DESIGN

of an

INTERNAL COMBUSTION ENGINE LABORATORY

for

Robert College

by

Fedon Papadopulos

Robert College

Graduate School of Engineering

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PREFACE

The work presented in this volume is an attempt to design an Internal Combustion Engine Laboratory for Robert College.

One of the early steps towards the accomplishment of this was to find out what has been done and what is being done along these lines in the leading universities of the U.S.A. Letters were written to several of them, requesting information. In almost 70 per cent of the replies it was stated that the I.C. engine laboratory had been dropped in order to teach more theoretical subjects, and that the engine laboratory equipment were rarely used.

However, it is the author's belief that the I.C. engine provides a convenient piece of equipment in which important applications of many basic physical and engineering principles may be found, and therefore a course in I.C. engines should be accompanied by adequate laboratory experimentation.

In view of the above, emphasis was laid on the design of the experiments, and only a few changes and additions to the existing laboratory were suggested.

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Fedon Papadopulos

CONTENTS

PART ONE

A.- The Importance of Practical Training and Laboratories

B.- Engine Laboratory

C.- How the Experiments were Selected and Designed

THE IMPORTANCE OF PRACTICAL TRAINING AND LABORATORIES

In the early days, when engineering first made its appearance as a profession, and during the first period of its development, an engineer was supposed and expected to know the practical side and the technical know-hows of his profession, in addition to being well acquainted with its theoretical side as well. There could be no excuse for a mechanical engineer who would not know how to handle, operate, adjust, and even repair any machine that existed at that time. He actually was considered to be a mechanic, who was well trained in theory, too.

As a result of the rapid development of science and technology, it is not possible any more to give to a young engineer a thorough theoretical background and also train him as a skilled mechanic, during the four or five years of College or University education. Because of this, more importance is placed on theory than on practical training during this education period, and the young engineer is expected to learn the practical side of his profession in the first years of his employment in industry.

But it is a known fact that theoretical education and what industry actually demands are two different things. Although today, mechanical engineers are not required to be able to compete with skilled mechanics, however, they are expected to have some practical experience.

The various laboratory courses which a student is require to take during his education, might be considered to form the cradle of his practical experience. It is in the laboratory that an engineering student has the first opportunity to get acquainted and become familiar with various measuring instruments, their calibration and use, actual measurement techniques, application and/or verification of theoretical principles, operation and testing of equipment, accuracy and limitations of methods and processes, etc. It, therefore, follows that in order to enable a young engineer to begin his actual training in industry with the least possible degree of difficulty and disappointment, it is essential to equip him with a good laboratory experience.

No simple statement can or should be made of the object of mechanical engineering laboratory. It is certainly not a course in machinery testing, nor is it a series of demonstrations to verify classroom theory. The object of a single experiment may be narrow or specific (to calibrate an instrument, to measure the properties of a fluid, or to obtain the performance curves for an engine), but, as it was mentioned before, the real purpose of the course is to provide occasions and equipment for the beginning of actual practice of the profession of mechanical engineering.

ENGINE LABORATORY

The internal combustion engine has become such an important servant in everyday life that every mechanical engineer must have sound knowledge about it. It is the kind of equipment that generates more power than all others combined. This is the present status of the internal-combustion engine. Perhaps the gas turbine or atomic power plants will cause sudden shifts, but versatility and mass production give great economic advantage to the piston engine, and the gas turbine is a combustion engine, anyway. Technical advantages of the internal combustion engine include economy, rapid acceleration and deceleration, w wide speed range, readily available fuel, great range of sizes, lightness and compactness, ease of control, reliability, long life, and high torque.

The comparatively high efficiency and reliability of the modern high speed internal combustion engine is mainly due to the application of test and research information and results. It can be stated that the only satisfactory method of developing present-day engines is along the same lines. In the early days of the internal combustion engine, the designer worked in an atmosphere of doubt and uncertainty, but with time he gradually gathered information and design data, as a result of constantly testing, adjusting, and making changes in the existing designs. The application of the test data enabled him to improve radically his products, to formulate theories in order to explain the observed phenomena, and to predict, as far as possible, the effect of certain changes in the design. Very often, also, while searching for an explanation of an observed effect, he ended with another and much more important result. In this connection the same possibility exists even today.

The testing of internal combustion engines usually falls into one of three categories, as follows:

1.- Routine and acceptance tests
2.- Tests of new types or designs to study the effects of certain design changes
3.- Analytical or research tests.

The former type of test is that generally carried out at factories, in order to ascertain whether an engine gives about the expected output, and to test its reliability. This is a simple test.

The second class of test is a more thorough one, and involves the use of additional apparatus and methods in general. It includes testing of the experimental designs of engines which are intended for the market at a future time. The modern tendency towards higher and higher efficiency and output from a given size of engine, and the existence of competition among firms, makes necessary for the manufacturer to improve and redesign his products constantly. It is clear that this type of test is a very important one, because the whole future of the internal combustion engine depends on it, as far as commercial products are concerned.

The third type of test comes into the domain of scientific research. It is undertaken in order to find out the reasons for complex phenomena known to occur, to test the validity of explanatory theories, which may eventually have great influence upon design, and to analyse the behaviour of existing and new types of engines with the purpose of indicating the ways in which they can be improved.

The only criterion by which the performance and possibilities of an entirely new design of engine can be accurately determined is that of research results. Thus, a new engine will be set up on a test-bed, and its speed, torque, fuel and oil consumptions, brake and indicated power, volumetric and thermal efficiencies, and heat balance, etc., calculated. From the results, a comparison will be made with those of existing, or ideal, standard engines, and a definite opinion will be formed as to its possibilities. Very frequently also, the process of the investigation will indicate the direction in which beneficial changes can be made.

The internal combustion engine is a complex machine which presents to the students a wide variety of problems. Experimental analysis of these problems is of interest not only to those who intend to specialize in the field of internal combustion engines, but also to mechanical engineering students in general, because the internal combustion engine provides a convenient piece of equipment in which important applications of many basic physical and engineering principles may be found.

One of the primary purposes of the internal combustion engine laboratory must, as the title implies, be the experimental investigation of the various problems involved in the internal combustion engine, and their influence on its performance. However, the laboratory, or experimental, approach to internal-combustion engineering does not begin and end with engine testing. On the contrary, it must begin with the basic experimental studies in thermodynamics, fluid mechanics, combustion, and heat transfer. It must include a knowledge of lubrication, properties of fluids, pumps and compressors, instrumentation, and control. These are good reasons why the subject is taught in the senior year. Most of the courses taken in previous years contain material which is of value in understanding the details of operation of internal combustion engines.

HOW THE EXPERIMENTS WERE SELECTED AND DESIGNED

Many experiments may be run on internal combustion engines. These may be either directly related with the operation of the engine itself, or they may be auxiliary experiments which help the student get acquainted with the operation, adjustment, or maintenance of various parts and components of an engine.

Another group of experiments might include methods of measurement of pressure, temperature, speed, torque, power, rate of flow of fluids, fuel-air ratio, etc., all of which constitute the necessary tools for the determination of the effects of various variables on the performance of an engine.

Still another group might consist of methods for adjusting and/or determining spark advance, valve timing, compression ratio, engine dead centers, etc.

The problem of selecting what is worthy of illustration, and designing an experiment to illustrate it, is not as easy as it might appear at first glance.

Simplicity and Completeness:

The experiment should be so designed that it will clearly indicate the effect of a certain variable on the operation of the engine. It should be simple, to enable the student to feel the dependence of the performance of the engine on that specific variable, while running the experiment, and not simply by trying to interpret in his report a number of data taken some time ago, very often weeks ago, when the experiment was actually made.

On the other hand, it should be complete, and it should not overlook the interdependence of certain variables, and their mutual effects on the overall performance of the engine.

Length of experiment:

Time available in a laboratory period is also of importance in designing an experiment.

The experiment should be planned in such a way that a normal laboratory session will be sufficient for its completion. It is not a good practice to continue performing an experiment for a considerable length of time after the end of the laboratory session devoted to it, or to cut it in half, and complete it in the next laboratory period. In the first case the students loose interest in the experiment itself, and they simply try to complete it without actually understanding what they are doing. In the second case the continuity of the experiment is lost, since it is not possible to duplicate laboratory conditions exactly as they were during the first half of the experiment.

However, despite the fact that its educational value is affected inboth cases, occasionally an experiment will have either to be extended beyond the normal laboratory period, or to be completed in the next laboratory session.

EQUIPMENT:

Availability of equipment and apparatus is not very important in the present situation, since these will be selected and their purchase decided on the basis of what is needed for the experiments. In other words, the fact that some of the necessary equipment might not be existing in the laboratory at present, introduces no problems.

Howeverm in designing the experiments, an effort has been made to keep the number of special equipment (required only for one experiment or two) low, in order to make the realization of the laboratory possible with a reasonable amount of money.

LIMITED TIME:

Owing to the limited number of laboratory sessions available during one semester (the course on internal combustion engines is normally taught in one semester), some of the experiments had to be shortened and combined into one unit capable of being completed in one laboratory meeting.

EDUCATIONAL VALUE:

The most important factor in selecting the various experiments, over and above all other criteria, was the educational value of each one, that is, its capability in aiding the student understand a particular phase of the operation of the engine, or the role of a certain variable on the performance of the engine, compared to the time required for its completion.

As far as the auxiliary experiments are concerned, the selection of each one of them involved the evaluation of several points, the most important of which were the following:

1.- Importance of the equipment or method involved as a tool for handling a particular problem frequently encountered in internal combustion engine experiments.

2.- Whether the student had any chance to become familiar with the operation of the equipment or the application of the method in courses taken in previous years.

CHARACTER OF THE EXPERIMENTS:

The experiments presented in this work are intended to guide the instructor or the student as to what to do and how to do it, usually giving him the method of approach in general lines only, but not very seldom, going deeper into details, too. In this way, a certain degree of flexibility is allowed, to satisfy special interests and needs of the individuals.

It is the author's belief that an experiment becomes more instructive if the students are given the general outline only, and they are allowed, and expected to work their own detailed methods of attack. This approach to laboratory work makes the students feel more important because more responsibility is placed on them, and this in turn stimulates their initiative. They begin to trust their abilities and qualifications as engineers and try to expend their creative thinking.

The old method of giving to students long and detailed experiment sheets is not considered to be a good approach, any more, because in this case the students' initiative is not required to play any role towards the solution of various problems, since the solutions are already in their hands. Then, the only thing the students have to do is to follow step by step the instructions given in the experiment sheet, record the data called for, and then feed these data into the formulas given, finally coming out with a result, which most of the times means very little to them.

It is obvious that such an approach to laboratory work is far from being interesting and of any benefit to the students.

On the contrary, in the method used in the present work, the students are encouraged to consider the experiments not merely as means to collect some empirical data, but rather as tools intended essentially to help them cultivate and develop initiative and self-reliance, as well as the spirit and techniques of rational experimental investigation.

PART TWO

I. C. Engine Experiments

ENGINE INSPECTIONS

INTRODUCTION:

Time is usually not available for obtaining the general data on an engine during the same period when a test is run. It is important to collect the general information required by the test, and if this information is available prior to the test, it is easier to interpret the engine performance.

Hence, this experiment covers a general survey of laboratory equipment and the assembling of preliminary data on the engines to be tested later.

INSTRUCTIONS:

(1) Make a list of the engines set up in the laboratory, giving name, type, rating, speed range, etc.

(2) Make a separate list of special equipment and instruments available for the testing of internal-combustion engines. (Record the data on forms similar to the ones provided at the end)

(3) For the spark ignition engine make an actual measurement of clearance if possible, by removing the cylinder head and filling the combustion-chamber recess with oil from a graduate (with piston on top dead center).

(4) Mesure the linear opening of each valve on one cylinder

of the engine, at intervals of 15 degrees of crank angle, over the entire cycle.

(5) Locate dead centers by the angular method.

(6) Determine:

(a) breaker-point gap

(b) spark-plug gaps

(c) spark timing.

REPORT:

(1) Present the lists and forms in orderly tabular form.

(2) Plot a curve of linear valve lift (on ordinates) against crank angle for both valves.

(3) Indicate dead centers and spark timing on the same diagram.

(4) Calculate theoretical otto and diesel-cycle efficiencies by the following equations:

$$E_{otto} = 1 - r^{k-1}$$

$$E_{diesel} = 1 - \frac{1}{r^{k-1}} \left[\frac{s^k - 1}{k(s-1)} \right]$$

where: k = specific heat ratio (= 1.4)

r = compression ratio

s = ratio of volume at fuel cutoff to maximum total volume of cylinder.

