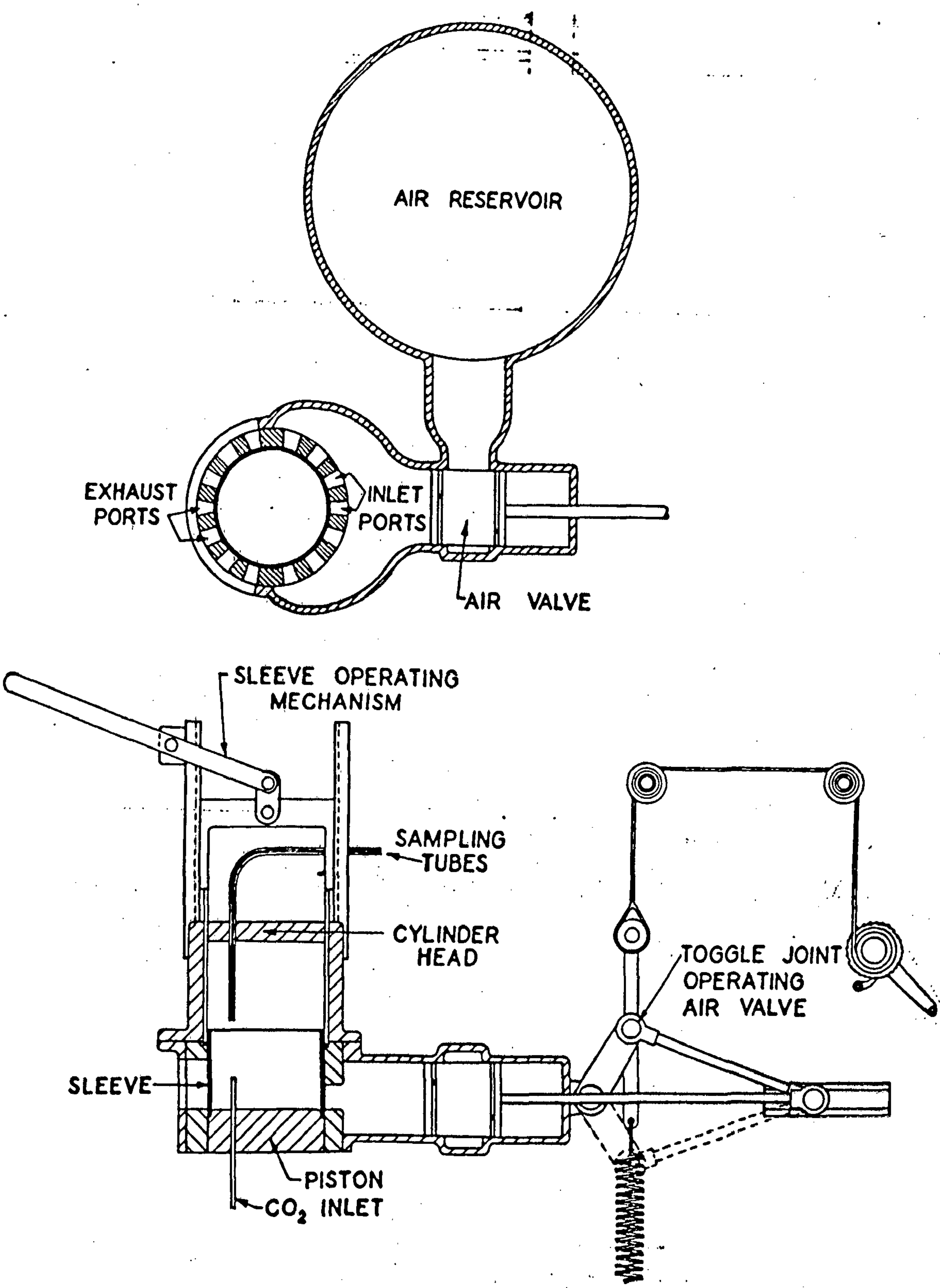


Fig. 10 – Curtis' Testing Apparatus for Determining the Efficiency of Scavenging.

for determining the CO2 concentration after scavenging.

$$\eta_{sc} = 1 - \frac{\%\ \text{of CO2 after scavenge}}{\%\ \text{of CO2 before scavenge}}$$

Test results were reproducible and agreed well with engine test.

2.2 Experiments with Gases [16]

(A) Ammonia-Diazo Paper Method

The ammonia method provides qualitative data in the form of photograph like picture which can then form basis of studying and refining the flow pattern. A paper (Diazo paper) coated with emulsion senstive to ammonia gas is pasted on the piston top or the cylinder wall. Ammonia is then made to flow through the ports at controlled pressure for a specific time duration. Where ever the gas comes in contact with the sensitized paper, a chemical reaction take place changing the colour of the paper from faint yellow to dark blue, depending on the emulsion used.

It is observed that colour of the paper is not uniform after exposure to ammonia. Low ammonia concentration produces a light shade. Whereas high ammonia concentration results in darker shade. Likewise, for fixed gas concentration area subjected to high gas velocity will produce darker shades of colour as compared to areas where ammonia velocity is low. These phenomena are the basis of this method.

The scavenging diagram similar to those obtained by pitot tube method, has been obtained. The arrangement for obtaining the impulsive and dynamic flow pictures with ammonia method is shown in Fig.11. The dynamic pictures were taken by putting a close cell foam on the paper and holding the assembly with the help of metal screen. Fig 12(A) and (B) show the scavenging pictures obtained by pitot tube and the ammonia method respectively. Probably becuase of the basic difference in the methods, the above patterns are not comparable at all. The tongue seen in Fig.12 (A) is not at all present in Fig. 12(B). On the other hand, a pocket formation opposite to exhaust port and some short circuit on the right hand side are indicated by ammonia method only. The Fig. 13 (A) and (B) show the picture obtained with the pitot tube and ammonia method respectively. The picture with both the methods indicate similar patterns regarding short circuited loss of symmetry and velocity distributions. The high velocity areas have turned out to be of higher value in equivalent ammonia method.

(B) Single Cycle Gas Simulation Method [18]

This concept involves the scavenging of a cylinder over a single crank shaft revolution and measurement of the scanging ratio and scavenging efficiency at the end of cycle. The complete scavenging characteristics is constructed by repeat testing over a range of scavenge ratios. The carbon dioxide is used in the crank-case to simulate the fresh

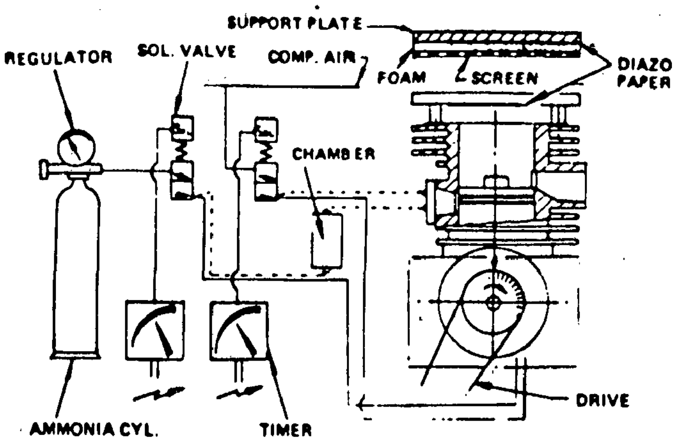


Fig. 11 - Impulsive and dynamic flow-test set up

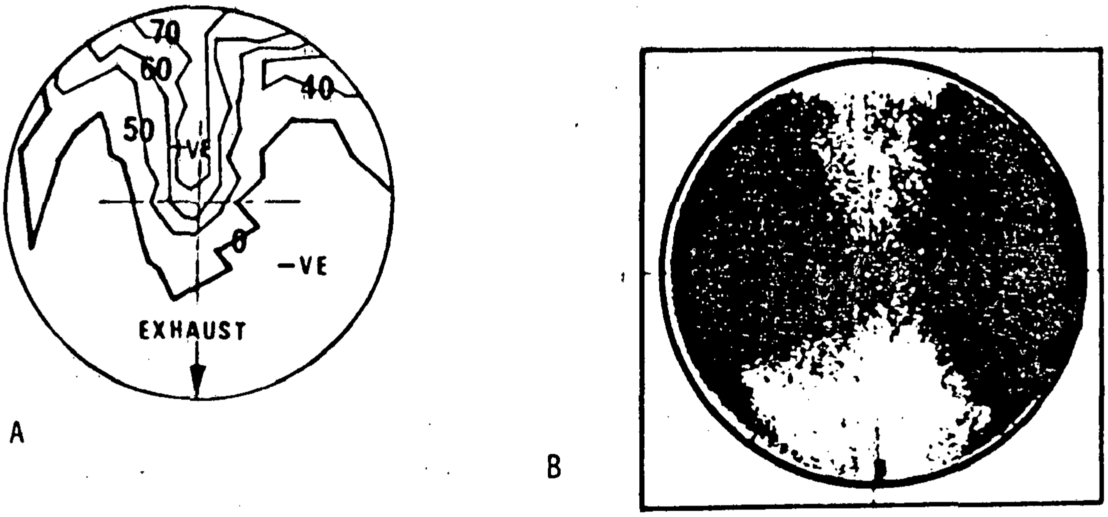


Fig. 12 - Scavenging picture - dynamic flow
A - Pitot tube method
B - Ammonia method

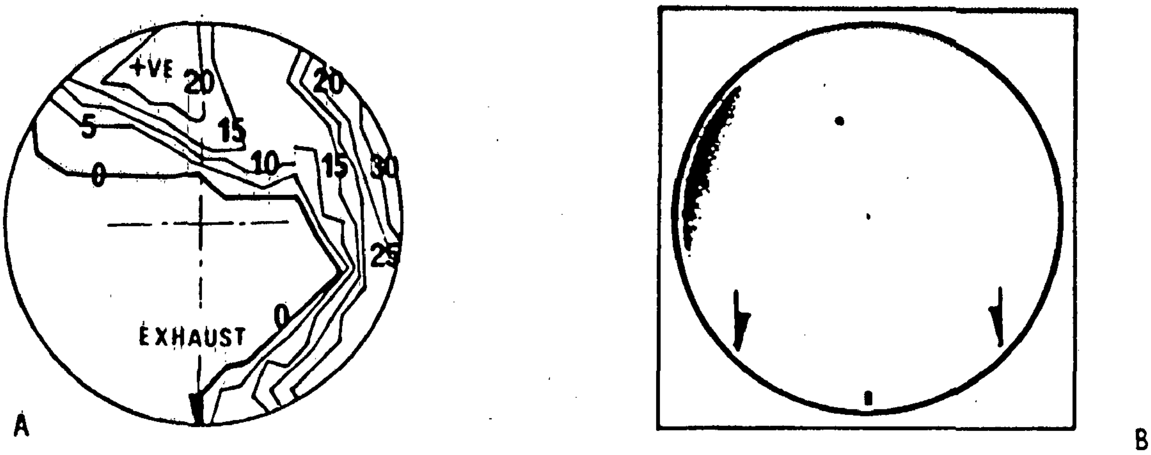


Fig. 13 - Scavenging picture - steady-flow
A - Pitot tube method
B - Ammonia method

charge and air in the cylinder represents the burned gas. The pressure in the crank case at the commencement of the test is higher than that of the air in the cylinder. The engine, with a constant volume cylinder and crankcase, is turned over once at a specified rotational rate and arrested after a complete cycle of scavenging. The cylinder contents are examined for carbon dioxide concentration and ultimately the scavenging efficiency. The depletion of the crankcase contents are recorded to reduce the scavenge ratio. The test are repeated by varying crankcase pressure. The density ratio of fresh charge to residual content in real engine is 1.6 at reference conditions.

The experimental rig is shown in Fig. 14. The crankcase is operated as a constant volume chamber. This is achieved by using counter piston cross-head construction. A CO2 reservior tank is connected to the crankcase through valve 3. A second tank is connected to crankcase to provide a rference pressure for differential micromanometer. A movable piston and cylinder arrangement 5 is used in conjunction with the micrometer for measuring the total scavenge flow from the crankcase. A piston 6 is used to simulate the cylinder head and rigidly connected to engine piston. This provides a constant volume cylinder. The single cycle operation is achieved using a wrape spring clutch brake which ensures that precisely one cycle is excuted.

For this test procedure, which operates the engine cylinder as a constant volume chamber, the scavenging ratio can be defined as :

$$\text{Scavenge ratio} = \frac{\text{Fresh charge volume at cylinder pressure and temperature}}{\text{Cylinder reference volume}}$$

$$\text{Scavenging efficiency} = \frac{\text{Volume of fresh charge in sample}}{\text{Total sample volume}}$$

Fig. 15 shows the results obtained on this rig for scavenging efficiency and engine performance of different cylinder. The rating of different cylinder from fuel consumption point of view is same as by the scavenging efficiency test.

2.3 Experiments with Water (Impulsive Flow)

For using a liquid model for scavenging analysis or flow visulization, a complete formulation of the similarity law between the real and the simulated engine is required. Dedeoglu [19] proposed a set of similarity law derived from the conservation equation under the following simplification (i) both fluids are incompressible (ii) no heat exchange takes place (iii) the liquid involved are easily miscible and (iv) no mass diffusion in any form take place. The author concluded that the following three laws are the most significant. The geometrical similarity, the Strouhal similarity and the density ratio similarity. The Strouhal number is defined as stroke/time for one revolution * mean piston speed. Dedeoglu has demonstrated that Strouhal number

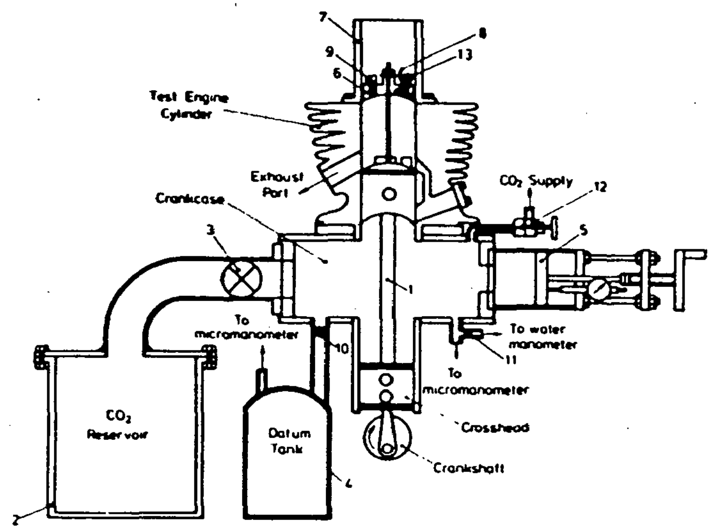


FIG.14-General arrangement sketch of single-cycle gas simulation apparatus.