(5) Define or explain the following engine terms:

(a) camshaft

(b) crankshaft

(c) push rod

(d) wrist pin

(e) injection valve

(f) connecting rod

(g) distributor

GENERAL DATA OF SPARK IGNITION ENGINE:

1.- Engine make and model

2.- Type of service

3.- Engine general type

4.- Number of cylinders

5.- Bore X stroke

6.- Total piston Displacement

7.- Clearance volume

8.- Compression ratio

9.- Compression pressure

10.- Cooling system

11.- Carburetor make and model

12.- Ignition type

13.- Firing order

14.- Spark-plug location

15.- Spark-plug gap

16.- Control of spark advance

17.- Lubrication system type

18.- Kind of fuel

19.- Heating value of fuel

20.- Grade of lubricating oil

21.- Dynamometer make and type

22.- Dynamometer arm length

23.- Room temperature

24.- Barometric pressure

GENERAL DATA OF DIESEL ENGINE:

1.- Engine make and model
2.- Type of service
3.- General type of engine
4.- Speed
5.- Number of cylinders
6.- Bore X stroke
7.- Total piston displacement
8.- Compression volume
9.- Compression ratio
10.- Compression pressure
11.- Type of cylinders
12.- Piston type and length
13.- Number of rings and kind
14.- Cooling system
15.- Type of fuel injection
16.- Fuel injection pressure
17.- Make and model of fuel pump
18.- Injection valve location
19.- Injection timing
20.- Lubrication system
21.- Grade of oil used
22.- Fuel used
23.- Heating value of fuel
24.- Method of starting.

25.- Dynamometer make and type

26.- Torque arm length

27.- Room temperature

28.- Barometric pressure

TUNE-UP AND ADJUSTMENTS
OF AN INTERNAL COMBUSTION ENGINE

INTRODUCTION:

Much specialized equipment has been developed for the service testing of engines, but most of the important checking may be done with simple equipment, including a few electric meters and pressure gages with suitable wiring and connectors.

Engine tests may be devided into three classes, for checking:

1.- The general mechanical condition

2.- The electrical system and its parts

3.- The fuel system.

Measurements of compression pressure and of the vacuum in the intake mainfold give some idea of the condition of piston rings, cylinders and valves. Electrical tests are concerned mainly with current and voltage readings on the low-tension side, and voltage and spark-gap tests on the high-tension side. Aside from a low charge battery or poor connections, ignition defects are most likely to be found in the spark plugs or the breaker points, although occasionally a poor condenser or a faulty coil will be found.

Performance of the fuel sytem is usually checked by means of the exhaust-gas analyser, giving approximate readings of fuel-air ratio.

When tests of each cylinder are made in multicylinder engines, as in measuring compression pressure or testing spark plugs, the uniformity of the readings is of more importance than their absolute value.

EQUIPMENT:

The checking and tuning-up of an internal combustion engine can be done with ordinary tools and instruments, but special testers, if available, are of course more convenient.

INSTRUCTIONS:

The following list covers the simpler adjustments and the more important tests:

A.- Chacking the general mechanical condition of the engine

1.- Start engine and allow it to warm up. Then connect vacuum gage to intake manifold. Note gage reading and fluctuation at idling speed. Also observe change in gage reading when throttle is suddenly closed (released) after high speed operation.

2.- Remove spark plugs and test compression in each cylinder with compression gage equipped with check valve. Recheck each cylinder after squirting in a little oil.

3.- Clean and test spark plugs. Then adjust spark gaps of plugs and replace them.

B.- Electrical checking, primary circuit.

1.- Check the specific gravity of the battery solution.

2.- Connect voltmeter across battery, and check open-circuit voltage.

3.- Connect voltmeter to generator lead and ground, and check generator voltage with engine running at about 75% maximum rated speed. Check voltage when engine is turned by starter.

4.- Remove distributor cap, and inspect all connections. Inspect breaker points, and measure maximum breaker-point gap. Check condenser.

5.- Take measurements of:

a) primary voltage at coil

b) primary current at coil, engine running and not running.

C.- Electrical checking, secondary circuit

1.- Measure high-tension voltage at coil and at each spark plug.

2.- Measure high-tension current at coil and at each spark plug.

D.- Carburator adjustment and gas analysis

1.- With vacuum gage connected to intake manifold change idling adjustmont on carburator to obtain least fluctuation of pressure.

2.- Take readings with exhaust-gas analyzer, using sampling tube inserted in end of exhaust pipe. These readings should be taken at idling speed, medium speed, and during acceleration.

REPORT:

Use given data sheet for recording readings. The report should include a discussion of the results of each measurement and suggestions for improvement of the condition of the engine.

NOTES and PRECAUTIONS:

1.- Compression pressure should be nearly the same on all cylinders if valves and piston rings are in uniform condition. To distinguish between faulty ring action and faulty valve action squirt a little oil into the cylinder to help seal the rings. If there is no change in pressure, the rings are sealing satisfactorily.

2.- If all spark plugs do not test about the same after cleaning, check distributor cap and high-tension leads. Uniformity at all plugs is of more importance than actual values of instrument readings.

3.- In making spark-gap settings or any other adjustments, follow the engine manufacturer's recommendations.

DATA SHEET:

Engine make:

Engine type:

Engine No. :

Date of test:

1.- Intake-manifold vacuum in Hg.

a) Turned by starter

b) Engine idling

c) Fluctuation when idling

2.- Compression pressures, lb gage

a) Dry

b) With oil

3.- Spark-plug gaps, in

4.- Specific gravity of battery

5.- Primary voltage of battery

a) Engine not running

b) Turned by starter

6.- Generator voltage,
engine running at 75% rated speed

7.- Breaker-point gap, max, in.

8.- Primary voltago at coil

9.- Primary current to coil:

a) Engine running

b) Engine not running

10.- High tension voltage

11.- High tension current

12.- Air-fuel ratio

a) Idling

b) Accelerating

c) At 75% rated speed.

VARIABLE LOAD TEST
OF AN INTERNAL COMBUSTION EINGE

INTRODUCTION:

The stationary internal combustion engine is usually a constant speed machine operating under governor control. Engines that actually operate at varying speeds may be kept running at a constant speed by manual control.

Whatever the type of engine, a test covering the full range of torque loads, at a number of constant speeds, will serve to identify its general characteristics. Such results as brake mep, exhaust temperature, and bsfc curves will provide an evaluation of the engine performance.

In the following discussion it will be assumed that the engine to be tested is a four-cycle, single- or multi-cylinder, spark ignition or compression ignition internal combustion engine operating on liquid fuel.

APPARATUS:

The engine should be provided with a suitable dynamometer and also with a cylinder pressure pick-up. Other apparatus required for the test is as follows:

a) Calibrated techometer

b) thermometer for air-inlet temperature

c) thermometer for inlet and outlet temperature of the cooling water.

d) thermometer for temperature of fuel

e) thermometer for exhaust-gas temperature measurement

f) Instruments for measuring rete of flow of fuel and of cooling water

g) planimeter

h) oscilloscope

DETERMINATIONS:

A steady state should be assured for each run. Preliminary observations establishing the attainment of steady state must be a part of the recorded test data, and each run must continue at least 15 minutes, with repetitive readings that check closely. At least 10 minutes are required between tests for the new condition to be established.

The number of test runs necessary to determine a curve depends on the nature of the curve and the quality of the runs, but it will be found sufficient for a student laboratory to test at full, three-fourths, one-half, and one-fourth maximun torque and no load.

During a given test the conditions must not deviate from the average for the test by amounts greater than the following:

Torque :	± 3%
Speed :	± 3%
Coolant outlet :	± 5 °F

Coolant temperature rise: ± 5 °F

While the test is in progress, an input output curve (weight of fuel per hour versus brake horsepower) should be plotted. If the tests are accurate the points will plot on a smooth line, slightly concave upward.

RESULTS AND REPORT:

The results to be reported in this test are indicated in the data sheet.

Curves should be plotted with brake horsepower on the abscissas, showing the variations of fuel consumption ,bsfc, mechanical efficiency, brake thermal efficiency, indicated thermal efficiency, and rpm if the engine has a governor.

In addition to tabular and graphical presentation of results the report should summarize the findings and should evaluate both the accuracy of the tests and the results obtained.

SPECIAL INSTRUCTIONS AND PRECAUTIONS:

1.- Before starting the engine see that the dynamometer is enchored or held in such a way that it will not cause damage if the engine backfires.

2.- Check the lubricating oil and the fuel supply.

3.- Turn on cooling water before (or immediately after) the engine has been started. Also check for proper lubrication.

4.- Be sure to allow sufficient time for the establishment of a steady state before beginning a set of readings.

DATA SHEET:

Engine data:

1.- Make of engine

2.- Engine type and classification

3.- Rating, hp.

4.- Rated speed, rpm.

5.- Number of cylinders

6.- Bore

7.- Stroke

8.- Type of carburetor, or fuel injection.

9.- Type of ignition

10.- Higher heating value of fuel used.

Expermental data:

1.- Duration of run, minutes

2.- Air inlet temperature

3.- Cooling water inlet temperature

4.- Cooling water outlet temperature

5.- Dynamometer arm length, ft.

6.- Force applied to dynamometer arm, net lb.

7.- Torque, lb-ft.

8.- Engine rpm

9.- Brake horsepower, hp

10.- Inicated horsepower, hp.

11.- Friction horsepower, hp

12.- Mechanical efficiency

13.- Quantity of fuel used for fuel consumption measurement

14.- Brake specific fuel consumption, lb/bhp-hour

15.- Brake thermal efficiency

16.- Indicated specific fuel consumption, lb/bhp-hour

17.- Indicated thermal efficiency

18.- Rate of heat loss to cooling water.

NOTE:

All the above items 1 to 18 will be filled separately for each run at:

a) full-load

b) three quarters maximum torque

c) one half maximum torque

d) one quarter maximum torque

e) no load

and at:

a) rated speed

b) three quarters rated speed

c) one half rated speed

ENGINE FRICTION

INTRODUCTION:

Friction is a serious loss in the I.C. engine, but it is difficult to measure. The term "engine friction" has, in fact, a rather indefinite meaning, unless the method of measuring the friction horsepower is specified. The sliding friction of lubricated surfaces is not easily separated from the pumping losses of fluid friction.

If friction-test measurements are to be significant, it is important that the operating conditions of the engine be as near as possible to the conditions existing when the engine is delivering power. Therefore, it may be desirable to obtain the friction data while other tests are being run, especially since the friction tests themselves are very short. In analyzing the performance of a given engine, it is desirable that friction tests be made by at least two of the three methods given below, if possible.

TEST METHODS:

1.- Motoring:

Motoring, or driving the engine by a dynamometer with the fuel supply and ignition cut off, is the usual method used for the measurement of engine friction. The friction test should be made immediately after the brake-horsepower test, before the engine has cooled and with the throttle in the same position as for the corresponding brake-horsepower test. Compression is not relieved, and all accessories such as generator and pumps should be in operation. Then, the friction horsepower is equal to the horsepower developed by the dynamometer.

The friction horsepower determined by this test at a number of speeds, for a given throttle setting, is plotted against speed.

2.- Cylinder Cutout:

The cylinder cutout method may be used only with multicylinder engines, preferably with six or more cylinders, and it is most satisfactory with a dynamometer that has a high flywheel inertia. By shorting out each spark plug in turn, the power delivered by each cylinder is measured. The load must be reduced by dynamometer adjustment to maintain the original speed. The loss in power at the shaft resulting from the sharting out of one cylinder then represents the entire indicated horsepower of that cylinder. The remaining cylinders are, in effect, carrying the friction horsepower of the cylinder under test, whether it is delivering power or not. Hence, the total indicated horsepower may be measured by this method, and the difference between this total and the full dynamometer horsepower at the same speed (all cylinders operating) is the friction horsepower of the engine at the particular operating conditions.

Multicylinder diesel engines may also be tested in this manner by making the governor inoperative and stopping the injection to each cylinder in turn.

3.- Extrapolation to Zero Load:

An input-output curve at constant speed, extrapolated to zero load, can be used for determination of approximate friction horsepower. This curve should represent tests at the same speed, with several light-load points, showing total fuel in pounds per hour on the ordinates and brake horsepower on the abscissas. The intersection of the extended curve with the axis of ordinates represents the total no-load losses, consisting of cooling losses, exhaust losses, and friction. To obtain a good degree of accuracy, it is necessary to determine both cooling losses and exhaust losses as a function of load, plotting and extrapolating in a similar manner, and subtracting to obtain the friction. The power absorbed by auxiliaries will, by this method, be included in the friction losses.

INSTRUCTIONS:

Of the test methods already described, it will usually be most convenient to use the dynamometer-motoring method and the cylinder-cutout method.

1.- Start the engine and allow it to warm up.

2.- Then gradually increase the load until the engine is running at wide-open throttle and maximum (rated) speed. Allow the engine to reach a steady state. Then:

A) If the motoring method is being used:

3.- Turn off the fuel supply and the ignition to all cylinders, and immediately run the dynamometer as a motor to drive the engine.

4.- Adjust the speed to the previous value and measure the horsepower delivered by the dynamometer to the engine. This is equal to the engine friction horsepower under the above mentioned throttle and speed conditions.

B) If the cylinder cutout method is being used:

3.- First measure the brake horsepower of the engine

4.- Then turn off the fuel supply or the ignition to one of the cylinders and adjust the speed to the previous value.

5.- Measure the new brake horsepower of the engine. The difference represents the indicated horsepower of that cylinder.

6.- In the same way measure the indicated horsepower of all individual cylinders, cutting off the fuel supply or the ignition to that cylinder only at a time.

7.- Be sure that the engine speed is adjusted to the original value (by varying the load) after cutting out any of the cylinders. The difference between the sum of the individual indicated horsepowers and the measured breakhorsepower of the engine with all cylinders firing, is the friction horsepower of the engine under the above mentioned throttle and speed conditions.

PROCEDURE:

1.- With either one of the two methods make a series of friction measurements at full throttle and decreasing speeds.

2.- Repeat the same series of friction measurements at throttle settings that allow the engine to develop, at each speed, three-fourths of the power that it developed with full-throttle opening at that same speed.

3.- Make similar tests at one-half and one-fourth loads.

If time is not available for the complete test as outlined above, the three-fourth and one-fourth load tests may be omitted. The time required may be further abbreviated by assuming that the throttle setting at which the engine will develop half load at one speed will also be the half-load setting for all other speeds.

Note: Since most of the total power loss in friction is caused by the sliding friction of lubricated surfaces, anything that increases the oil viscosity (low temperature, for instance) will increase the toal friction.

RESULTS:

Test results at different throttle settings and speeds should be plotted against motor speed. Plot a curve for each throttle setting and discuss the results.

DISCUSSION:

All three methods of friction measurement given in this experiment are only approximations.

In the motoring method as well as in the cylincer cut-out method, the cylinders, of which the friction horsepower is to be measured, are made imperative by cutting either the ignition or the fuel supply to them, or both. This means that the cylinders under question are not sujected to the same conditions of pressure (and temperature) as when they are actually delivering power. The reduced pressure results in a lower friction horsepower of the cylinders under question, which makes the measurements to be approximations of actual values.

The only method that gives the true friction horsepower is to measure the indicated horsepower of each cylinder by means of indicators, and simultaneously measure the brake horsepower of the engine. In this method all measurements are taken while the cylinders under question operate under actual conditions, delivering power. However, in order to be certain about the accuracy of this method it is necessary to use very sensitive (and therefore expensive) pressure pick-ups on the cylinders.

DATA SHEET:

Friction-horsepower test

1.- Duration of run

2.- Mean temperature of cooling water

3.- Lubricating oil temperature

4.- Lubricating oil pressure

5.- Rpm

6.- Length of dynamometer arm

7.- Weight of dynamometer scales

8.- Friction horsepower, or

9.- brake horsepower

Note: The above readings will be taken for each speed and throttle setting.

AIR-FUEL RATIO

INTRODUCTION:

The theoretical or stoichimetric ratio of air to fuel should be expected to give best engine performance. For gasoline and light fuel oils this ratio is close to 15 to 1, (or F/A = 0.066). Actually, both otto and diesel cycle engines give good performance at this ratio, provided that all other conditions are favorable. For practical reasons, however, the compression-ignition engine is usually operated slightly lean (less fuel) and the spark-ignition engine slightly rich. In both cases this is due mainly to the difficulty of securing perfect mixing and distribution of air and fuel.

The simple carburetor tends to give a richer mixture at high flow rates. This is favorable for developing maximum power, but rich mixtures are also required at low engine speeds and for idling. The problem is further complicated by the extreme variation in manifold vacuum caused by operation of the main throttle. It is for all these reasons that the commercial carburetor becomes a complex of jets with special devices for serving the idling, starting, acceleration, full-power, and cruising phases of car operation. In general, the resulting mixture is rich at high and low flows and leaner in the mid-range where economy is important.

In the diesel engine the mixture problem is one of liquid injection and atomization. Whether the system has individual timed injection pumps or a common high-pressure supply to individual injection nozzles, the fuel orifices must be very small and the pressures very high. In any case, exact metering and perfect mixing are very difficult at light loads, and the extra fuel required at heavy loads causes carbon and smoke problems.

In this experiment the mixture requirements of the spark-ignition engine are emphasized. The mixture requirements of the compression ignition engine could also be studied in a similar way.

PREPARATIONS:

Either a single-cylinder or a multicylinder engine may be used. (The additional problem of manifold distribution can be studied in the latter case).

Successive runs in the test will involve small differences in power and fuel rate. Hence, the dynamometer balance, speed and fuel measurements must be made with great care.

The engine must be equipped with an adjustable carburetor.

(Spark-plug thermocouples are necessary if the problem of cylinder distribution is to be studied at the same time). A direct-indicating combustion-gas analyzer, or an orsat is necessary. Great care should be given to the adequacy of gas-sampling arrangements. It is very important to secure well-mixed samples.

INSTRUCTIONS:

In all tests the torque, speed, brake horsepower, brake specific fuel consumption, manifold vacuum, spark-plug thermocouple temperatures, and exhaust temperatures are to be read and recorded, with exhaust-gas analyses added as necessary.

1.- The first set of runs will be made with normal carburetor adjustment. Set the carburetor for best torque at full throttle and intermediate speed. Make a series of variable load runs at low speed and one at high speed. Use at least four throttle settings at each speed

a) full-throttle
b) three-quarters
c) one-half
d) one-quarter

2.- The second set of runs is to be made at intermediate speed and full throttle only. Start with the richest mixture that will give steady operation. Make a run at each of six, or more air-fuel ratios, including the leanest that gives steady operation.

RESULTS:

The results of the first set of runs, plotted against load, will establish the normal performance of the engine with the carburetor adjusted for maximum power, that is, slightly rich. (The curves should include plug electrode temperature, to indicate uniformity of distribution, if this problem is being studied at the same time).

The second set of runs, plotted against air-fuel ratio, should show maximum economy at about 16 to 1 air-fuel ratio, and maximum power at about 13 to 1 air-fuel ratio.

Numerical results and the accuracy of determinations should be carefully analyzed in the report.

COMPRESSION RATIO and SPARK TIMING

INTRODUCTION:

A spark ignition engine will deliver high torque output at low speed only under favorable conditions. For an engine with a given compression ratio, certain fuel properties are required, and the spark timing is important. At the higher compression ratios, a fuel of high octane number is demanded for heavy-load operation (as when a car is ascending a steep grade at low speed in direct drive). Knocking tendency may be reduced by retarding the spark and by a richer mixture, but economy and engine response are then affected.

The theoretical advantage of high compression ratio is directly indicated by the efficiency equation for the ideal cycle

$$E = 1 - \left(\frac{V_2}{V_1}\right)^{k-1}$$

where: V_2 = clearance volume

V_1 = total cylinder volume

k = ratio of the heat capacities of air (= 1.40).

Engine capacity, as measured by mean effective pressure, is limited by the knocking tendency, but the choice is also an economic one. An engine with a 10 to 1 compression ratio might show a knock-limited brake mep (mean effective pressure) of over 150 psi, while the brake mep of a similar engine with 6 to 1 compression ratio might be below 100. The latter engine then must be larger for equal performance. But the high-compression engine would probably require 100-octane gasoline, while the other could use 65 to 70 octane, at a lower price. In a multicylinder engine the knock-limited output at low speeds is reduced if the manifold distribution is poor so that one or two cylinders persist in knocking.

In this experiment, using a given fuel, the engine compression ratio and the spark timing will be varied, other conditions remaining the same.

PREPARATIONS:

In this experiment a single-cylinder variable-compression (CFR) engine is to be used. A convenient spark-timing indicator is necessary, and an electrical pressure pickup with oscilloscope will be of great help.

Complete descriptive data on the engine should be obtained, including valve timing. Fuel data should include octane rating. Exact methods for determining engine speed, torque, and compression ratio are especially important. Rapid and simultaneous readings of speed and torque are necessary as the conditions are being explored to determine borderline or incipient detonation. Intake air temperature is another important variable.

INSTRUCTIONS:

Set the engine accurately at a low compression ratio (not over 6). Check the accuracy of the spark-time indicator for position. Set the spark advance at the position recommended (or use 20 deg. before top dead center) and operate the engine at medium speed. Adjust the carburetor for best torque.

1.- Make a short test at full throttle observing the knock intensity by ear, and record the detonation (none, incipient, light, medium, heavy).

2.- shift the spark in 5-degree steps and repeat the observations.

3.- At the spark position for best torque, make a complete test, including fuel-rate measurements.

4.- Change to next higher compression ratio and repeat steps 1, 2 and 3. Make the complete test at or below the setting for incipient detonation.

5.- Repeat at higher compression ratios.

6.- After making the above tests at medium speed, increase the speed and determine the optimum spark advance for a given throttle setting at each higher speed (say 2500, 3000, and 3500 rpm).

<u>Caution:</u> 1. Do not operate the engine with heavy detonation.

2. Take care that cooling conditions are maintained as nearly constant as possible throughout the tests.

RESULTS:

The report should illustrate the effects of changing compression ratio and spark advance on engine performance.

Results can be plotted against compression ratio, spark advance, and speed. It should be kept in mind that all the above runs are tests of the effects of compression ratio and spark timing and this should be recognized in the discussion.

As a rough comparison, the maximum mean effective pressure might be expected to increase 10 psi for each advance of one number in the compression ratio, provided that the fuel is adequate.

QUESTIONS:

1.- Explain briefly the variation of power and efficiency with compression ratio.

2.- Discuss and explain the effects of compression ratio on engine reliability and durability.

3.- Explain briefly the variations of best-power spark-advance with engine speed and inlet pressure.

4.- Discuss the effect of exhaust gas dilution on the rate of burning and spark position.

DETONATION

INTRODUCTION:

Detonation is the spontaneous burning of the last part of the compressed mixture of air and fuel in the engine cylinder during normal combustion. It is caused by the increase in temperature and pressure of the charge during the early stages of combustion.

As the flame front proceeds in the compressed mixture, the temperature and pressure of the remaining unburned mixture increases rapidly, until it reaches a critical point, where, the remaining mixture burns spontaneously with a further and sudden increase in temperature and pressure.

The characteristic sound that accompanies this spontaneous burning is called knock. It is a pressure wave that travels back and forth in the cylinder.

In addition to its being a characteristic of the fuel itself, detonation depends on the following:

1. Form of combustion chamber. Combustion chambers designed to give a high degree of turbulence reduce the tendency of the fuel to detonate.
2. Number and position of spark plugs. The greater the number of spark plugs and the more equal their spacing, the less likely is detonation to occur.

3. The inlet temperature, and to some extent, also the cylinder temperature influence detonation. The lower the inlet temperature, the greater the allowable compression pressure without detonation occuring.
4. Detonation depends also upon the degree of turbulence, as it was previously stated. The tendency to detonate increases with decreased turbulence.
5. Detonation is most apparent over the range of mixture which lies between the points of maximum economy and maximum power, so that it can not, in practice, be avoided by changing the misture strength.

Apart from the characteristic knocking sound produced by detonating conditions, the power output is reduced, heat losses to the cylinder walls and pistons are increased, and the thermal efficiency is decreased. Furthermore, the high impact pressure effects combined with the increased cylinder temperatures may cause fracture of the piston, burning of the cylinder head, gumming of the piston rings in their grooves, etc.

All these show that detonation is to be avoided. But with a given fuel, the most effective way to avoid detonation is to use lower peak pressures, that is, lower compression ratio. On the other hand, it is known that decreasing the compression ratio, reduces the efficiency.

Therefore, the solution is to operate the engine under conditions of incipient detonation and try to improve the knocking characteristics of the fuel used.

The knock tendency of a fuel is expressed by its "octane number", which is defined by and is numerically equal to the percentage by volume of iso-octane(2, 2, 4 trimethylpentane) in a mixture of iso-octane and normal heptane which shows the same knocking characteristics with the fuel under question, when used in the same engine under the same conditions. Thus, by definition, normal heptane has an octane number of zero, and iso-octane of 100.