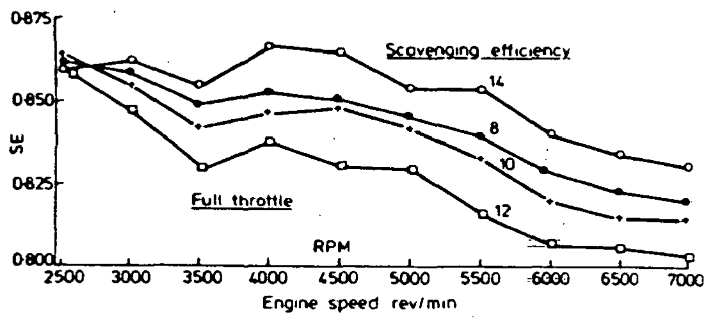


FIG.15 Scavenging efficiency - speed behaviour (A) at full throttle for cylinders numbered 8-15

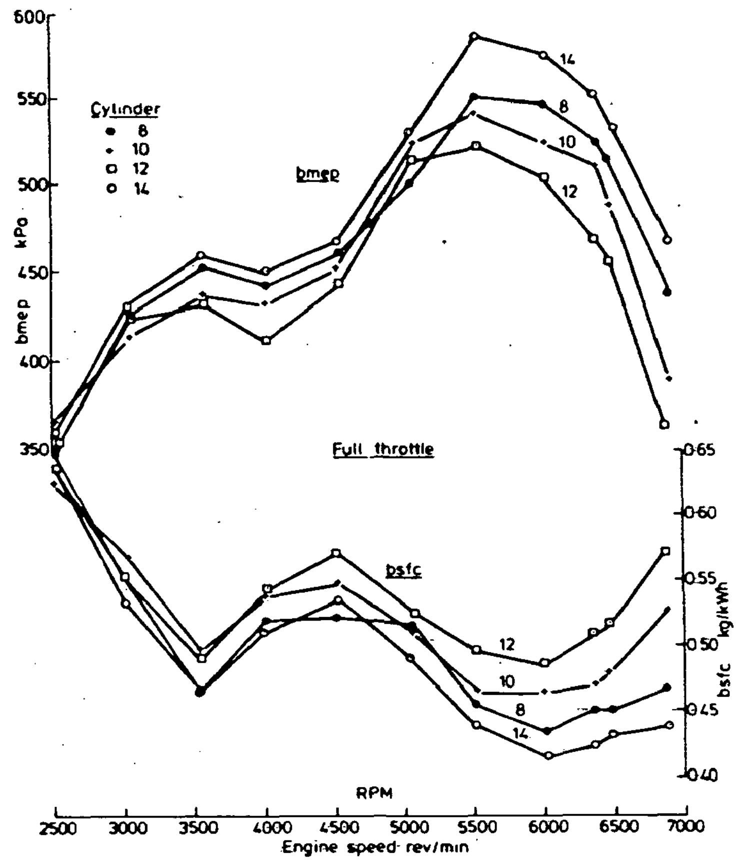


FIG 15 ~~Bmep-bsfc-speed~~ characteristics at full (B) throttle for cylinders numbered 8-15 is most signification for dynamic similarity of scavenging process and considerable liberty can be taken with respect to Reynold number as long as flow is in turbulent region.

The use of liquid media has several advantages:

- Simple measurements of liquid flow
- Simple determination of the concentrations of the component in the cylinder and in the exhaust
- Possibility of substantial slowing down the process
- Simple determination of the individual components that is obtained by their colouring. This makes also the visualization of whole process possible.

Different researchers has used varying combinations of liquids to simulate the process. These are summerized below:

Water and Water with Dye are used by Rizk [14] to represent the residual gas and the fresh charge, respectively. The dye provided good photographic visualization.

Sodium Hydroxide Solution and Water have been used, with qauntification by means of titration methods and visualization by means of pH indicators.

Cyclohexane and Tetrachloroethylene are used by Dedeoglu [19] and closely represent the density ratio in the prototype. Quantification is carried out through specific gravity.

Sugar Solution and Water are used by Blair [20]. A specific gravity of 1.2 was used for the scavenging fluid in order to improve the accuracy of the scavenging efficiency evluation by means of a hydrometer. This high sugar concentration resulted in a considerable increase in the viscosity and an undesirable lowering of the Reynold number.

Sanborn [21] has used kerosene and water combination. Water with red dye was used to simulate the fresh charge. It was introduced into the residual gas, simulated by kerosene. The desired fine emulsion of water in the kerosene did not appear to have formed. This may indicate that flow velocities are not high enough for intertia forces to over come the surface tension forces. This discrepancy appears to have a significant effect on the qualitative evaluation of this particular scavenging arrangement.

De-Ionized water and tap water proved to be very paractical combination and avoided any effects arising due to immiscibility. Tap water has sufficient ion-content to give it an electrical conductivity. The cylinder was filled with de-ionized water (having negligble conductivity) and scavenged with tap water. The scavenging efficiency could easily be determined by a quasi-linear interpolation of the conductivity of the resultant trapped mix.

The test apparatus is shown in Fig. 16. The cylinder and attached ducting are of transparent plastic. The simulated

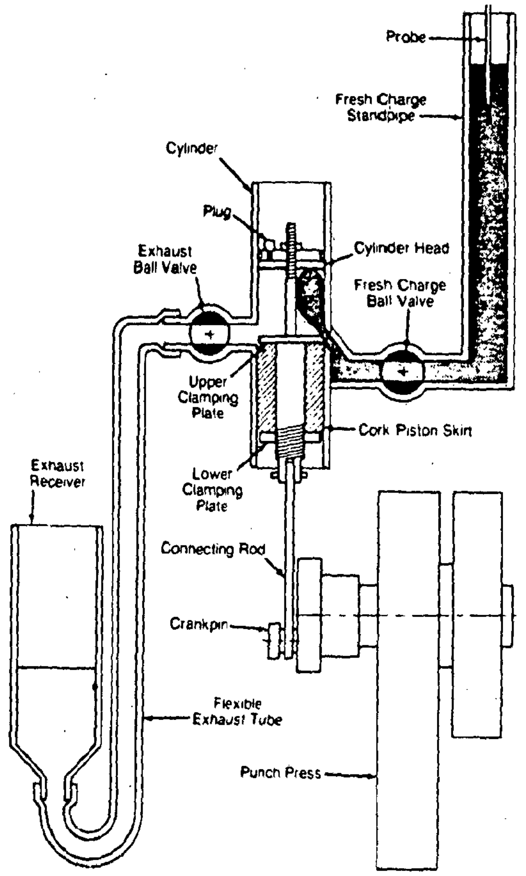


Fig.16-Single Cycle Test Rig

fresh charge was delivered from stand pipe and exhaust was collected in the receiver.

The scavenging characteristics curves presented in Fig. 17 and the photographs are in Fig. 18.

E. Sher [32] Visualized the mixing phase by using alkali ions added to water representing fresh charge. Initially the cylinder is filled with the acid ions added in water. A pH indicator was added to fresh charge reservoir. Indicator is colour less in acid solution and red in basic solution. Therefore, visible interfacing may appear during the scavenging process. By analyzing the chemical composition of the cylinder content at the end of the scavenging period and the chemical composition of samples taken from the exhaust flow during the process. The scavenging efficiency can be estimated.

Ekchian (24) has used polystyrene pallets as a tracer to visualize the flow. These pallets were almost naturally bouyant (1.01 to 1.04 sp. gravity) and ranged in size 0.8 mm to 1.0 mm. The photograph obtained in this way were used to determine the structure of the flow, to the velocity measurement and particle trajectory.

3. Selection of Measurement Technique

It is difficult to conclude which method is superior and should be preferred. Since the process dynamics under

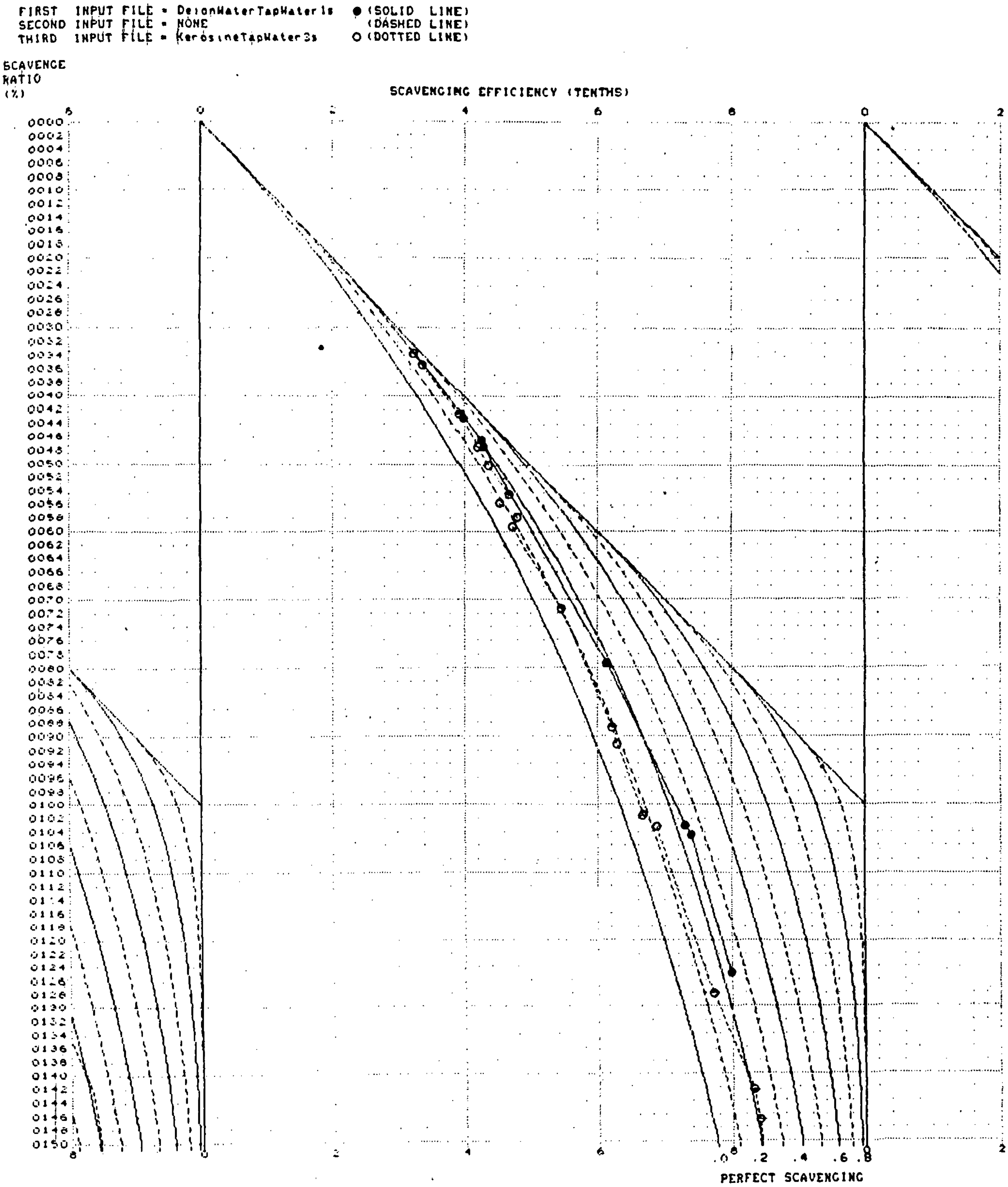


Fig. 17-Scavenging Efficiency vs Scavenging Ratio for Kerosene/Water Compared with De-ionized Water/Tap Water