A practical method of detecting and measuring detonation is that known as the "bouncing pin" method. The "bouncing pin" device is screwed into the wall of the cylinder in the combustion chamber end and is arranged to form what is essentially a small thin-walled section of the wall. One end of the bouncing pin rests on this wall. The pin is guided so that its movements occur at right angle to the wall, the motion in this direction being controlled by a spring, which, when deflected closes an electric circuit. When thus closed a water electrolysis apparatus is brought into operation. The amount of detonation is then measured by collecting the gas evolved through the passage of the current through a 10% sulphuric acid solution. The quantity of gas evolved per unit time serves as a measure of the detonation period. Also, visual observations of detonating conditions can be arranged.

The bouncing pin method, while extremely useful for comparing pronounced detonations in the case of different fuels, is not altogether satisfactory for detecting incipient detonation, a phenomenon which requires rather more delicate means of indication, described and explained in a different section. (see: Engine Indicators)

INSTRUCTIONS:

The test consists in the comparison of the engine knock produced by the fuel under test with that produced by one higher and one lower octane-number reference fuel. Also, the change in performance of the engine with detonation is to be studied. Secondary reference fuels which have been calibrated against the octane-heptane standards may be used for testing, since the standard fuels are very expensive.

Ample time must be allowed after changing fuels for steady conditions to be established with the new fuel.

DETERMINATIONS:

1.- Run the engine with the lowest octane number fuel at rated speed and wide open throttle.
2.- Gradually increase the compression ratio until detonation is detected. Note the compression ratio.

3.- Measure break horsepower just before detonation starts, and at a compression ratio 1 higher than that at which detonation starts. Be sure to keep the speed always constant by adjusting the load (torque).

4.- Decrease the speed by increasing the torque only (keep throttle wide-open) and repeat steps 2 and 3.

5.- Repeat step 4 for at least 2 lower speeds.

6.- Run the engine at half throttle and repeat steps 2, 3, 4, and 5.

7.- Change to higher octane number fuels and repeat steps 2, 3, 4, 5, and 6, noting each time the compression ratio at which detonation begins.

8.- With engine running with correct air-fuel mixture, increase the compression ratio slowly, until detonation is detected. Note the compression ratio.

9.- Repeat step 8 for the following air-fuel mixtures:

a) 20% weak

b) 10% weak

c) 10% rich

d) 20% rich

e) 30% rich

f) 40% rich

RESULTS:

1.- Discuss the effect of engine speed and throttle setting (i.e. inlet maniforld vacuum) on detonation.

2.- Discuss the effect of detonation on engine power and efficiency.

3.- Plot compression ratio at which detonation is noted for various mixture compositions, against mixture composition and discuss the results.

HEAT REJECTION

OBJECT:

This experiment deals with the investigation of the effect of certain engine operating variables on the amount of heat rejected to the water jackets.

INTRODUCTION:

The heat rejected by an engine to its cooling system may be divided into three parts:

1.- Direct heat loss, caused by the temperature difference between the cylinder gases and the cylinder walls.

2.- Heat generated by engine friction.

3.- Heat flow from the exhaust system.

Since the principles governing the heat transfer are not the same for the three items, and since these items cannot be conveniently isolated from each other in making an experiment, a strictly rágorous analysis of total heat rejection is not possible.

In the case of direct heat loss, the average rate of heat transfer may be approximated by:

$$Q = K_1 \Delta T (\rho_{cyl} s)^{n} L^{1+n}$$

$$Q = K_2 \; \Delta T(e \rho_i \; sL^2)^n \; L^{1-n}$$

where:

Q = average rate of heat transfer

ΔT = average temperature difference across cylinder-gas boundary layer

ρ_{cyl} = average density of cylinder gas

ρ_i = inlet air density

e = volumetric efficiency

s = piston speed

L = characteristic length of cylinder

K_1 , K_2 , ----, n = constants

For a given engine, the above equation may be reduced to

$$Q = K_3 \Delta T \; (e \rho_i \; sL^2)^n$$

$$Q = K_4 \; \Delta T M^n$$

where: M = air consumption

If the engine operates at constant isac, (indicated specific air consumption), then

$$Q = K_5 \; \Delta T \; (ihp)^n$$

Thus, the heat transfer per unit work done is:

$$\frac{Q}{ihp} = K_6 \; \Delta T \; M^{n-1}$$

$$= K_7 \; \Delta T \; (ihp)^{n-1}$$

Note that the rate of heat transfer is completely determined by air consumption, regardless of how the air consumption is obtained, provided ΔT remains constant.

Strictly speaking, the above relations apply only to direct heat loss. However, the total heat loss to the jackets may be approximated fairly well by these same relations.

APPARATUS:

Any properly equipped engine may be used for this experiment. An electric dynamometer and equipment for measuring heat rejection, air flow, fuel consumption, temperatures, pressures, etc, are necessary.

PROCEDURE:

1.- Measure heat rejected to the water jackets under each of the following conditions:

a) Varying piston speed, with best power fuel-air ratio and best-power spark advance, at constant imep.

b) Varying imep, with best power fuel-air ratio and best power spark advance, at constant piston speed.

Keep inlet temperature and jacket-water temperature constant.

2.- Measure motoring friction under each of the above conditions, in order to determine indicated power output of the engine.

RESULTS:

Plot the following curves:

1.- For series (a) above:

Heat rejection in Btu/hour and in Btu/ihp-hour, versus piston speed.

2.- For series (b) above:

Heat rejection in Btu/hour and in Btu/ihp-hour, versus imep.

3.- For series (a) and (b) above:

Heat rejection in Btu/hour versus air consumption in lb/hour, on a log-log sheet.

QUESTIONS:

1.- What are the principal engine operating variables which control heat rejection per unit time from the gases to the cylinder walls ? Explain the influence of each such variable.

2.- Explain why when ΔT is constant, heat rejection per unit time from a given engine is a function of air consumption only, regardless of the manner by which the air consumption is controlled.

3.- How was ΔT kept approximately constant in this experiment ? Explain.

4.- Would pre-ignition tend to cause overheating ? Why ?

5.- Would automotive engines tend to overheat when run too lean ? If so, which parts are more likely to be overheated ? Explain.

ENGINE HEAT BALANCE AND EFFICIENCY

INTRODUCTION:

The engine heat balance is an energy distribution analysis in which an effort is made to account for all the energy supplied in the fuel. It differs from the efficiency analysis in that it is concerned, not with ideal performance and deviations from it, but rather with the nature and extent of all the energy losses. In this experiment, however, both the losses and the efficiencies are to be analyzed. An efficiency is a quantitative measure of the approach to an ideal, and therefore it gives a direct method for quickly comparing one test with another or one engine with another. A heat balance directs attention to each specific energy loss.

One very important measure of the useful performance of an engine is omitted by both the heat-balance and the efficiency analysis, and that is the economic cost. In order to make the analysis more complete, the cost of fuels should be investigated and the fuel cost per horsepower-hour computed.

EQUIPMENT:

Any available engine may be equipped and used for this experiment, single or multi-cylinder, spark ignition or compression ignition. Each engine will have its special characteristics, but all engine heat balances are similar in that they comprise three major items of roughly equal magnitude:

a) shaft horsepower

b) cooling losses

c) exhaust losses

As engine load is increased, the efficiency increases because losses do not increase so rapidly. Similarly, a large engine is more efficient than a small one.

PREPARATIONS:

From the list of heat-balance items and definitions of efficiencies given later, determine what readings are required, and list the instruments to be used. Prepare a complete data sheet accordingly, and obtain preliminary data such as dimensions and take weights before the test is started. (A suggested form is given at the end of this experiment).

DETERMINATIONS:

Make a complete test at each load, using preferably the full rated load, and three-fourths, one-half, one-fourth rated load. Tests must be long enough for obtaining several complete and consistant sets of Orsat analysis of the exhaust gases during each run, as well as accurate weights of fuel and cooling water. Maintain the same cooling-water discharge temperature during all tests.

RESULTS:

The items included in the engine heat balance are:

1.- Heat to useful work in brake horsepower

2.- Heat lost in the cooling water

3.- Sensible heat in the exhaust gases

4.- Hydrogen and moisture loss in the exhaust

5.- Losses due to incomplete combustion

6.- Radiation and unaccounted for

All values are given as percentage of heat supplied in the higher heating value of the fuel.

The following efficiencies are to be computed for each run:

1.- Mechanical efficiency, the ratio of brake horsepower to indicated horsepower.

2.- Brake thermal efficiency, the ratio of the heat equivalent of brake horsepower to heat supplied as higher heating value of the fuel.

3.- Indicated thermal efficiency, the ratio of heat equivalent of indicated horsepower to heat supplied in fuel.

4.- Ideal efficiency, the efficiency of the ideal engine, (otto or diesel cycle), at the actual compression ratio and cut-off ratio.

5.- Engine efficiency, or efficiency ratio, the ratio of the actual thermal efficiency to the ideal efficiency. The indicated engine efficiency is the most significant, but the brake engine efficiency is used if reliable indicated horsepower values are not available.

6.- Volumeteric efficiency, the ratio of the weight of air actually taken into the cylinders to the weight of the discplacement volume of air at the pressure and temperature existing near the intake.

Plot curves of the heat-balance items gainst load on the abscissa, using that scheme of plotting in which the curves are plotted one above another and the distance between the final curve and the 100 per cent line represents the losses unaccounted for. Plot also curves of efficiencies against load.

DISCUSSION OF EXPECTED RESULTS:

The heat-balance results will depend considerably on the type and size of engine tested, on the cooling-water temperature, and on other operating conditions. Otto cycle engines have higher exhaust temperatures than diesels, hence larger exhaust losses.

This experiment concentrates attention on the variations of efficiency and of losses with torque load. It is important that the analysis of results should take the method and results of speed control into account. Since torque is the independent variable, the engine will be kept at the specified constant speed either manually or by an automatic governor. In the spark-ignition engine the throttle controls the entire mixture, while in the compression-ignition engine it controls mainly the fuel injection. In the spark-ignition engine the air-fuel ratio and the exhaust-gas analysis are therefore substantially constant, but the volumetric efficiency changes with load. In the compression-ignition engine the air-fuel ratio varies greatly with load

The engine efficiency, or efficiency ratio, is especially significant for full-load or full-throttle conditions. The ideal air-standard otto and diesel-cycle efficiencies may be computed by the following equations:

Air-standard otto-cycle efficiency:

$$E_o = 1 - \frac{1}{r^{k-1}}$$

Air-standard diesel -cycle efficiency:

$$E_d = 1 - \frac{1}{r^{k-1}} \frac{S^k - 1}{k(S-1)}$$

where:

k = specific heat ratio (=1.4)

r = compression ratio (> 1)

s = ratio of volume at fuel cut-off to clearance volume

The air-standard ideal efficiency is, of course, inadequate because it fails to take account of the real constituents of the mixture and neglects dissociation and the chemical-equilibrium conditions.

AIR CAPACITY, VOLUMETRIC EFFICIENCY and SUPERCHARGING

INTRODUCTION:

The pressure in the intake manifold of an I.C. engine is below atmospheric. Since this vacuum is produced by the downward moving piston and there is some pressure loss through the intake valves, the cylinder pressure at the end of the intake stroke must be even less than that in the manifold. Thus the charge of air taken into the cylinder, being at a lower pressure and a higher temperature than that of the atmosphere, is much less dense. The ratio of the weight of air actually taken into the cylinders to the weight of a similar volume of atmospheric air at the pressure and temperature existing near the air inlet is called the volumetric efficiency. This is not an efficiency in the usual engineering sense but rather a ratio of weights, densities, mass, or volumes.

Although the volumetric efficiency has a minor effect on fuel economy, it greatly affects the total capacity or power developed and hence is given considerable attention in the case of airplane engines, racing-car engines, or any engine in which the power to weight ratio is important.

The major factors that effect the full-throttle volumetric efficiency are the size and design of carburetors, intake manifolds, and valves, the mixture temperature, and the engine speed. At partial throttle the volumetric efficiencies are, of course, still lower.

In diesel engines the problems are somewhat different, but the need for high air capacity is equally pressing. Because of the heavier construction and of the high weight of a diesel engine per cubic inch displacement, it is very important to secure high volumetric efficiency.

Two methods are available for greatly increasing the air capacity and/or the volumetric efficiency. These are:

1.- The substitution of the two-stroke cycle instead of the four-stroke cycle.
2.- Supercharging.

The compression ignition (diesel) engine is adaptable to both of these modifications since it compresses air only, not an air-fuel mixture. The supercharger can thus act as a scavenging pump.

In this experiment the engine will not be supercharged because of the reason that supercharging imposes high cooling loads which the cooling system of a nonsupercharged engine can not handle. The opposite effect of supercharging the engine will be illustrated by throttling the engine.

The volumetric efficiency is of major importance at high speed, with wide-open throttle, but in this experiment a wider range will be covered in order to illustrate the relationships involved.

INSTRUCTIONS:

The engine should be prepared for a high-speed full-throttle test. A suitable means for measuring the intake air is to be provided. The most convenient air meter is a large inlet tank on which an orifice plate is mounted. The small differential pressure produced is red on an inclined manometer.

1. Make one run at full-open throttle and others at partial-throttle settings. Each run will consist of four or more determinations at different speeds. Fuel consumption and power measurements are to be included as well as air flow and intake manifold pressure measurements. Use best-power spark advance.

2. Repeat one run with the engine driven by the dynamometer. Shut off the fuel but leave the throttle open.

3. Plot the volumetric efficiency and specific fuel consumption against speed for each throttle setting.

4. Plot the power output against total air flow, with test points for all runs shown on a single curve.

5. Volumetric efficiency should also be plotted against brake horsepower, one curve for each throttle setting.

6. Plot bsac against bhp for all runs.

DISCUSSION:

With a constant air-fuel ratio and combustion efficiency, and best power spark advance, the indicated horsepower should depend on the air-pumping rate only. But when air flow is plotted against brake horsepower, differences in engine friction will be shown by the speed of the points. Maximum volumetric efficiencies are attained at full throttle and intermediate speeds.

QUESTIONS:

1. From the consideration of power output, is a high or a low specific air consumption desirable ? Explain.

2. What may be the causes of an unusually high specific air consumption ? List and explain in detail.

3. Based on the concept of air capacity, what appears to be the most effective means of controlling the power output of spark-ignition engines ? What part of the air inlet system is used to accomplish this control ?

4. Explain the variation of volumetric efficiency with inlet temperature (in intake manifold).

5. Explain the variation of volumetric efficiency with inlet pressure (in intake manifold).

6. Give physical reason for the variation of volumetric efficiency with piston speed.

SCAVENGING OF THE TWO-STROKE ENGINE

OBJECT:

To determine the scavenging characteristics of a two-stroke engine.

INTRODUCTION:

The scavenging characteristics of the two-stroke engine may be analyzed with the aid of two special terms,

a) scavenging efficiency , e_s

b) scavenging ratio , R_s

defined as follows:

$$e_s = \frac{M}{\rho_s V_t N}$$

$$R_s = \frac{M'}{\rho_s V_t N}$$

where: e_s = scavenging efficiency

R_s = scavenging ratio

M = mass of air retained in the cylinder per unit time

M' = mass of air supplied per unit time by the scavenging pump

ρ_s = scavenging air density, calculated on the basis of inlet temperature and exhaust pressure.

V_t = total cylinder volume

N = revolutions per unit time

The experimental determination of scavenging ratio presents no special difficulty, as all of the primary quantities entering its definition are directly measurable. However, the same cannot be said of scavenging efficiency, because there is no direct way to measure the mass of air retained in the cylinder.

In the present experiment, the mass of air retained will be estimated on the assumption that the isac of the two-stroke engine based upon the mass of air retained in the cylinder is equal to (1 + a) times the isac of a four-stroke engine of similar design, operating at same compression ratio, same fuel-air ratio and otherwise similar conditions. The correction factor, a , is used to account for the effect of early exhaust opening of the two-stroke engine. For average engines a value a = 0.05 may be assumed.

APPARATUS:

Two-stroke spark ignition engine and electric dynamometer, standard equipment for measuring air and fuel consumption, temperatures, pressures, etc.

PROCEDURE:

At a given speed, exhaust pressure and inlet temperature, at best-power fuel-air ratio and best-power spark advance, make runs varying scavenging pressure over a wide range. Measure air consumption, fuel rate, required temperatures and pressures, and brake horsepower as well as friction horsepower.

REQUIREMENTS:

1.- Calculate: ρ_s , e_s , R_s and isfc based on total quantity of fuel supplied

2.- Plot scavenging efficiency (e_s), versus scavenging ratio (R_s).

3.- Plot isfc (based on total fuel quantity supplied) versus scavenging ratio (R_s).

DISCUSSION:

1.- Explain the variation of scavenging efficiency with respect to scavenging ratio.

2.- Explain the curve of isfc versus scavenging ratio.

3.- Is there any reason why the method used in this experiment for estimating the mass of air retained in the two-stroke engine cylinder is particularly suitable for an engine running on pre-mixed fuel-air charge ? Can this method be used at all on a fuel-injection engine ?

4.- Explain why the spark-ignition two stroke engine does not idle well.

PART THREE

Auxiliary Experiments

DYNAMOMETERS AND POWER MEASUREMENT

INTRODUCTION:

Determination of the power of a rotating machine involves three measurements:

a) force

b) moment arm

c) rotational speed

The terms dynamometer and torque meter are sometimes applied to the force measuring device only. In fact other types of force meters such as spring scales are also called dynamometer. But in mechanical engineering this term is understood to mean any assembly that measures mechanical power.

PRINCIPLES:

Absorption dynamometers usually consist of a rotor and a credle mounted stator. The rotor is directly coupled to the machine the power output of which is to be measured. The stator is caused to exert a retarding torque on the rotating rotor. According to the principle of equal action and reaction, the rotor exerts an equal and opposite torque on the stator. In order to keep the stator stationary, another moment must be applied on it, equal in magnitude but opposite in direction to that exerted by the rotor. By suitably measuring this last moment and the rotor speed, it is possible to calculate the power developed by the machine, because the measured moment is equal to that developed by the machine.

TYPES:

1.- Absorption dynamometers dissipate the power being measured by converting it to heat, either electrically or by friction.

2.- Transmission dynamometers measure the torque as it is transmitted. When the twist of a shaft is measured, the device is called a torsion dynamometer.

The type most commonly used in engine laboratories is the absorption dynamometer. There are many kinds of absorption dynamometers:

a) Solid-friction or Prony brakes

These absorb the power by converting it into heat by means of solid friction. The generated heat is dissipated by suitably cooling the dynamometer. Automotive brake lining, wood blocks, or ropes are used for friction against the rotor of the dynamometer.

b) Water brakes or hydraulic dynamometers

In these dynamometers the water flow is varied to control the brake torque, and also to dispose the heated fluid. The casing or stator is cradle-mounted on ball or roller bearings, and the rotor consists either of one or more plain smooth disks, or it may have pockets or vanes to increase fluid friction and consequently the capacity of the dynamometer.

The hydraulic dynamometer is a compact unit of high capacity at moderately high speeds but it is somewhat less flexible and more difficult to control than an electric dynamometer.

c) Fan brakes:

These usually consist of flat paddles rotating in the open. They are cheap, but they are noisy and dangerous. Moreover, they have relatively small torque range at any given constant speed, and they are difficult to control..

d) Electric dynamometers

The d-c dynamoelectric machine may be used as a dynamometer, either by cradle mounting or by calibration.

If a test or calibration is run on an electric motor, using one of the brakes mentioned above to absorb its output, and the results are plotted either as an input-output or as an efficiency curve, these results may be used for exact determination of power when the motor is put into service for driving other machines. A generator may be similarly calibrated by the determination of its input-output, or efficiency curve, at various speeds, and it then becomes an accurate absorption dynamometer.

For such applications as the testing of internal combustion engines, where a variety of speeds are necessary and it is desirable to use the electric machine either as a motor or as a generator, it is much simpler to cradle-mount it, then it is to determine and use the large number of calibration curves which would be necessary.

One of the advantages of the electric cradle dynamometer is the fact that all operations are electrically controlled, and hence the starting, stopping, speed and torque controls may be easily and accurately handled by a single operator.

e) Magnetic-drag, or eddy-current dynamometers:

These are similar to cradle-mounted generators, but the electrical energy is dissipated within the machine itself. Load rheostats are therefore not necessary, and the entire installation is more compact than that of a cradle-mounted d-c machine, but of course the motoring feature cannot be obtained in a magnetic dynamometer. This type of dynamometer is usually water cooled.

HORSE POWER EQUATION:

Assume a force of F pounds acting at the end of a dynamometer moment arm r inches long, in a direction perpendicular to the plane defined by the dynamometer axis and the moment arm. The product Fr is equal to the torque developed by the driving machine (see section: principle). The work done by this torque in one revolution of the shaft is $2\pi Fr$ in-lb or $\frac{2\pi\ Fr}{12}$ ft-lb. If n is the speed of the shaft in rpm, then the work done per minute is $\frac{2\pi\ Frn}{12}$ ft-lb/min. Since 33000 ft-lb/min is equivalent to a horsepower, the power developed by the driving machine is given by:

$$hp = \frac{2\pi\ Frn}{12 \times 33000} = \frac{Frn}{63000}$$

where:

F = force at the end of the moment arm, lb

r = length of moment arm, in.

n = speed of driving machine or dynamometer, rpm.

Note: F is the net force acting at the end of the moment arm, that is, measured reaction minus (or plus) tare-weight, if any.

Dynamometers are conveniently made with a moment arm of such length that the expression for horsepower reduces to

$$hp = \frac{Fn}{C}$$

where: C is an even number such as 1000 or 2000. If the same scale is to be used always with a given dynamometer, then, any length may be used for the moment arm, and the scale calibrated to read torque (Fr), or $\frac{F}{C}$, or simply F.

REQUIREMENTS:

1.- Examine the various types of dynamometers available in the laboratory.

2.- Make actual power measurements.

3.- For the cradle-mounted electric dynamometer plot power measured by the arm and scale method, against electrical power output or input of the dynamometer, depending on whether it is used as a generator or motor, respectively.

4.- Discuss advantages and disadvantages of each type of dynamometer, compared to the other types.

PRECAUTIONS:

1.- Learn how to make an emergency stop. In testing power machinery such a necessity may arise at any time.

2.- Do not leave a dynamometer running without an attendant. Some accident may cause overspeeding, which is very dangerous.

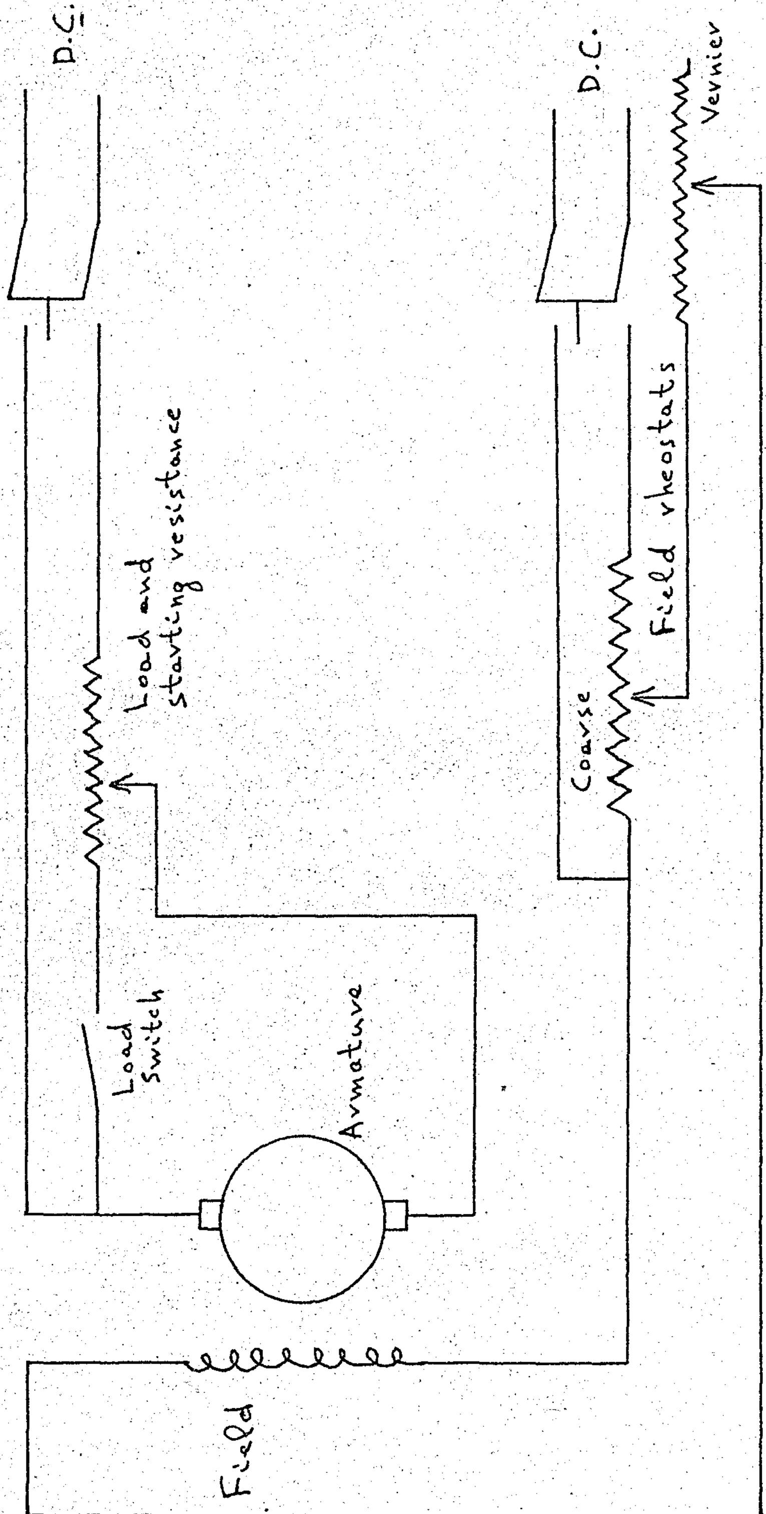
3.- Always keep within safe speeds for both dynamometer and coupled machine.