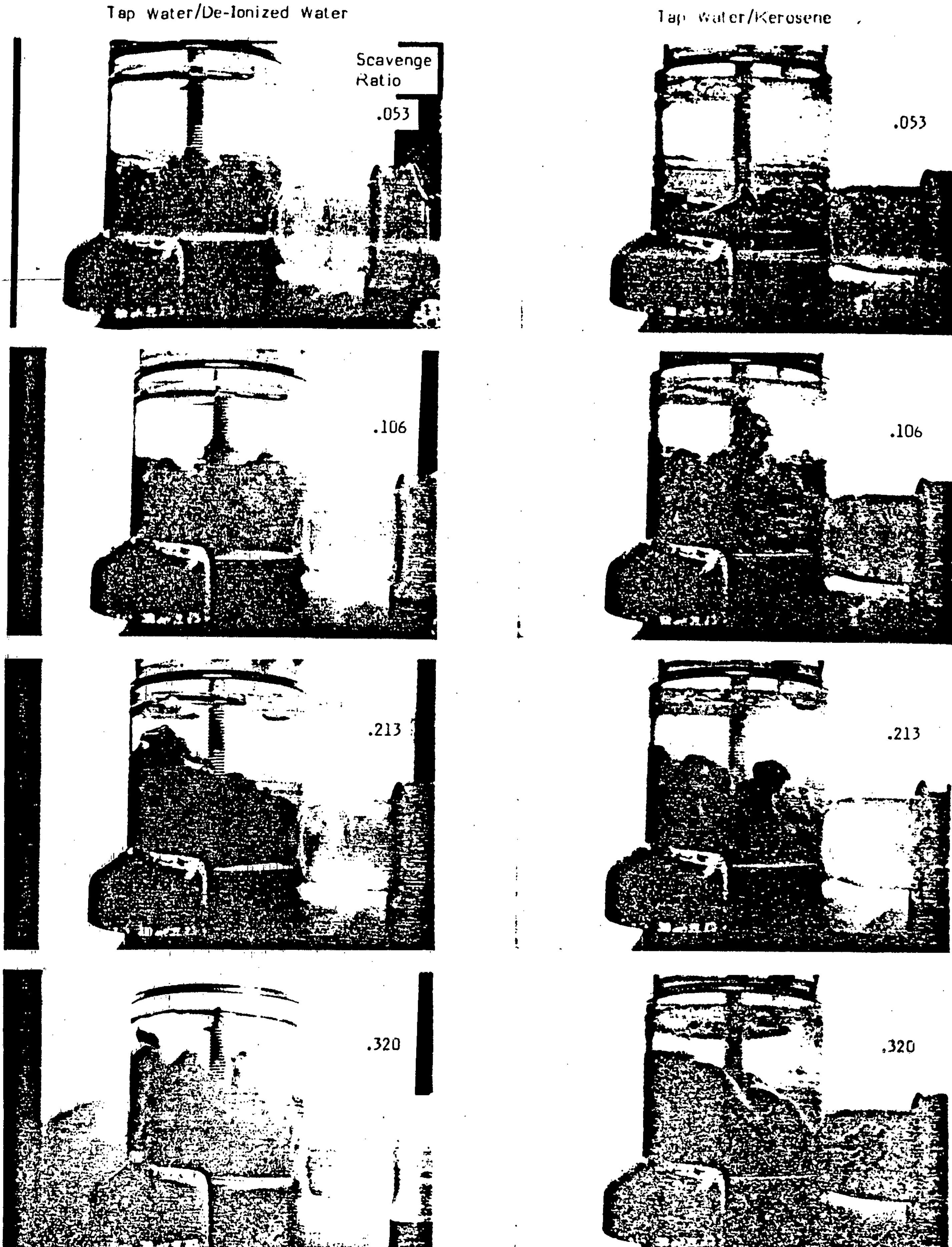


Fig.18 Comparative Photographs of Scavenging Tests with Kerosene/Water and De-Ionized Water/Tap Water

investigation is itself very complex and access for actual on cylinder measurement is almost impossible. The merits and demerits of each systems are to be weighed at the time of selecting one, under given limitations.

Ideally the method should have the following features:

i) Simple and quick

ii) Inexpensive

iii) Safe

iv) The data recorded should be in permanent form

v) Data should indicate mixing symmetry, short circuiting and flow pattern close to the walls.

For quantitative evaluation of existing engine, the method used are tracer gas, gas sampling and IMEP. These methods give substantially the same results. (Fig-19) It can be concluded that for the engines scavenged with a crabureted mixture, the IMEP method is to be preferred, provided IMEP can be measured accurately. The tracer gas method is not suited to this type of engine on account of its high exhaust temperature. Gas sampling method is however, combersome.

Blair [12] has concluded that Jante's [13] method has failed to differentiate between good and bad scavenging. Phatak [15] method of using ammonia with diazo paper has given scavenging diagrams similar to those obtained using pitot tube method in steady state conditions.

Visual methods are good to have an over all idea of flow

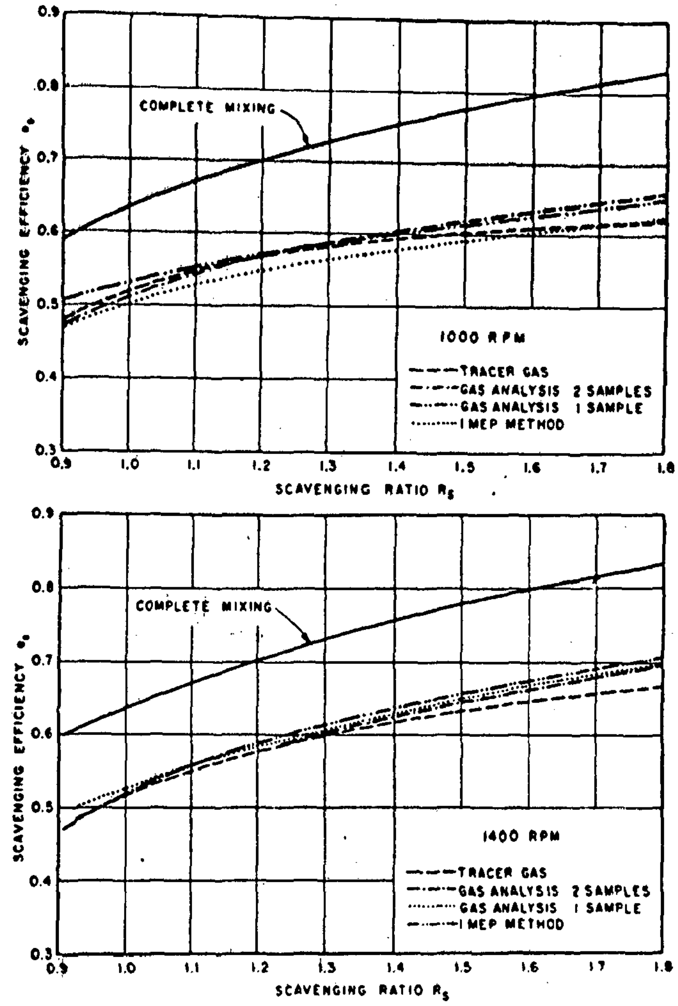


Fig. 19- Scavenging efficiency as determined by four methods

configuration. High speed photography through a transparent cylinder can give a approximate estimation of velocity while the plane of a picture remain unknown. Visual methods provide qualitative answer to guide an improvement strategy for engine.

Liquid model methods are the efficient in the first phase of projecting of a scavenging system in two stroke engine. They are very convenient as far as the time and cost are concerned.

Scavenging flow in the two stroke engine is a transint process and it should be investigated as such. The semi-qualitative technique have on the whole proved more use- ful in demonstrating the basic characteristics of the system and could be of greater value in investigating the problem, than methods of obtaining accurate absolute measurements under highly simplified conditions.

4. Work Plan

Thus a qualitative approach, to visualize and understand the bulk air motion in a small two stroke engine cylinder is undertaken.

In this work an experimental rig with a transparent cylinder is fabricated to visualize the incylinder gas flow in two stroke cycle engines. A tracer particle is used make the flow stream visible. The effect of piston shape and crankcase pressure on flow pattern are studied.

CHAPTER - III

EXPERIMENTAL SET UP AND TEST PROCEDURE

A two stroke engine with two transfer ports has been selected for the flow visualization studies. The engine specifications are given in Appendix I. The port timing and geometries are shown diagramatically in Figure 20 and 21. In the present work flow visualization studies are done with two different piston designs. Experimental set up giving full details is shown in figure 22-24 . salient features of the experimental set up are described below.

1. Cylinder and Cylinder head

A portion of original two stroke engine cylinder was removed for the purpose of adding transparent glass chamber to achieve access for photography of the flow. The portion of the engine cylinder above the engine exhaust port was removed. The glass cylinder head was provided the required shape by blowing the glass in an actual cylinder head. The transparent cylinder head is fixed to the cast iron cylinder using silicon rubber adhesive. The dimensions of glass cylinder are 28 mm hight and 57 mm inner diameter, the same as of the original engine cylinder. The photograph of the modified cylinder is shown in figure 25.

2. Piston

The two types of pistons (figure 25 & 26) are being

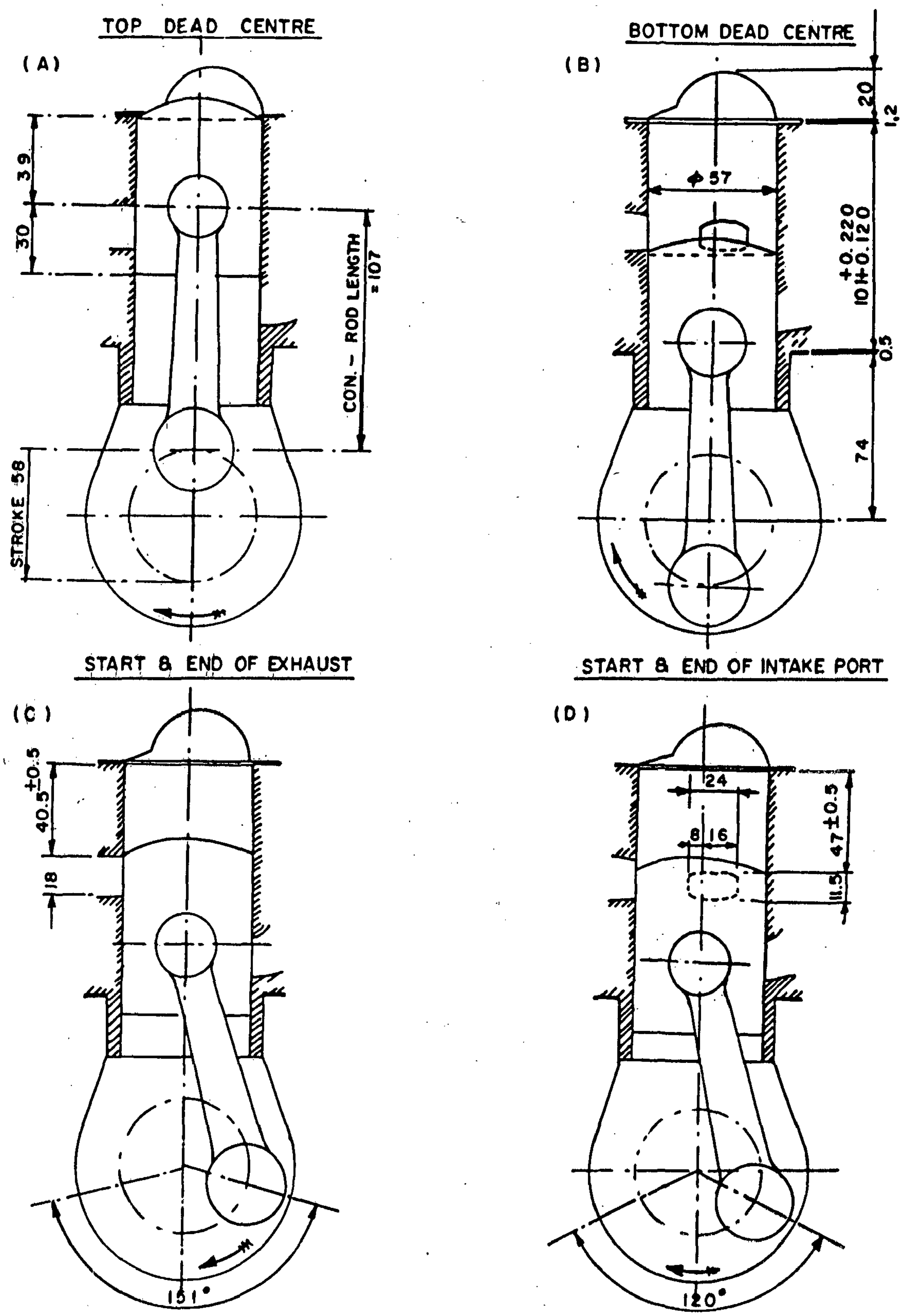


FIG. 20 – PORT TIMING DETAILS.

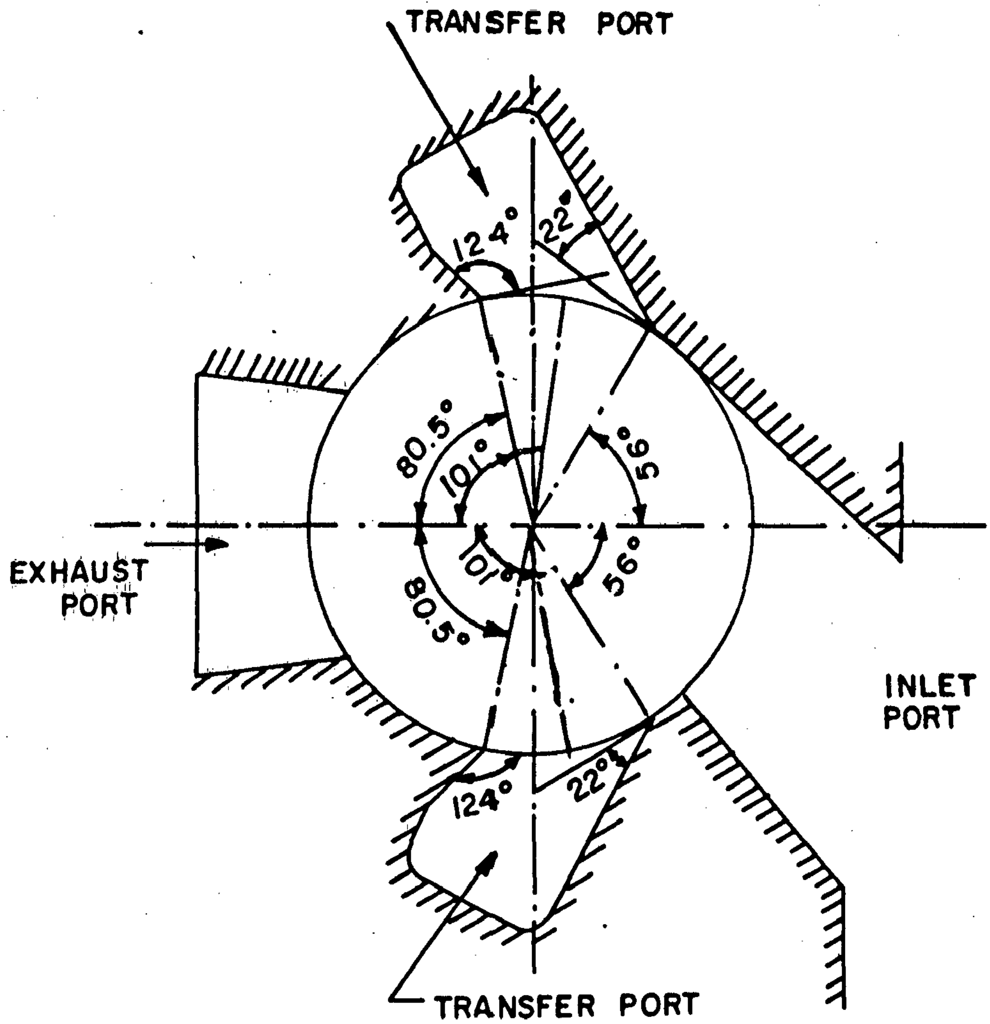


FIG. 21- PORT GEOMETRY DETAILS.

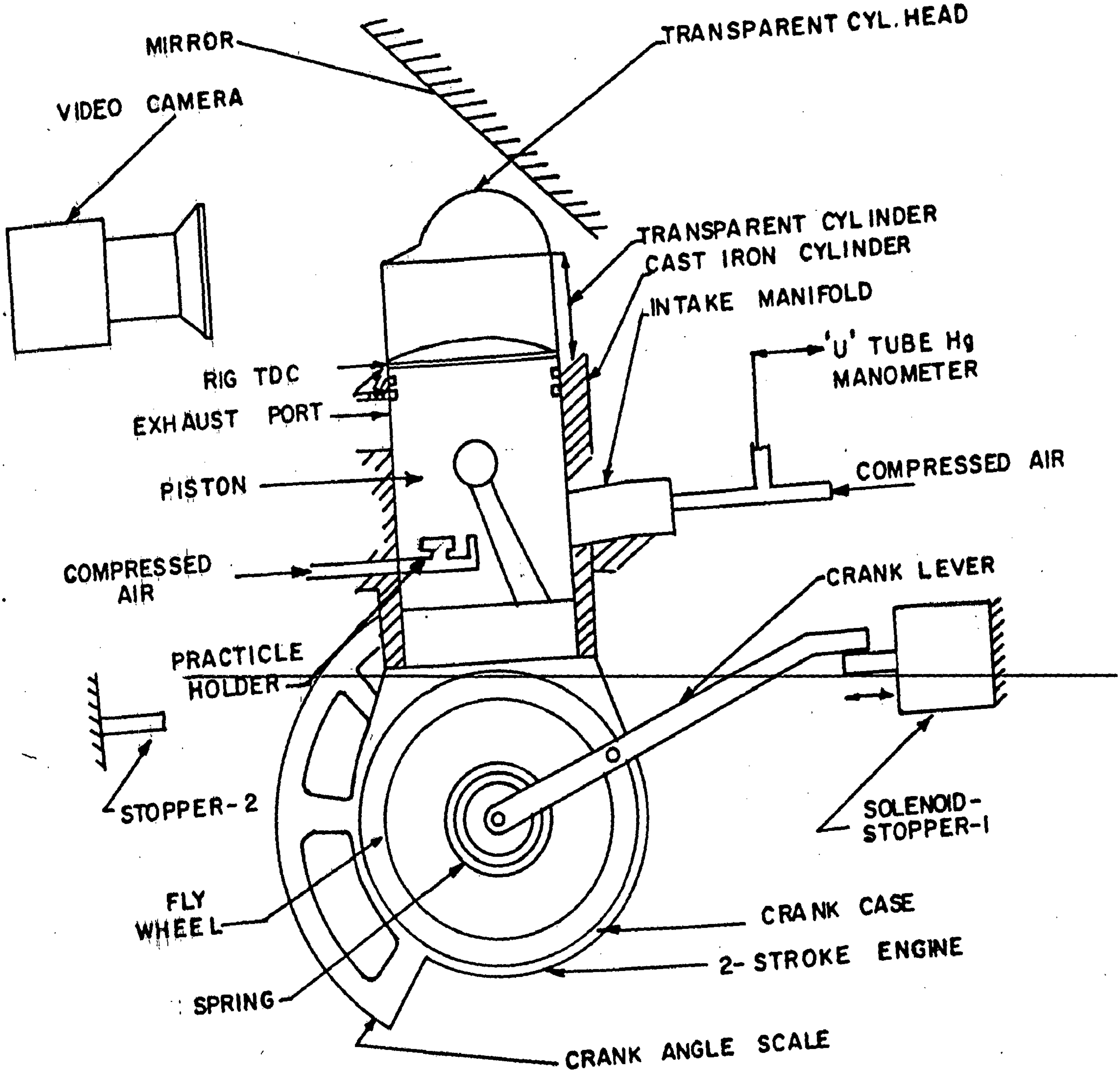


FIG. 22 - EXPERIMENTAL SET-UP.

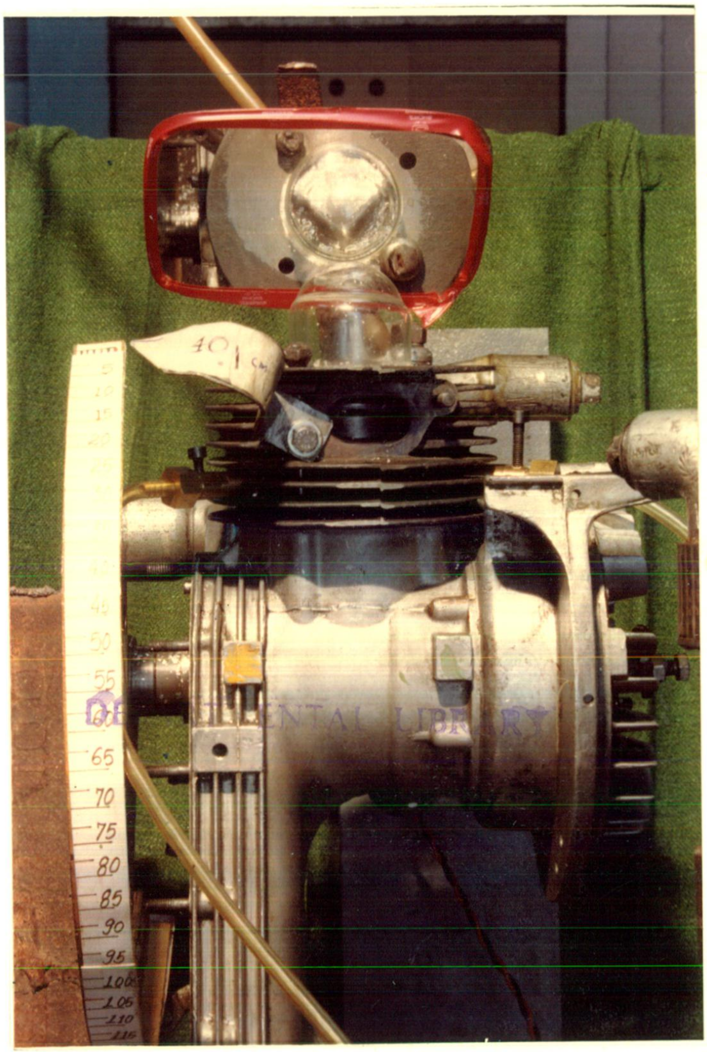


FIG. 23 - Photograph of Experimental Set-up (Front View)

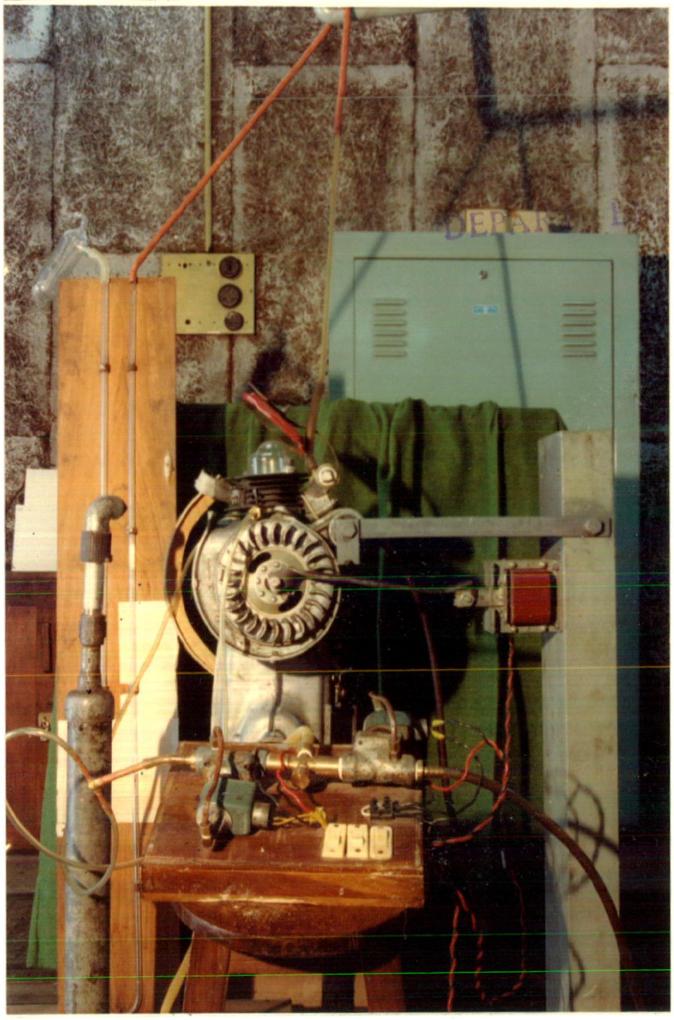


FIG. 24 - Photograph of Experimental Set- up (Side View)

FIG. 25 - Photograph of Piston and Transparant Cylinder

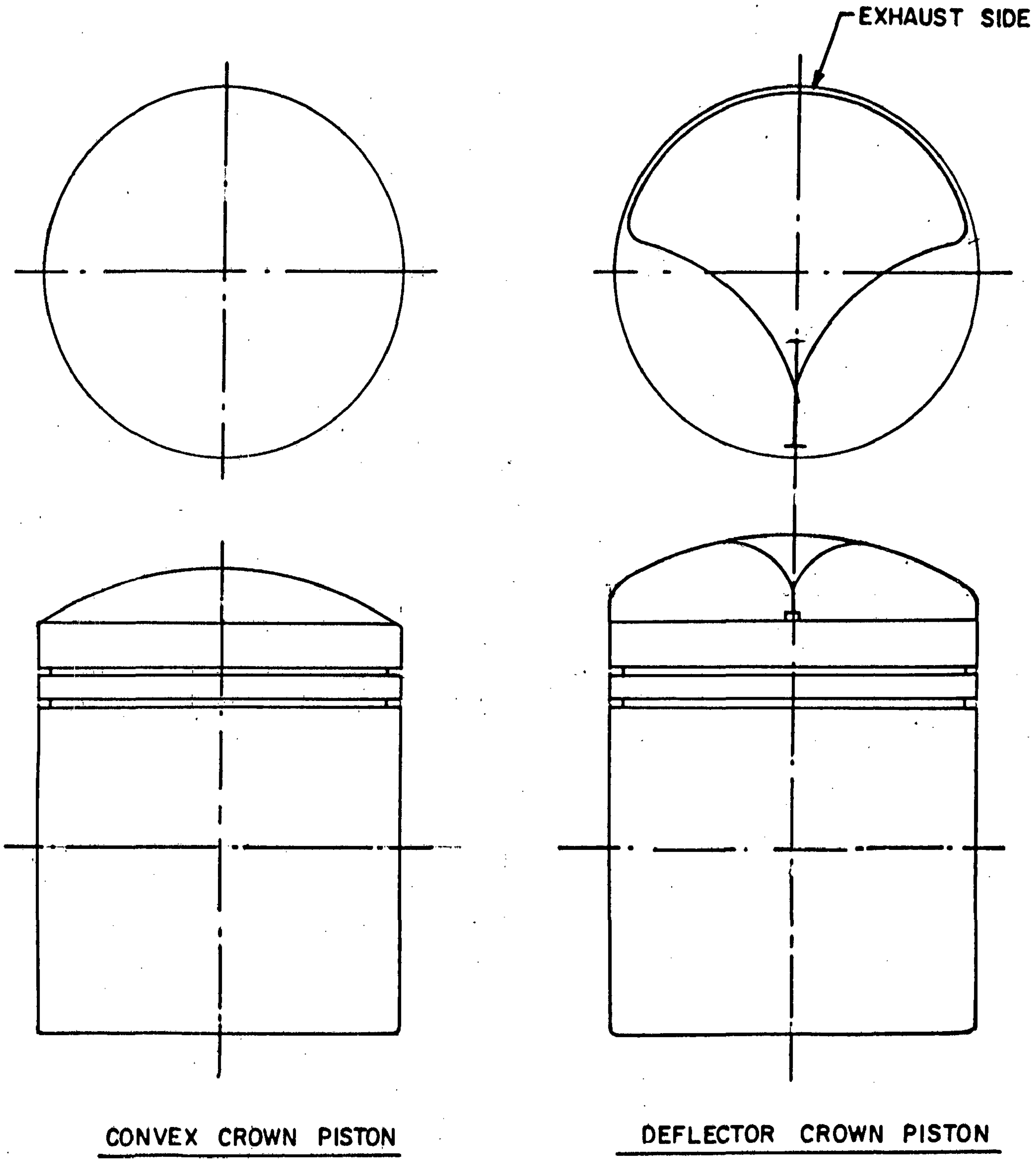


FIG. 26 - CONVEX CROWN & DEFLECTOR CROWN PISTONS.

investigated.