4.- Always check the tare-weight before starting.

5.- Lock the stator of an electric dynamometer when startin

6.- Do not exceed the rated current of an electric dynamometer.

7.- Take force (or torque) and speed readings simultaneously.



Wiring diagram for electric dynamometer

ENGINE INDICATORS

INTRODUCTION:

The indicated horsepower of an engine, that is, the power developed by the cylinder gases, can be determined if the variation of the cylinder gas pressure with cylinder gas volume is known for each cylinder. In other cases a knowledge of the maximum or mean cylinder pressure is desirable. These may be obtained by means of engine indicators.

TYPES:

There are several types of engine indicators.

The mechanical engine indicator consists of a piston-and-spring mechanism actuating a pencil for the ordinates and an oscillating paper drum driven from the engine piston rod to give horizontal displacement. Indicator springs are calibrated in terms of the pressure change required to move the marking point 1 inch. The scale of the diagram can be varied by changing indicator springs, changing drums, reducing motions, etc. For engine speeds above 400 rpm the inertia effects with mechanical indicators and reducing motions make it difficult to secure accurate diagrams. In order to overcome these difficulties stiffer springs, lighter indicator parts, and reduced drum travel were used. (One type has a tapered cantilever spring, a large piston, and a small paper drum). But the so-called <u>micro indicators</u> trace very small diagrams that must be greatly magnified for analysis.

<u>Optical indicators</u> obtain magnification by optical means. In these instruments, a piston or a diafragm exposed to engine pressure operates against a stiff beam spring. The very small motion, proportional to pressure, is transmitted to a mirror which reflects light from a point source. Another motion is transmitted to the mirror by a suitable connection from the engine piston. The resulting light-beam diagram, after being magnified optically, is viewed on a screen or photographed. Optical indicators are better than mechanical indicators because they have less inertia and they produce larger diagrams. They also change the compression ratio to a smaller extent by introducing a smaller additional volume to the cylinder, as compared to mechanical indicators.

<u>Multicycle indicators</u> give a composite indicator diagram that represents the approximate average of a large number of cycles. The diagram is built up point by point from a large number of cycles. The <u>balance pressure indicator</u> uses an external balancing pressure and matches it against engine cylinder pressure. A flexible diaphragm, mounted between the two pressure sources, opens and closes an electrical contact once or twice each cycle at the instant the two pressures become equal. Each opening or closing of the contact gives a point on the P-V diagram. By varying the balancing pressure the electrical contact can be made to operate at various points

of the cycle, thus giving a series of pressure readings, each one corresponding to a different point of the average cycle. With this type of indicator the inertia problem is satisfactorily solved, but the engine should operate steadily while the diagram is being taken.

Several forms of <u>maximum pressure indicators</u> are available for showing only the maximum pressure in an internal combustion engine cycle.

<u>Electrical indicators</u> generate a signal that can be read by means of an oscillograph or oscilloscope. The following may be used to convert pressures to electric signals:

1.- Electromagnetic impedance elements are located in an electric bridge circuit. The reactance change is obtained by varying the air gap in a magnetic circuit.

2.- A capacitance gage, or variable condenser is obtained by using two electrodes and mechanically displacing them with respect to each other.

3.- Resistance wire elements change in resistance slightly when they are subjected to strain.

4.- Piezoelectric crystals produce electrical impulses proportional to the pressure exerted upon them.

5.- The magnetostrictive principle is applied, i.e., the permeability of a magnetic element is changed by stressing the material.

For more precise indications at high speeds a piezoelectric crystal pressure pickup is used with the oscilloscope. It consists of two quartz crystals contained in a pressure unit which is screwed into the cylinder head with a diaphragm exposed to cylinder pressures. This eliminates entirely the transfer passage of the mechanical indicator. As the pressure in the cylinder increases, the quartz crystals are compressed and an electrical charge appears on the crystals in an amount proportional to the stress. This property is called the piezoelectric effect. A small fraction of the electrical charge passes into an amplifier and then to the oscilloscope. The oscilloscope consists of a beam of electrons emitted from a hot fillament and focused on a fluorescent screen. The beam is moved in a horizontal plane by applying to the horizontal deflection plates a voltage which describes the volume of the cylinder gases. Vertical movement of the beam results when the amplified variable voltage of the quartz crystals is applied to the vertical deflection plates of the oscilloscope. The result on the flurescent screen is the pressure-volume diagram for the cylinder in question.

The electrical indicator described above does not have the disadvantages of the mechanical indicator. However, although it is extremely sensitive for indicating rapid variations in pressure, specific values of pressure may be open to question in regard to magnitude. Moreover, complete diagrams can not be obtained at engine speeds below 1000 rpm due to the lack of persistence of sight.

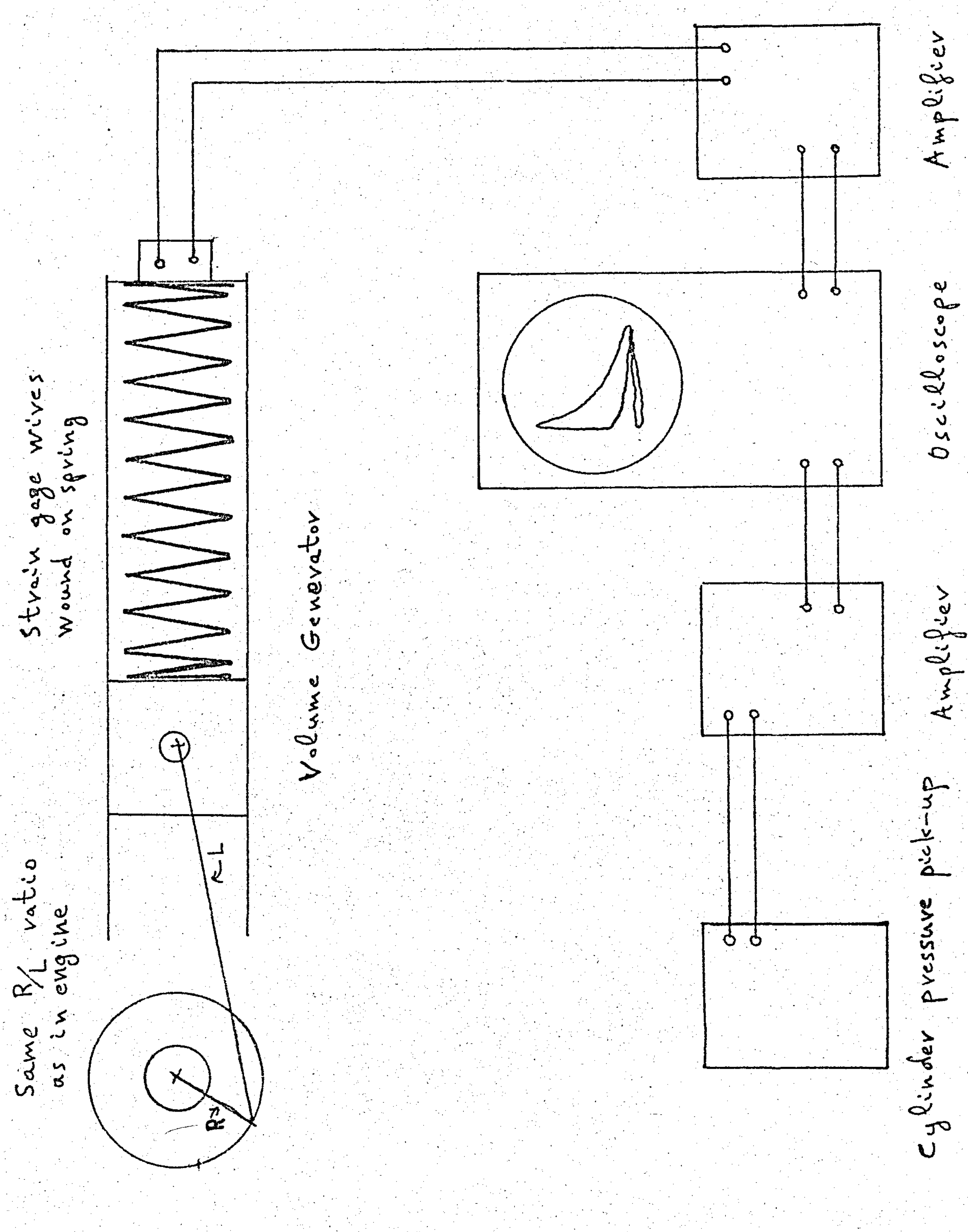
INSTRUCTIONS:

1.- Examine the indicators available.

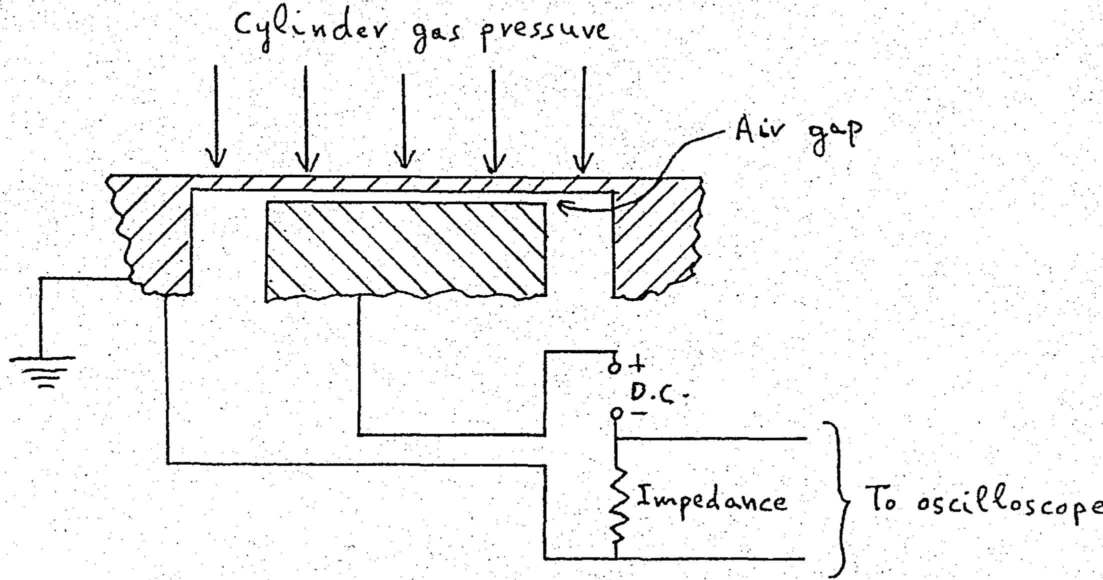
2.- Sketch and explain their working principles.

3.- Take pressure-volume diagrams.

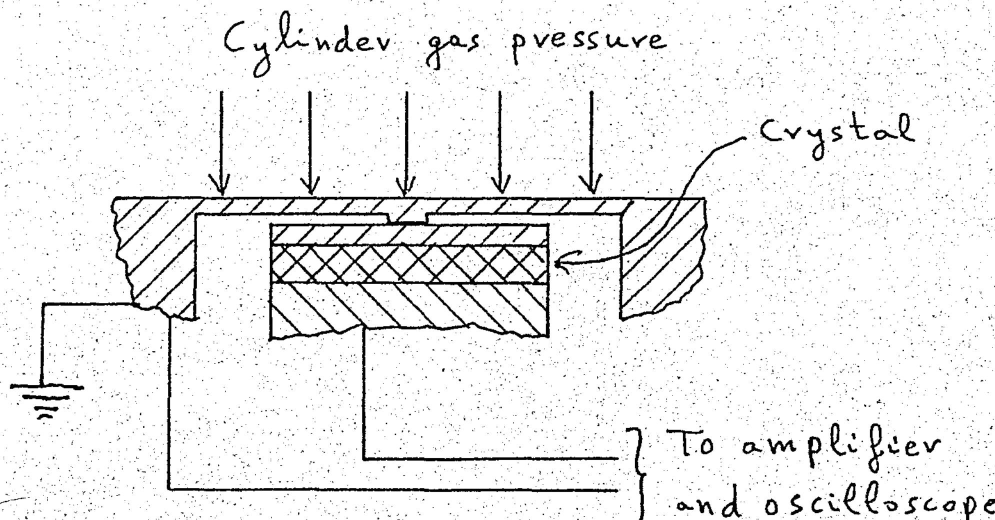
4.- Discuss accuracy and limitations of the various types of indicators, and make suggestions for improvements.