(1) Convex Crown shape

(2) Deflector on the crown.

The cast iron piston rings were replaced by O rings to completely seal the air leakage through the rings. The piston motion was restricted in the cast iron cylinder part only, that is, between the rig tdc and the bdc. The rig tdc is referred to as the restricted position of the piston in the cast iron cylinder portion (figure 22) and is about 12mm above the exhaust port opening. This has been done to accomodate piston rings above exhaust port for perfect air sealing. Since the opening and closing of exhaust and transfer ports is piston controlled, the piston motion is restricted by using two stoppers.(fig. 22)

A helical spring with proper initial tension and a lever on the crank are used to achieve the piston motion. The other end of the lever is resting on stopper, controlled by an electro magnetic solenoid. The solenoid when actuated releases the lever and provides the desired movement of piston between rig tdc to bdc and back. The stopper-2 is used to constrain the piston movement beyond the metalic cylinder piston. During this period air flow occurs from the crankcase through the transfer passages to the engine cylinder.

3. Piston Speed Measurement

The average speed of the crank is required to be measured. This is done placing two pins 15Ø^{o}CA apart on the engine flywheel (figure 27). The flywheel motion between these two points is sensed by an electromagnetic inductive proximity tranducer and recorded on a storage oscilloscope and subsequently plotted on x-y plotter. The recorded diagrams are shown in figure 28. The average crank speed is estimated to be 21Ø rpm that remained fixed throughout the experimentation in this work.

4. Flow Tracer Particles

Flow visualization technique used in the work require illuminating particles. Very small pieces of aluminium foil of size 1-2 mm^{2} and Ø.ØØ8 mm thickness are being used to trace the flow. Light aluminium foil particles are introduced in the transfer port alongwith air just before the piston is actuated. This eleminates the possibility of settling of the particles in the crankcase.

5. Crankcase Pressurization

The crankcase of experimental rig is pressurized to simulate the conditions in actual engine operation. In real crankcase scavenged engines, the pressure in the crankcase generally ranges between 1.1 to 1.3 bar (11Ø-13Ø kpa) absolute. The typical crankcase and cylinder pressure

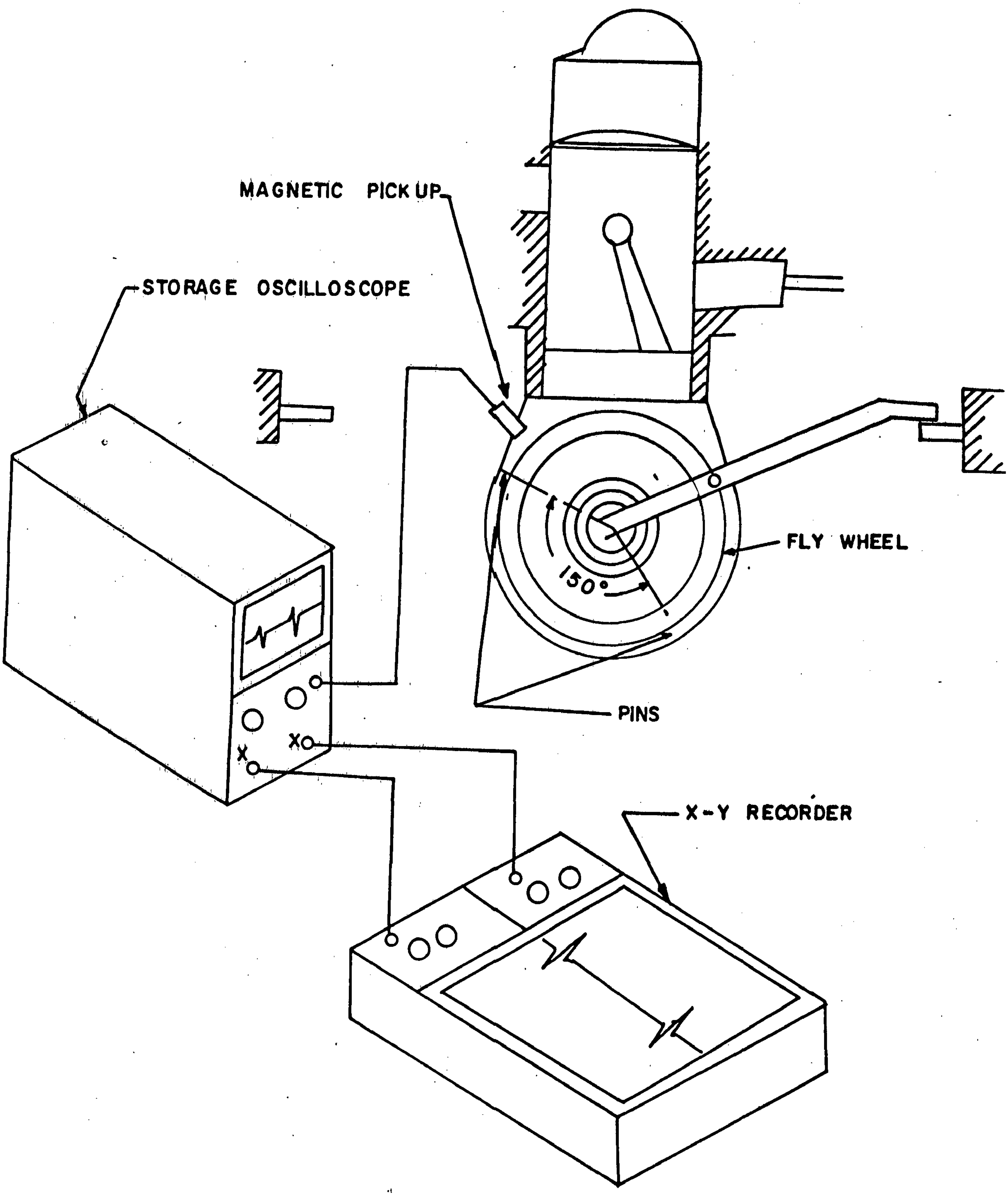


FIG. 27 – SETUP FOR SPEED MEASUREMENT

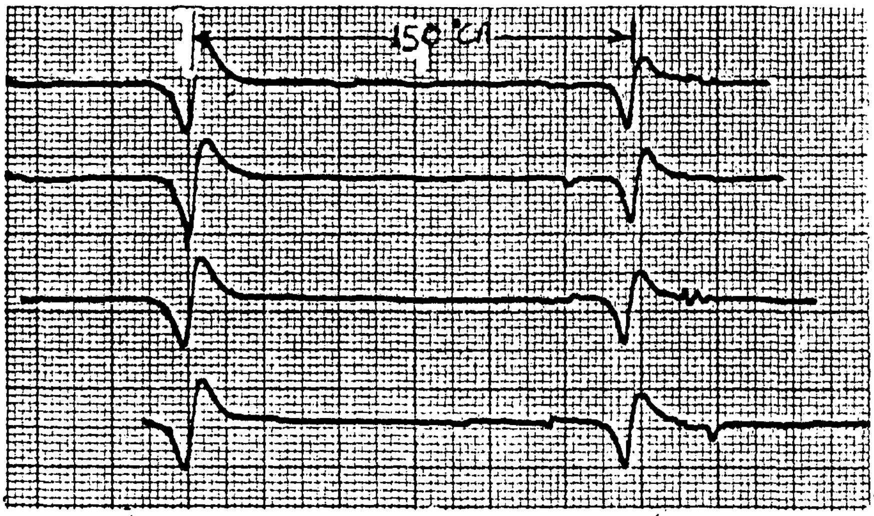


FIG. 28 - Time Diagram for speed Mreausrement on the rig (Oscilloscope settings 20 ms/cm)

histories for a similiar engine are shown in figure 29. From this data, the crankcase pressures were chosen for the present experiments. The chosen crankcase gauge pressures are between 70-180 mm Hg (9.3-24 kpa) correspond to the usual engine crankcase pressure range mentioned above. Compressed air is introduced in the crankcase through the intake port and the pressure is regulated using throttling valve. The pressure measurement is done using a U tube mercury manometer.

Two solenoid valves were used in the compressed air circuit to control the timing of introduction of air into the crankcase. Initially the solenoid valve 1 is opened to allow air into the crankcase through the intake port. Prior to the crank movement, the solenoid valve 2 is opened to allow flow of compressed air in the passage of the particle holder. The circuit controlling these actuations is shown in figure 30.

6. Motion Photography

The particle motion is photographed using a video camera !National M7!. The full specifications of the camera are given in Appendix II. Video camera filming speed is about 24-25 frames sec. The shutter speed 1/1000 sec was selected for photography, for best possible clarity of the video film.

This speed of filming is rather low for quantitative analysis of the flow pattern but could provide an adequate

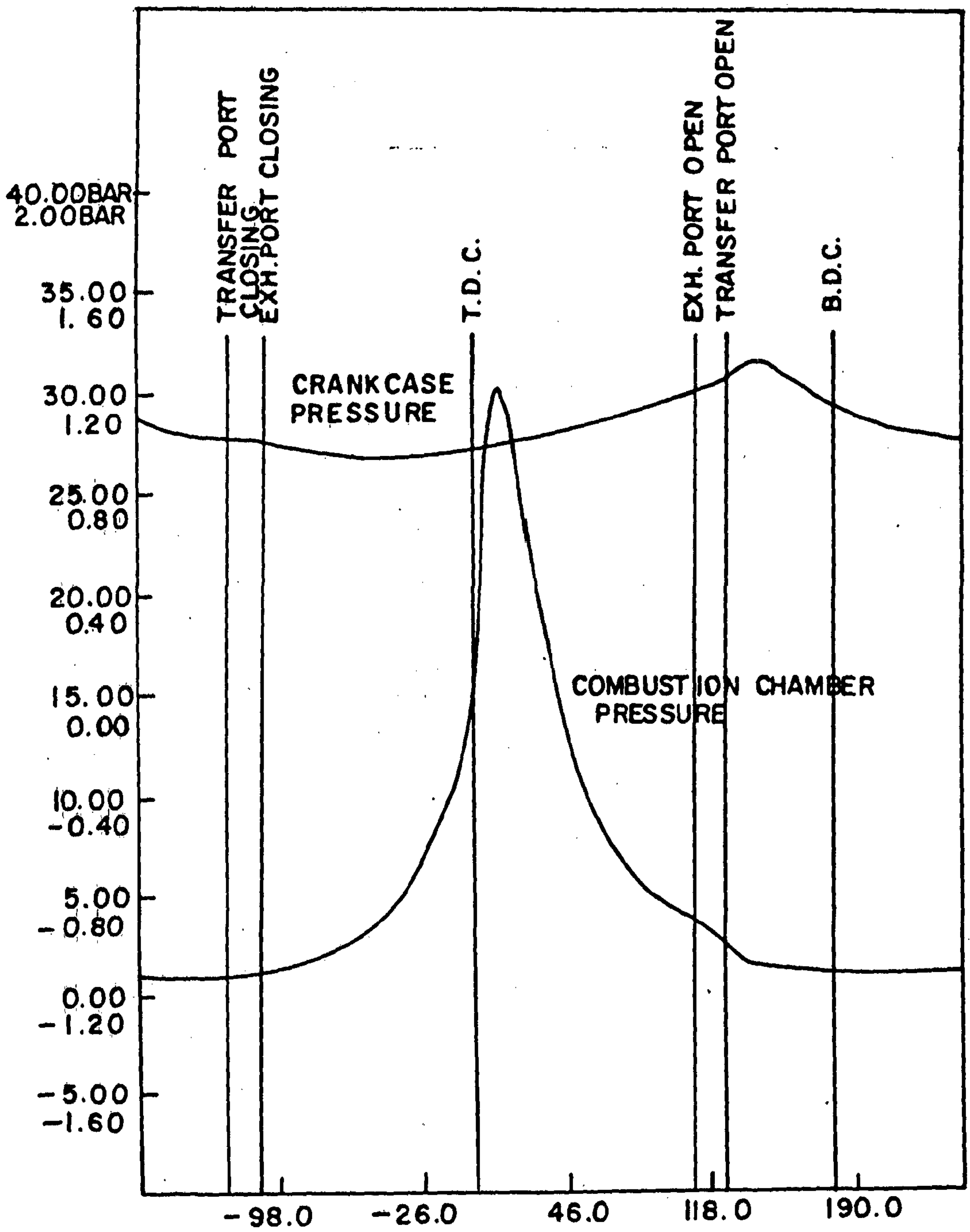


FIG. 29 - COMBUSTION & CRANK CASE CHAMBER PRESSURE TIME DIAGRAM.

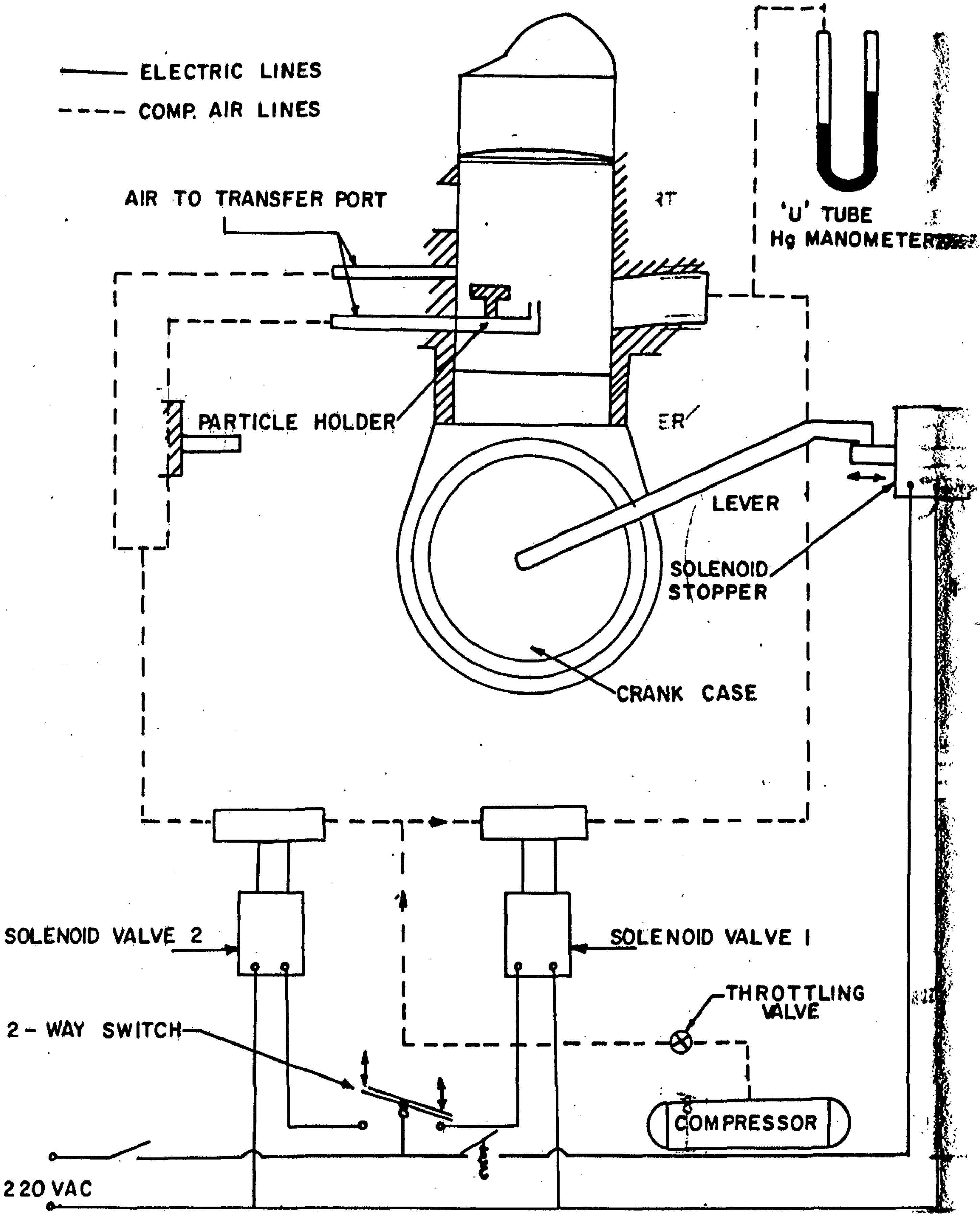


FIG. 30 - COMPRESSED AIR & ELECTRIC CIRCUIT.

qualitative picture of the process at slow piston motion (210 rpm in present case).

A mirror is mounted in the rig above the engine cylinder head at an angle of 45° to enable simultaneous viewing and recording of the front and top views of flow patterns.

For recording crankangle a circular angle scale is fixed on the crank. The video records obtained in the experiments are re-recorded on another video cassette frame by frame giving adequate pause.

This slow motion record helps in the analysis of flow field. The video photographs are evaluated by fixing a transparent grid arrangement on television screen and the particle motion then is traced on a graph paper.

CHAPTER IV

RESULTS AND DISCUSSION

The flow visualization experiments are carried out to obtain details of the flow pattern during scavenging process in two stroke engine cylinders. The results of these investigations are shown in figure 31 to 38 in the form of flow diagrams.

Several tracer particles were tried to achieve this objective. Fine graphite powder when introduced with air showed very poor particle visibility. While smoke of herbal mixture posed difficulties on account of its fast diffusion. In another attempt, the smoke was generated inside the cylinder, near the transfer port, by electrically heating a resistance wire, smeared with mineral oil. Though it was possible to trace the flow with some difficulty, the problem of smoke diffusion remained dominantly. The experimental trials as above yielded the choice of a suitable tracer to the small size aluminium foil pieces. These are used in this work.

These particles gave a reasonable representation of the flow path and high reflection of light from these particles facilitates the photographic recording.

The experiments at varying crankcase pressure and piston crown geometries are conducted.

1. Convex Crown Piston

Spiral type flow motion is observed with convex crown piston as shown in figure 31. Looking at the flow from the exhaust side, it appears that the right hand side port has a dominant influence on flow (anti-clock motion if viewed from top). As such the two transfer ports are geometrically identical and equally spaced on either side of the central axis and it is difficult to attribute dominance of right side flow observed in the diagrams. Following Rizk (14) a possible explanation is a mutual suction action between the jets merging the two streams under certain conditions of flow geometry. To isolate the flow path from either transfer ports the tracer particles were introduced from one port at a time that is left and right transfer ports respectively(fig.32 & 33). In these cases the general nature of flow appears identical and almost similar to that when particles are introduced from both the transfer ports simultaneously. The detailed measurement giving pressure & velocity field should possibly yield better explanations in this regard. In figure 32 where particles are introduced from left side port it is observed that they travel in clockwise direction for a little while before carried by the right side jet in anticlock wise direction.

1.1 Effect of Crankcase Pressure

The observation in figure 31 to 35 pertains to

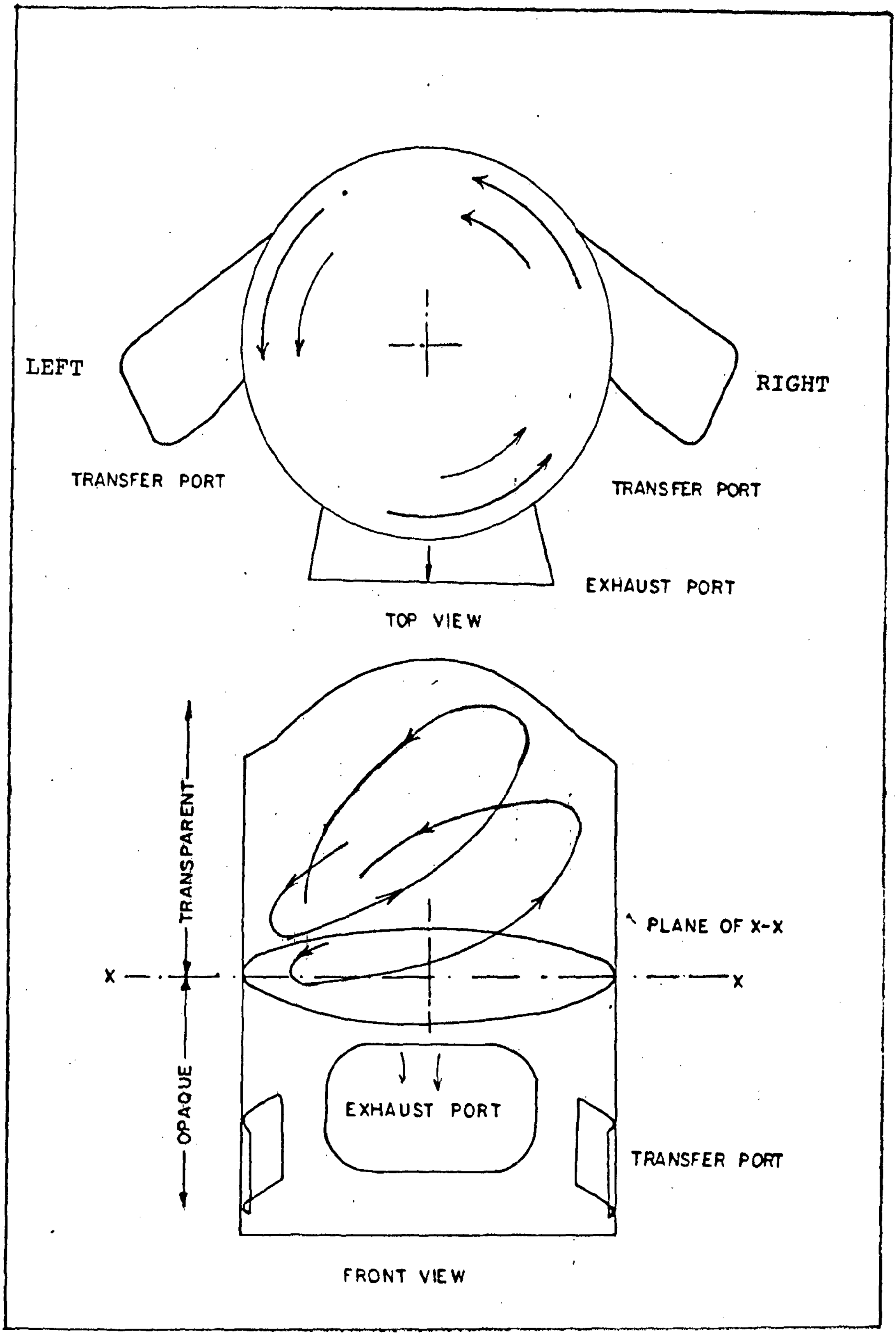


FIG. 31- FLOW Diagram with Convex Crown Piston at 70 mm Hg Crank case Pressure.

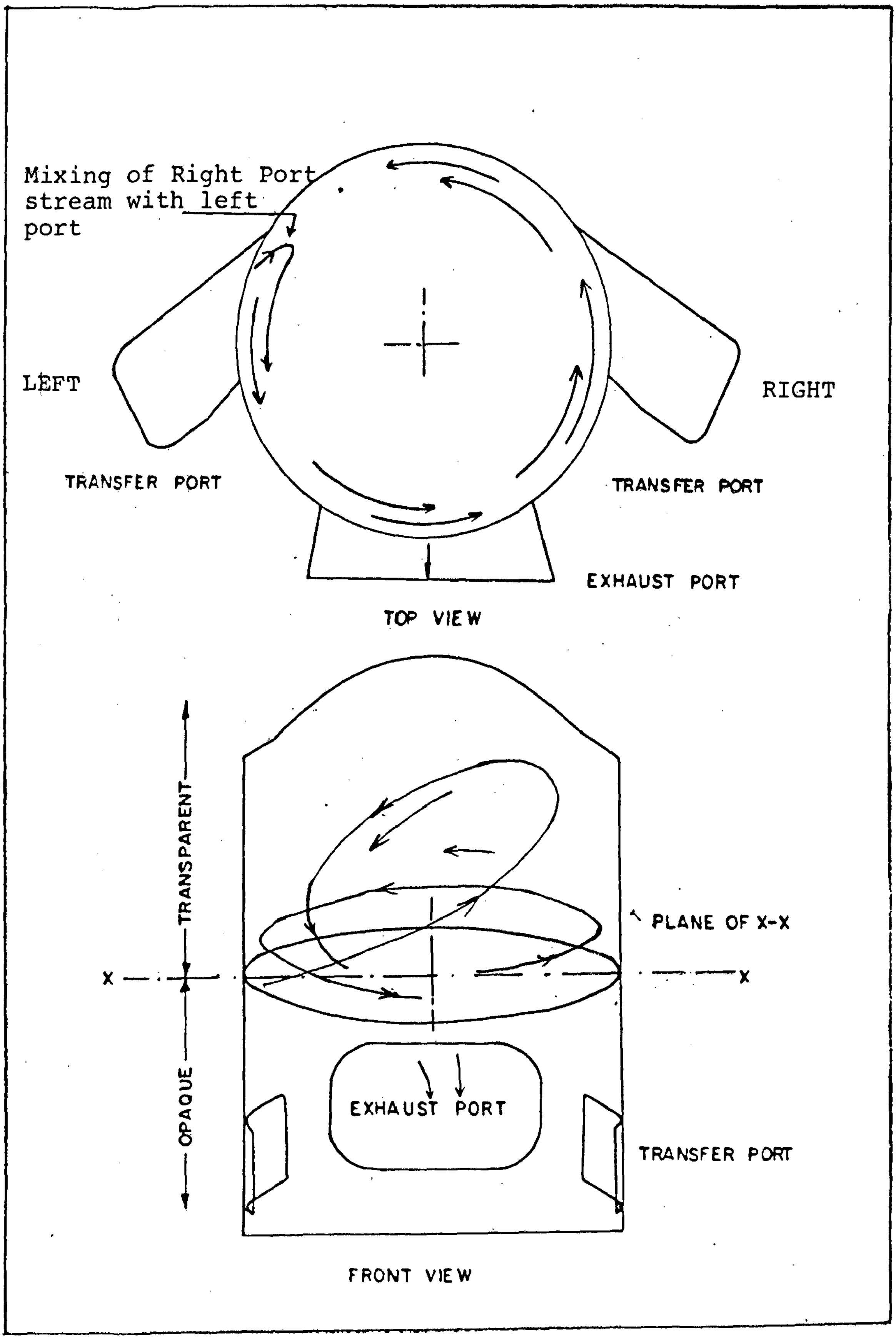


FIG. 32 - Flow Diagram with Convex Crown Piston at 70 mm Hg Crank case pressure with particles from Left Port.