Indicator Set-up



Principle of condenser type pressure pick-up



Principle of piezoelectric pressure pick-up

DETERMINATION OF ENGINE DEAD CENTERS AND CLEARANCE VOLUME

INSTRUCTIONS:

1.- Placing Engine on Dead-Center Positions

The internal combustion engine has two dead centers

a) the top dead center (or head center)

b) the bottom dead center (or crank center)

To locate the dead center positions:

1.- Turn the engine until the piston is almost half-way its stroke, and make a mark on the periphery of the flywheel, opposite to a reference mark on the engine body.

2.- Mark the position of the piston.

3.- Turn the engine past the dead center, until, the piston is exactly at the same position as before.

4.- Make a second mark on the periphery of the flywheel, opposite to the same reference mark on the engine body.

5.- Locate the mid-points of the two arcs to which the periphery of the flywheel is divided by the two marks.

Placing one of these mid-points opposite to the reference mark on the engine body, corresponds to the top dead center, and placing the other mid-point opposite to the reference mark on the engine body, corresponds to the bottom dead center.

Note: Turning the flywheel in the direction in which the engine runs takes up wear in the opposite direction to that which is the case when the engine is moved under its own power. Interprete and apply this fact to the present situation.

2.- Clearance Volume:

Clearance volume is the volume contained between the face of the pistzon and the haed of the cylinder, when the piston is at top dead center.

To determine clearance volume:

1.- First place the engine on top dead center
2.- (Be sure the valves are tightly closed)
2.- Remove the spark plug and fill in the clearance volume with a liquid, being careful to avoid trapping air.
3.- Measure the weight of liquid required to fill the clearance volume and its temperature, and convert from weight to volume using the

density of the liquid at the measured temperature. This volume is the clearance volume of the engine.

Knowing the piston displacement volume (by measuring bore and stroke), V_d , and having determined the clearance volume (by the method outlined above), V_c , the compression ratio of the engine can be calculated by:

$$\text{Compression ratio} = \frac{V_d + V_c}{V_c}$$

QUESTIONS:

1. Discuss inaccuracies involved in the measurement of engine clearance volume by the method explained above.
2. Explain why the method outlined locates engine dead centers with a higher degree of accuracy than if the dead centers are located by simply watching the motion of the piston near the ends of the stroke.

REPORT:

The report should include tabulation of the measurements and calculations made on available engines.

CARBURETOR STUDY

INTRODUCTION:

The function of the carburetor in gasoline engines is to supply a combustible mixture of air and finely dispersed liquid fuel (partly vaporized), in correct proportions for all speeds and loads of the engine, to the inlet manifold leading to the cylinders. To do this, it must not only regulate the quantity of mixture to suit the load requirements, but it must also supply the correct proportions of air and fuel to start up from the cold, to run slowly (idle), to work over a wide range of engine speeds and torques.

The following are the chief diverse conditions for which the correct mixture must be supplied:

a) full load, at moderate or low speed
b) full load, at high speed
c) partial load, at high speed
d) light load, at low speed (idling)
e) operation in very cold or very warm weather.

The same mixture ratio is not suitable for operation in all the above conditions. Tests have shown that in order to obtain maximum power from an engine (spark ignition), the mixture should be considerably richer than normal. If it is desired, on the other hand, to operate at maximum efficiency (fuel economy), the mixture should be somewhat leaner than normal. At low speed and power demand a rich mixture is required .

REQUIREMENTS:

1.- Draw a diagram of a simple carburetor and explain its operation. Label all parts.

The simple type can be designed to operate satisfactorily at one given speed supplying the correct fuel air mixture at this speed. It will not, however, supply the same mixture ratio at different speeds, nor will it regulate the mixture ratio in a way to suit the various sets of conditions mentioned above. Its chief defects are the following:

a) A given increase in air velocity (due to increased engine speed) will produce a proportionately greater increase in fuel flow, and vice versa. The mixture will thus be enriched as engine speed increases, and weakened as engine speed decreases.

b) Due to the weak mixture at low speed, starting will be difficult or impossible.

c) Rapid acceleration will be impeded by the inertia of the fuel, which causes a momentary weakening of the mixture.

d) Warm weather results in decreased air density and dedreased fuel viscosity, both causing a richer mixture.

Cold weather has the opposite effect. Changes of altitude have a similar effect, and are of special importance in aircraft engines.

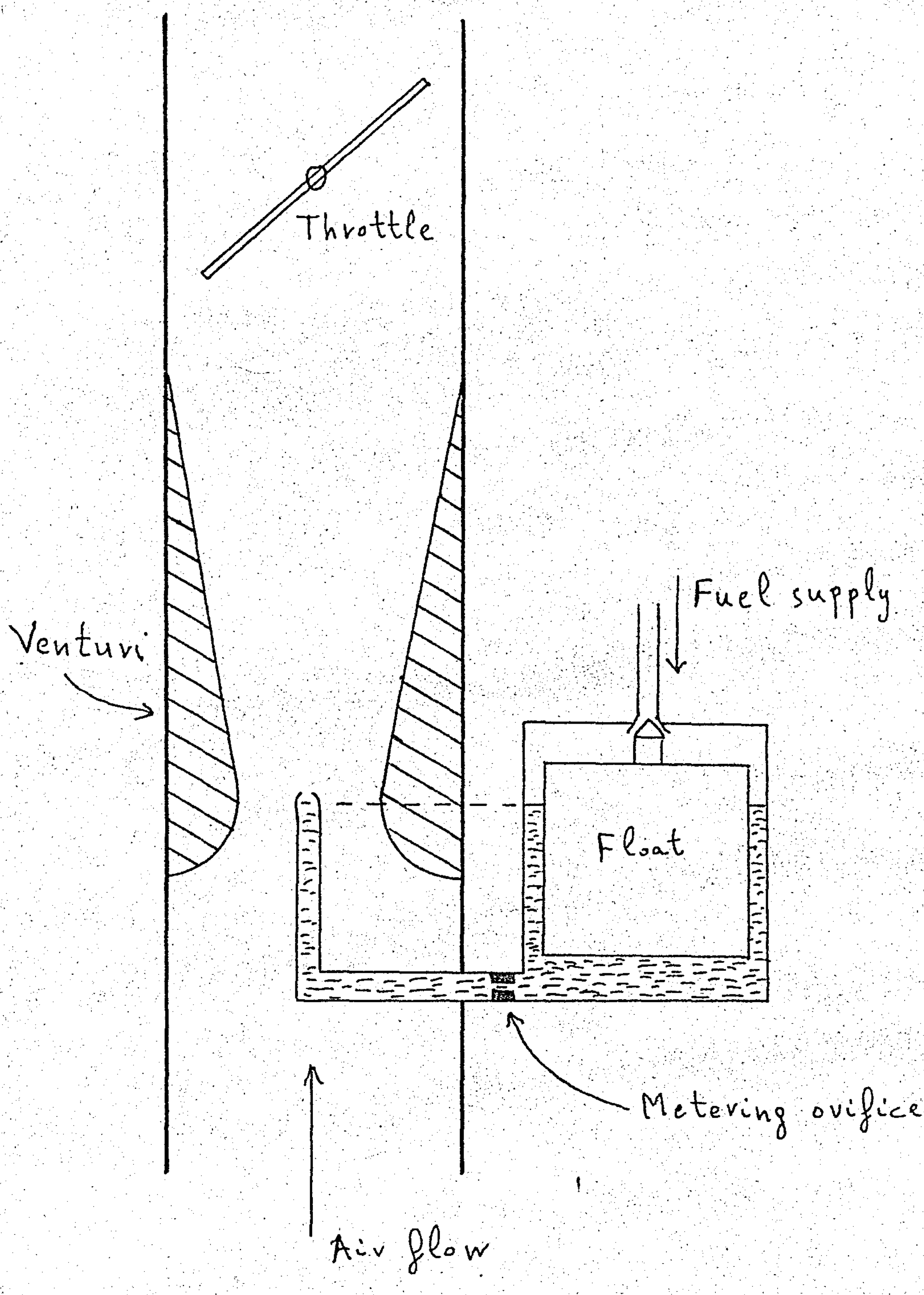
2.- Explain what features are included in carburetor designs to solve the problems discussed above, and show how they operate.

QUESTIONS:

1.- Why is an idling system necessary on a simple carburetor?

2.- What is the effect of altitude on the fuel-air ratio delivered by a simple carburetor ?

3.- Explain the function of an accelerating pump on an automotive carburetor.



Simple Carburetor

AIR FLOW MEASUREMENT

INTRODUCTION:

Measurement of the air consumption of an internal combustion engine is often required by engine tests.

Two general classes of flow measuring devices are recognized on the basis of

1) quantitly measurement
2) rate or velocity measurement

Quantity measurement by volume or by weight of fluid is usually accomplished by counting successive portions. Rate measurements are inferred from the effects of the flow rate on pressure, temperature, or position.

The types of metering elements most widely used for the measurement of air flow are:

a) orifices
b) flow nozzles
c) venturi tubes

The same theory applies to all of them since they all have constant area and they depend on changes of pressure for measuring the flow.

THEORY:

Any restriction placed in the path of a flowing fluid causes a pressure drop. When the area of flow at the point of restriction is a constant, the rate of flow is a function of the pressure drop. Thus, a measurement of the pressure drop will enable the determination of the rate of flow.

The energy equation for steady flow may be utulized to relate the rate of flow to the pressure drop. For two plains, one before, and one just after the restriction, the energy equation reduces to

$$(P_1 - P_2)v = \frac{V_2^2 - V_1^2}{2g}$$

where:

Subscript 1 refers to a plain before the restriction.

Subscript 2 refers to a plain just after the restriction.

This is true for incompressible fluids, with no heat transfer. Since the restrictions placed in the flow of compressible fluids for flow measurement purposes cause a very small pressure drop, the fluids may be considered to be incompressible, without introducing an appreciable error. Further, assuming that the velocity in the upstream side is so low that it may be neglected, ($V_1 = 0$), the velocity at the downstream reference plain becomes

$$V_2 = \sqrt{2g\,(P_1 - P_2)\,v}$$

where:

V = velocity

P = pressure

v = specific volume

The quantity $(P_1 - P_2)v$ equals the static head, h, of the fluid causing flow. Expressing the velocity in terms of this head,

$$V_2 = \sqrt{2g\,h}$$

The volume rate of flow of a fluid through a given area equals the product of the area and the velocity, or

$$q' = A_2\,\sqrt{2g\,h}$$

where: (1) g is expressed in feet per second, (2) h in feet, (3) A in square feet, and (4) q' has the dimensions of cubic feet per second.

The above equations are theoretical. They are based on the assumption of perfect transformation of static pressure into velocity pressure. However, because of friction and turbulence this is never true. The actual velocities and volume rates of flow are less than those predicted by these equations. The ratio of the actual to theoretical volume rates of flow is termed the coefficient of discharge C.

Thus, the actual volume rate of flow $q = Cq'$. Then,

$$q = CA_2 \sqrt{2g\,h}$$

This equation is applicable for noncompressible fluids, with adiabatic conditions, and with negligible velocity of approach.

The mass rate of flow, W, may be obtained by multiplying both sides of the above equation by the density, ρ, of the fluid. Thus:

$$W = C\,A\rho\,\sqrt{2g\,h}$$

Since the pressure drop $\Delta P = h\rho$,

$$W = CA\,\sqrt{2g\rho\,\Delta P}$$

When g has the units of feet per second square, ρ must be in pounds per cubic foot, and ΔP in pounds per square foot, A in square feet. Then W will be given in pounds per second.

The area A to be used in the above equation is the actual area of the orifice, nozzle, or venturi.

In practice the pressure difference across the restriction is measured (usually by inclined liquid in glass tube differential manometers for greater accuracy) and this reading is used to determine the mass rate of flow, from specially prepared tables and charts. To obtain the actual mass flow rate, corrections for actual temperature and pressure are applied, again through the use of special tables and charts.