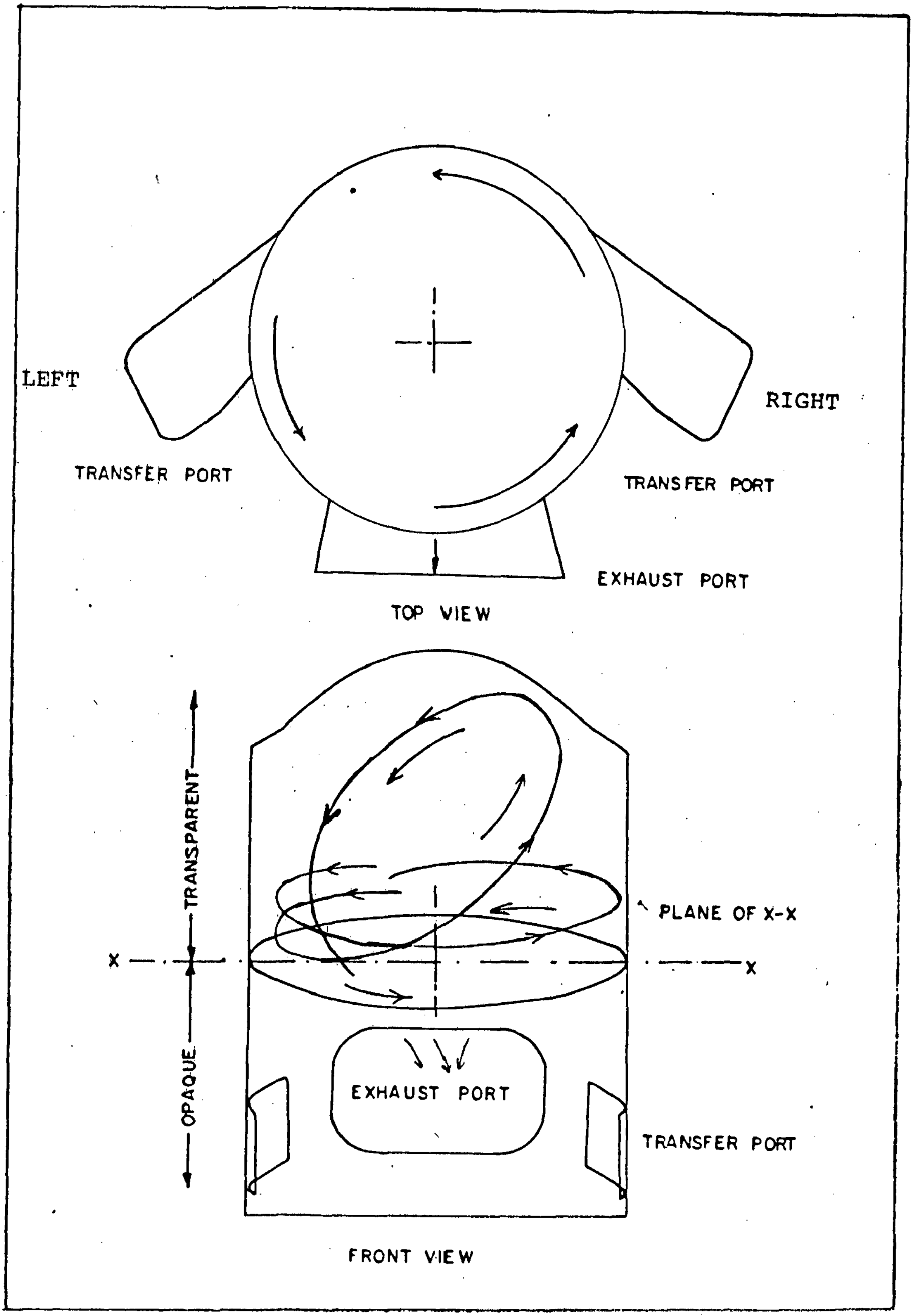


FIG. 33 - Flow Diagram with Convex Crown Piston at 70 mm Hg Crank case pressure with particles from Right Port

crankcase pressure value from 70 mm to 180 mm Hg. In case of 70 mm Hg pressure, the particle motion is spread to the cylinder wall (figure 31) . At 140 mm Hg pressure the jet velocity increases and spiral motion seems to confine in the central portion it self of the cylinder (figure 34). Further increase in crankcase pressure to 180 mm Hg, the jet spread is again extending to the wall region. This may be due to the effect of cenrtrifigual force acting on the particles due to the high velocity spiral motion, (figure 35) needing a quantitative confirmation. The direction of motion remains anti-clock wise in each of these cases.

Some secondary flow path visualized in these diagrams show that the part of intake flow moves faster, towards the exhuast port suggesting a kind of suction effect. During these experiments,the particles are seen coming out of the exhaust. This is perhaps the well known charge short circuting.

These findings concerning the spiral motion near walls is confirmed from the view point expressed by Phatak [16] in similar investigations based on ammonia diazo paper technique. He observed while the jet fluid is in contact with cylinder wall, the flow does not detach but continues to move around wall in circular path until the path return to its origin or finds an escape passage that is exhaust port.

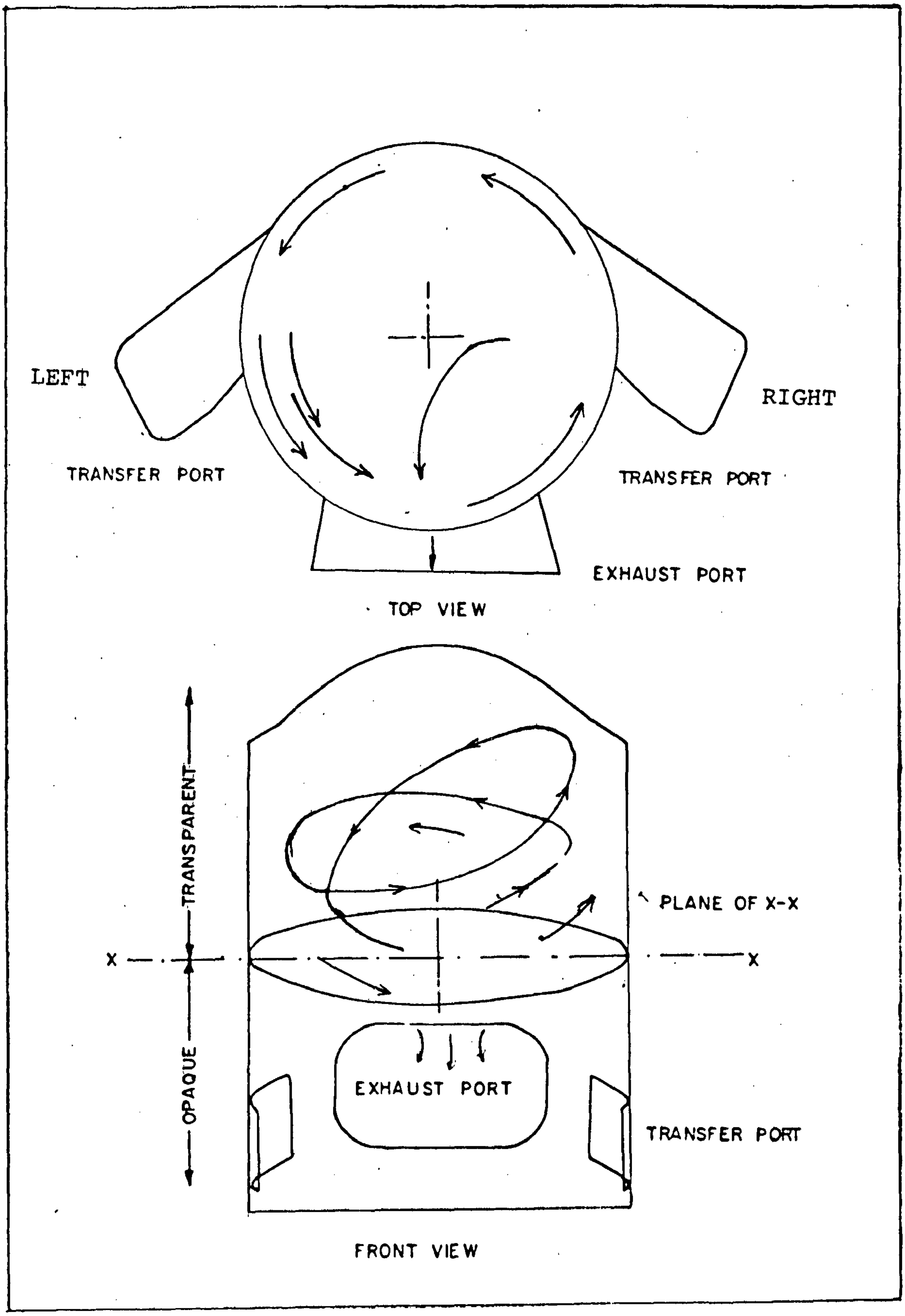


FIG. 34 - Flow Diagram with Convex Crown Piston at 140 mm Hg Crank case Pressure.

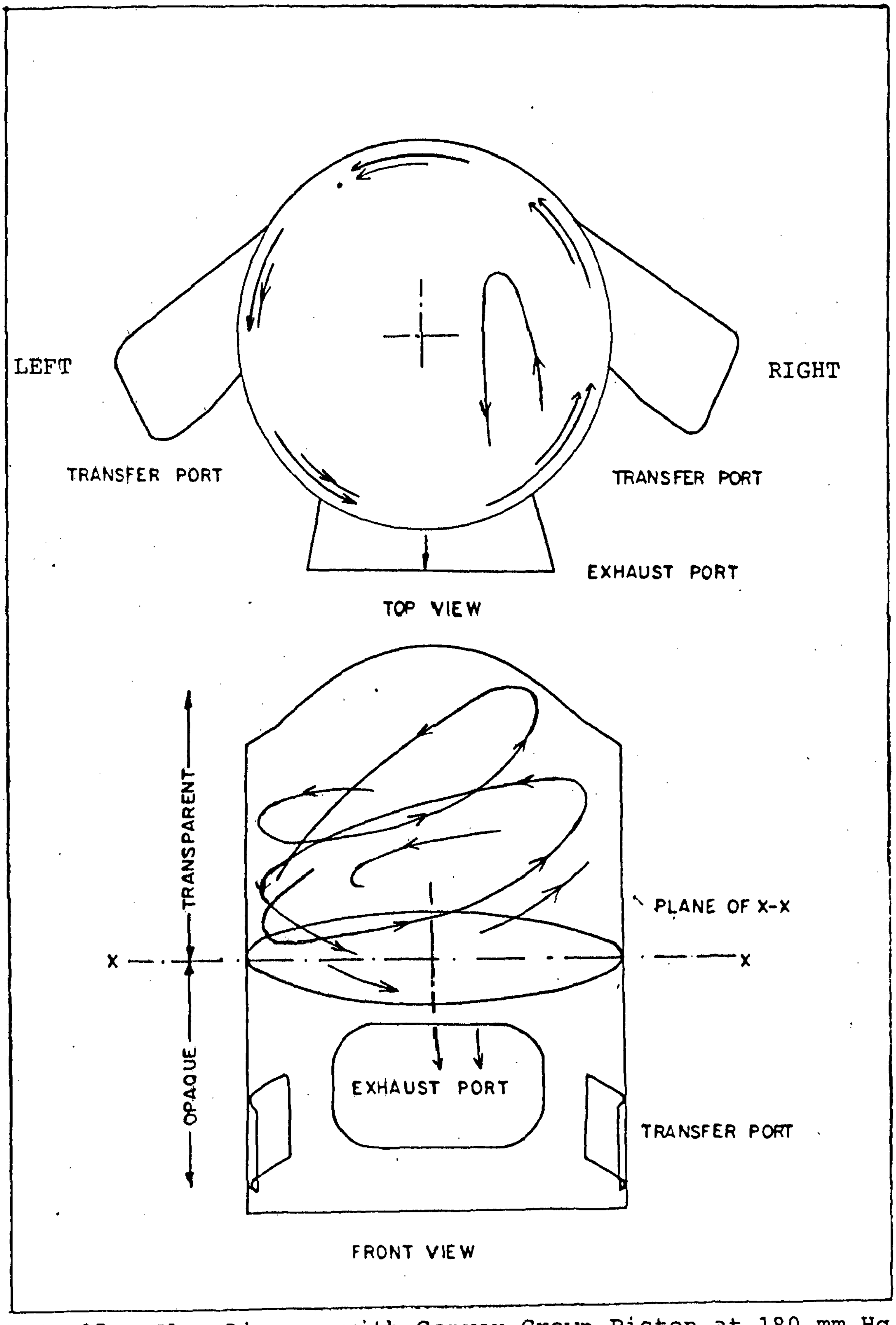


FIG. 35 - Flow Diagram with Convex Crown Piston at 180 mm Hg Crank case Pressure.

2. Deflector Crown Pistons

The results of another set of experiments conducted using deflector crown piston are shown in figure 36 to 38 at varying crankcase pressure values of 70,140 and 180 mm Hg respectively. The incoming air jets deflect towards the cylinder head and then towards the exhaust port side (figure 36). The nature of flow patterns is generally observed to be loop type alongwith spiral motion.

2.1 Effect of Crankcase Pressure

At crankcase pressure 70 mm and 140 mm (figure 36 and 37) spiral motion appear alongwith the loop type of motion. However, further increase in crankcase pressure to 180 mm Hg shows a dominent spiral motion (figure 38.)

3. Comparison of Piston Shape

The spiral motion is observed with convex crown piston at all crankcase pressures. In case of deflector crown piston, a spiral motion along with a rising current towards the cylinder head, possibly after striking the piston deflector, is observed at low crankcase pressure. At high crankcase pressure, spiral motion dominates the flow pattern. It suggests that the influence of the piston on the nature of motion is significant at low crankcase pressure. But at high crankcase pressure the differences due to piston crown are insignificant and the flow is mainly governed by the port geometry.

The experimental observations presented in this work remain limited to two parameteric variations only, due to large amount of efforts spent on devising and setting up the test bench and a technique of flow visualization, which is relatively simple and still provides adequate confirmation at least in terms of qualitative observations. The present set up uses an actual engine cylinder limiting the operation to the critical period of scavanging only for the purpose of cold dynamic simulation.

The influence of actual piston motion is thus preserved. One of the limitation in this set up is that air has been introduced to the air medium (density ratio = 1 : 1) although in real process fuel air mixture is introduced to residual gas mass (density ratio 1.6 : 1). The potential of the present technique would have increased considerably if high speed photography was possible. This would have made even the quantitative prediction possible. Non-availability of high speed photographic facility proved an handicap to prove the point in the limited time available.

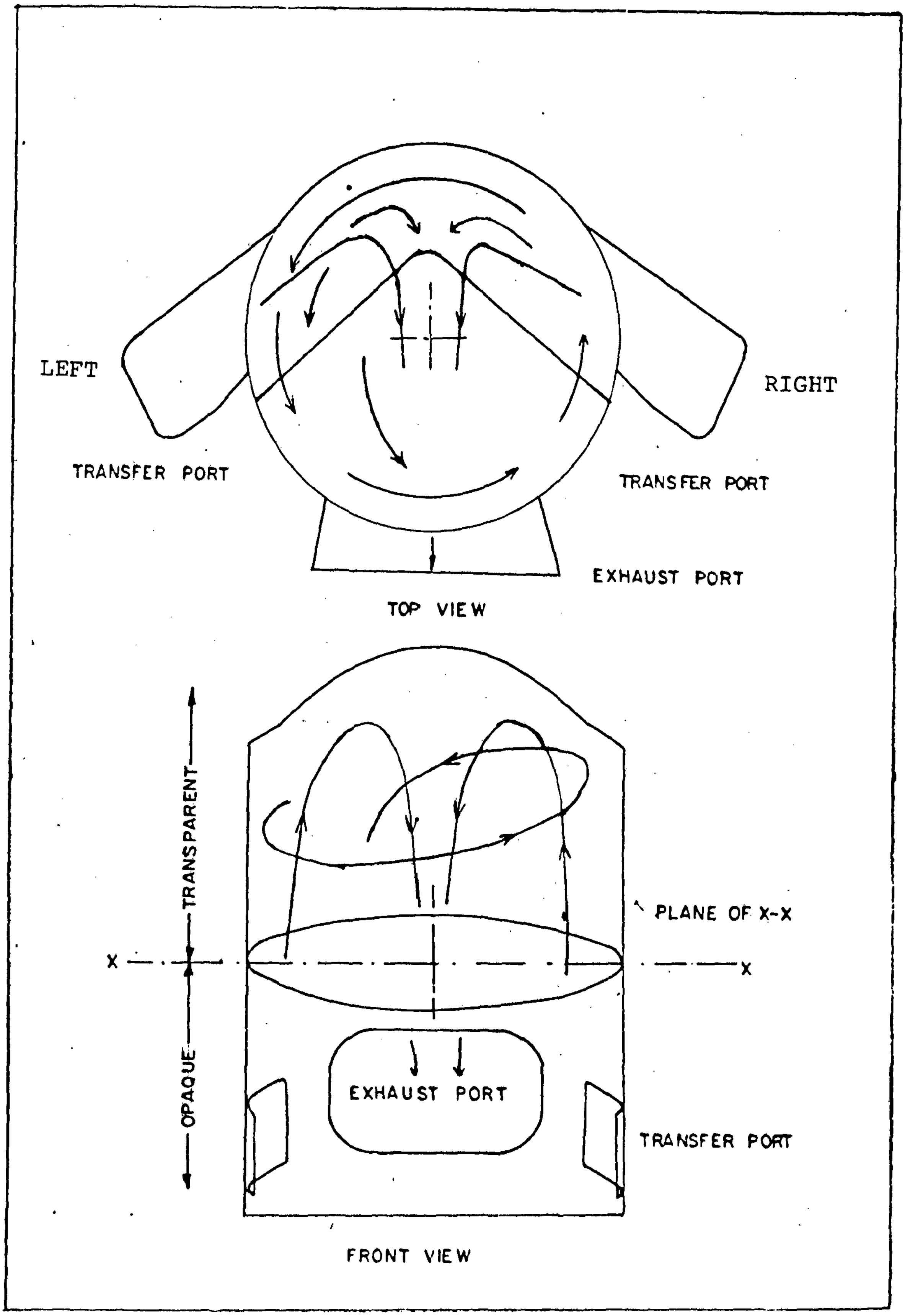


FIG. 36 - Flow Diagram with Deflector Crown Piston at 70 mm Hg Crank case Pressure.

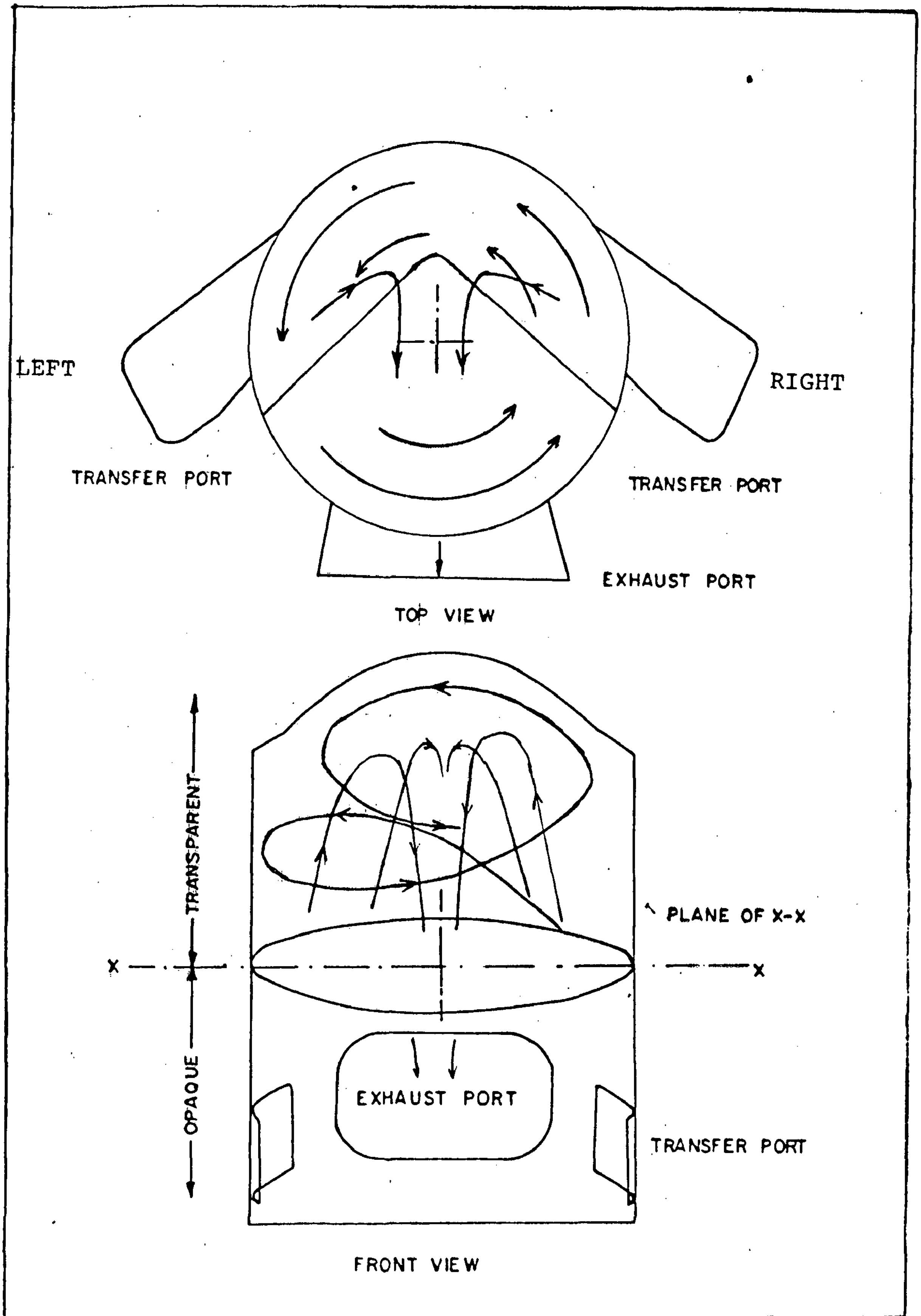


FIG. 37- Flow Diagram Deflector Crown Piston at 140 mm Hg Crank case Pressure.

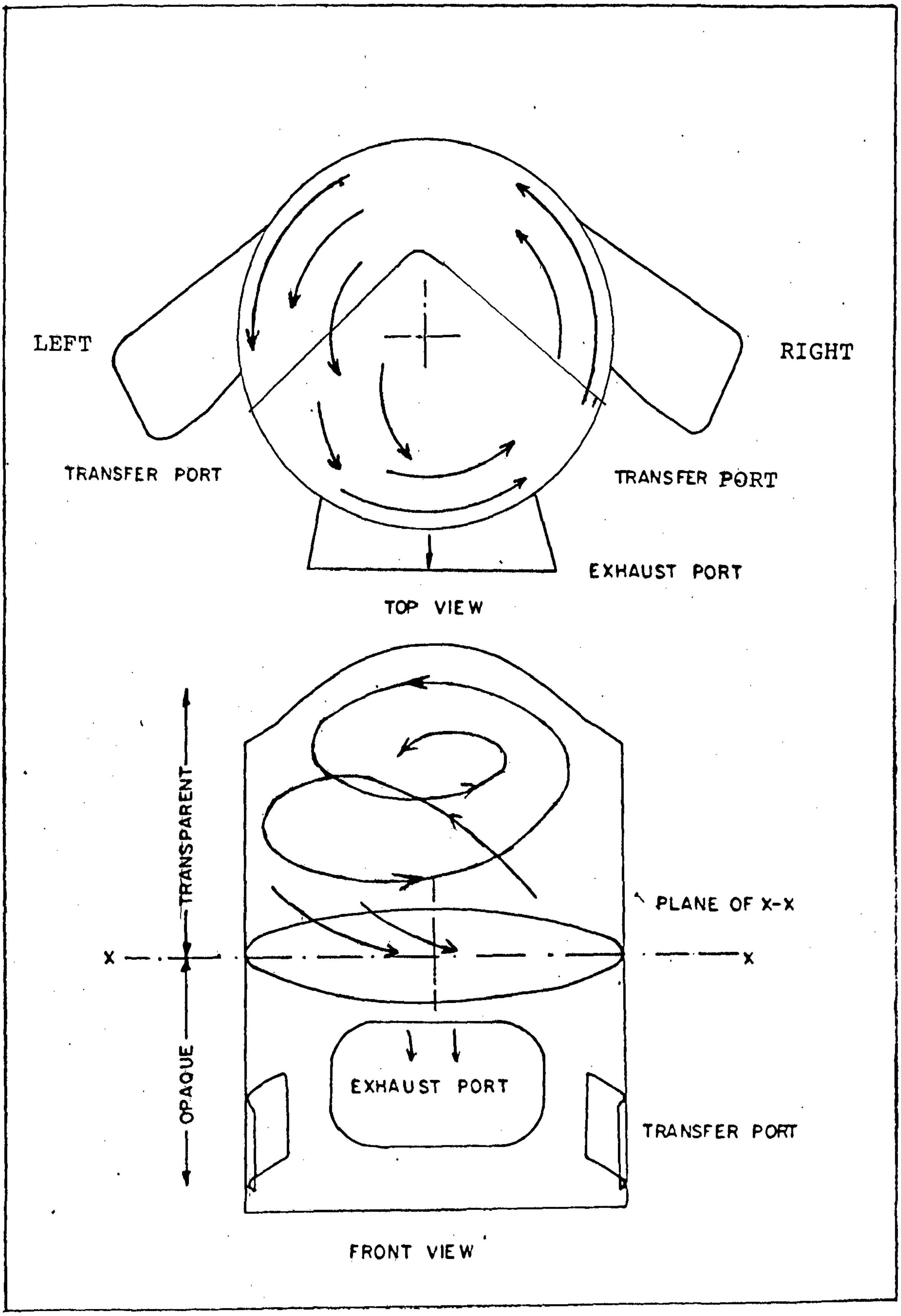


FIG. 38 - Flow Diagram with Deflector Crown Piston at 180 mm Hg Crank case Pressure.

CHAPTER - V

CONCLUSIONS

A test rig for flow visulization during scavenging period in two stroke cycle engine has been developed. The technique provides a view of the flow pattern in an actual engine. The technique employed video photography which though is at low speed but is quicker and cheaper. From the qualitative analysis of the photographic records the following conclusions are drawn:

1. The port design investigated provides spiral motion in the cylinder. In the test design, the flow through right hand side transfer port dominates in deciding the flow direction.

2. The flow pattern is influenced by port design and piston crown shape. At higher crankcase pressure, port design influence dominates the flow pattern.

3. Spiral flow patterns for convex crown piston and spiral motion along with loop type flow patterns for deflector crown piston are observed. The loop type pattern became less predominant at high crankcase pressure with deflector type pistons.

4. For quantitative analysis of the flow, high speed photography should be tried. Also the type of flow structure that results in good engine performance is to be identified.

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APPENDIX -I

ENGINE SPECIFICATIONS

Engine	2-stroke, single, horizontal cylinder, blower cooled.
Bore (mm)	57
Stroke (mm)	58
Capacity(cc)	150
No. of ports	4
Comp. ratio	7.8
Transfer port opening, (deg)	120
Transfer port closing, (deg)	240
Intake port opening, (deg)	292.5
Intake port closing, (deg)	67.5
Exhaust port opening, (deg)	104.5
Exhaust port closing, (deg)	255.5

(TDC = 0 or 360 deg)

APPENDIX -II

VIDEO CAMERA SPECIFICATIONS

Make	National M7A
Video Recording System	4 Rotary heads, helical scanning system
Shutter speed	Normal,1/500 ,1/1000 s
Tape speed	23.39 mm/s
Tape Format	VHS tape
Image sensor	1/2 CCD Image sensor
Lens	6:1 Power Zoom lens with Macro function, Auto Focus system F 1.2(9-54 mm) Lens Front diameter 49 mm
Standard illumination	1400 lux
Minimum required illumi-nation	10 lux