INSTRUCTIONS:

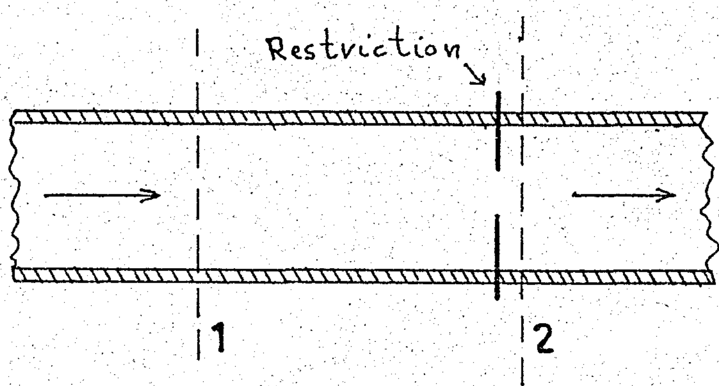
1.- Examine the air-flow measurement set-up carefully.

2.- Take several manometer readings and compute the corresponding mass rate of flow of air.

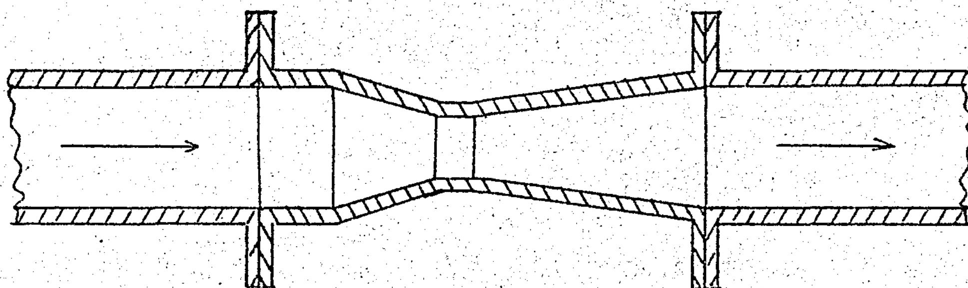
QUESTIONS:

1.- Why is it necessary to apply corrections for the actual temperature and pressure ?

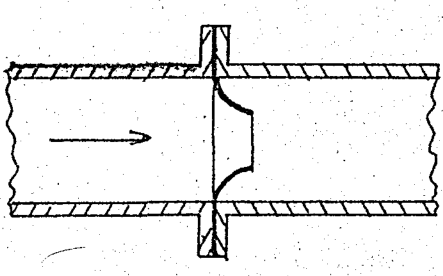
2.- Discuss the effect of pressure drop across the restriction, on the capacity of the engine. At what speeds and throttle settings is the effect most noticeable ?



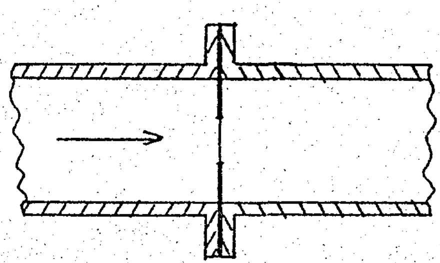
Reference Planes



Venturi Meter



Nozzle



Orifice

ANALYSIS OF EXHAUST GASES
USING THE ORSAT ANALYZER

OBJECT:

This experiment covers the technique of the analysis of exhaust gases by the Orsat apparatus and computations of weight of exhaust gases and weight of air supplied.

INTRODUCTION:

There are five principal constituents usually found in exhaust gases. These are carbon dioxide, oxygen, carbon monoxide, nitrogen and water vapor. Under some conditions hydrogen and hydrocarbons may be present in some quantities, (there may also be traces of sulfur dioxide and trioxide). Usually the five main constituents give a sufficiently accurate indication of combustion conditions. In fact, either the carbon diodixe or the oxygen percentage alone gives a rough approximation of these conditions.

Chemical analysis of the products of combustion is best accomplished by means of successive absorption pipettes, using a representative sample of the gas mixture. In the Orsat apparatus the analysis of the gases is made by the successive absorption of only three constituents, CO_2, O_2 and CO, the balance being reported as nitrogen.

APPARATUS:

The following are required:

1) Orsat apparatus

2) Storage tank for gas samples

3) Rubber tubing and connectors

4) Gas-sampling pipe

The Orsat should be set up at a convenient height, in a good light, and secured so that it will not be overturned or broken. The sampling tube should be an open-end pipe projecting into the center of the gas stream. Cooling fins on the external sampling pipe may be desirable, or a sufficient length should project so as to cool the gas before it enters the rubber tubing.

DESCRIPTION:

The Orsat consists of three main parts:

1) A measuring burette, usually water-jacketed to maintain constant temperature.

2) A leveling bottle, partly filled with water and connected to the burette by a rubber hose. By the use of this bottle the gas may be drawn into or forced out of the burette.

3) A series of three absorption pipettes. These are used in order, beginning next to the burette, and they absorb CO_2, O_2, and CO, respectively.

PROCEDURE:

The manipulation for the analysis consists of the following steps:

1.- Flush out the burette once or twice with fresh gas, and then draw in slightly more than 100 cu.cm. of gas.
2.- Bring the burette water level exactly to the zero mark by discharging the excess gas to the atmosphere, taking care not to introduce any air. (Read the water level from the bottom of the meniscus).
3.- Holding the leveling bottle well above the zero mark, open the stopcock to the first pipette, and pass all the gas slowly in and out of this pipette several times. Bring the reagent in the pipette back to the zero mark in the capillary neck before closing the stopcock.
4.- Read and record the new water level in the burette. This will show the percentage of CO_2 which the reagent has absorbed.
5.- Repeat operations 3 and 4 with the same pipette until further manipulations do not increase the burette readings, i.e., until two successive readings check each other.
6.- Repeat operations 3 to 5, using the second, or oxygen pipette. The final water level in the burette will represent the total of CO_2 and O_2, and the CO_2 percentage must be subtracted in order to determine the

percentage of oxygen.

7.- Repeat operations 3 to 5 for the third, or CO, pipette.

RESULTS:

The data and results are to be reported in the form of a tabulation showing, for each analysis made:

1.- The composition of the exhaust gas by volume, in terms of percentage of CO_2, of O_2, of CO, and of N_2.
2.- The corresponding analysis by weitht.
3.- The engine load, speed, and adjustments
4.- The computed air-fuel ratio, pounds of air actually used per pound of fuel burned.
5.- The fuel-air ratio, reciprocal of (4) (This ratio is used by some).
6.- The theoretical air-fuel ratio
7.- The per cent excess air.

The heating value of the fuel should also be noted

CALCULATIONS:

There are various ways of setting up the calculations leading to the determination of the air-fuel ratio (or its reciprocal the fuel-air ratio). Essentially, they are all modifications of the stoichimetric computations. In any method, the analysis of both fuel and combustion products must be introduced, together with the molecular weights of various constituents. The latter are used to convert the volumetric (Orsat) analysis to gravimetric.

1.- Actual air - fuel ratio

The determination of the actual air-fuel ratio involves the volumetric analysis of combustion products (using the Orsat), and a gravimetric analysis of the fuel. Then:

$$\frac{\text{lb exhaust gas}}{\text{lb fuel}} = \frac{\text{lb carbon burned}}{\text{lb fuel}} \times \frac{\text{lb exhaust gas}}{\text{lb carbon burned}} = =$$

$$= \frac{\text{lb carbon burned}}{\text{lb fuel}} \times \frac{44\ CO_2 + 32\ O_2 + 28\ (CO + N_2)}{12\ (CO_2 + CO\ )} =$$

$$= \frac{\text{lb carbon burned}}{\text{lb fuel}} \quad \frac{11\ CO_2 + 8\ O_2 + 7\ (CO + N_2)}{3(\ CO_2 + CO\ )}$$

where the symbols CO_2, O_2, CO, and N_2 are volumetric percentages from the Orsat analysis of the exhaust gases.

The ratio

$$\frac{\text{lb carbon burned}}{\text{lb fuel}}$$

can be determined by chemical analysis and determination of the carbon content of the fuel, or else, if the chemical composition and formula of the fuel is known, by stoichiometric computations.

Since the simple orsat analysis neglects unburned hydrogen and hydrocarbons, these computations do not take them into account, nor do they account for the burning of sulfur, if any. Usually neither of these omissions causes a significant error.

To convert from the exhaust gas-fuel ratio to the actual air-fuel ratio, the nitrogen content of the exhaust gas, and that of the air is used, as follows:

$$\frac{\text{lb air}}{\text{lb fuel}} = \frac{\text{lb exhaust gas}}{\text{lb fuel}} \times \frac{\text{lb nitrogen}}{\text{lb exhaust gas}} \times \frac{\text{lb air}}{\text{lb nitrogen}}$$

where:

1) $\frac{\text{lb exhaust gas}}{\text{lb fuel}}$ is calculated as shown above.

2) $\frac{\text{lb air}}{\text{lb nitrogen}} = \frac{1}{0.77} = 1.30$, since the approximate composition of air by weight is 23 per cent oxygen and 77 per cent nitrogen (considering the rare gases as nitrogen).

3) $$\frac{\text{lb nitrogen}}{\text{lb exhaust gas}} = \frac{28\ N_2}{44\ CO_2 + 32\ O_2 + 28\ (CO + N_2)} = \frac{7\ N_2}{11\ CO_2 + 8\ O_2 + 7\ (CO + N_2)}$$

where the symbols CO_2 , O_2 , CO, and N_2 are the volumetric percentages from the Orsat analysis of the exhaust gases.

Therefore:

$$\text{Actual } \frac{\text{lb air}}{\text{lb fuel}} = \frac{\text{lb exhaust gas}}{\text{lb fuel}} \times$$

$$\times \frac{1.30 \times 7 \; N_2}{11\, CO_2 + 8\, O_2 + 7\,(CO + N_2)}$$

where CO_2, O_2, CO, and N_2 are the volumetric percentages from the Orsat analysis of the exhaust gases.

2.- Theoretical air-fuel ratio:

The air theoretically required per pound of fuel is calculated from the combining weights. For example if

a) $CH_4 + 2\,O_2 = CO_2 + 2\,H_2O$, then

$$\frac{\text{lb air}}{\text{lb fuel}} = \frac{\text{lb oxygen}}{\text{lb fuel}} \times \frac{\text{lb air}}{\text{lb oxygen}} = \frac{2 \times 32}{12+4} \times \frac{100}{23} = 17.4$$

b) $2\,C_8H_{18} + 25\,O_2 = 16\,CO_2 + 18\,H_2O$, then

$$\frac{\text{lb air}}{\text{lb fuel}} = \frac{25 \times 32}{2 \times 114} \times \frac{100}{23} = 15.26$$

In general, using the gravimetric analysis of the fuel:

$$\text{Theoretical } \frac{\text{lb air}}{\text{lb fuel}} = \frac{32}{12} \times \frac{100}{23}\, C + \frac{16}{2} \times \frac{100}{23}\left(H - \frac{O}{8}\right) +$$

$$+ \frac{32}{32} \times \frac{100}{23}\, S =$$

$$= 11.6\, C + 34.8\left(H - \frac{O}{8}\right) + 4.35\, S$$

where C, H, O, and S represent the weight content of carbon hydrogen, oxygen, and sulfur in the fuel respectively.

3.- Percentage of excess air:

The percentage of excess air above the theoretical is computed from the following equation:

$$\text{Per cent excess air} = \frac{\dfrac{\text{Actual lb air}}{\text{lb fuel}} - \dfrac{\text{Theoretical lb air}}{\text{lb fuel}}}{\dfrac{\text{Theoretical lb air}}{\text{lb fuel}}} \times$$

or,

$$\text{Per cent excess air} = \frac{\text{Actual lb air} - \text{Theoretical lb air}}{\text{Theoretical lb air}} \times 10$$

where all quantities of air are referred to the same quantity of fuel.

NOTES AND PRECAUTIONS:

It is difficult to obtain a high degree of accuracy in Orsat analysis, and it is particularly important that all reasonable precautions be taken to prevent errors and inaccuracies. The following suggestions cover most of the common difficulties:

1.- The reagent in each of the pipettes must be drawn up to the zero mark in the capillary before the gas sample is taken in.

2.- To obtain atmospheric pressure in the measuring burette when a reading is being taken, the levelling bottle must be held so that its water level corresponds with the water level in the burette.

3.- The apparatus should be carefully tested for leakage before an analysis is started. A simple method of doing this is to take in a 100 cu.cm. sample of gas (or air) and then set the leveling bottle on the top of the frame. Leakage at the stopcocks or connections of the absorption pipettes will cause the reagent to recede from the zero level. Leakage in the balance of the apparatus may be detected by again checking the zero in the measuring burette by bringing the water levels in line.

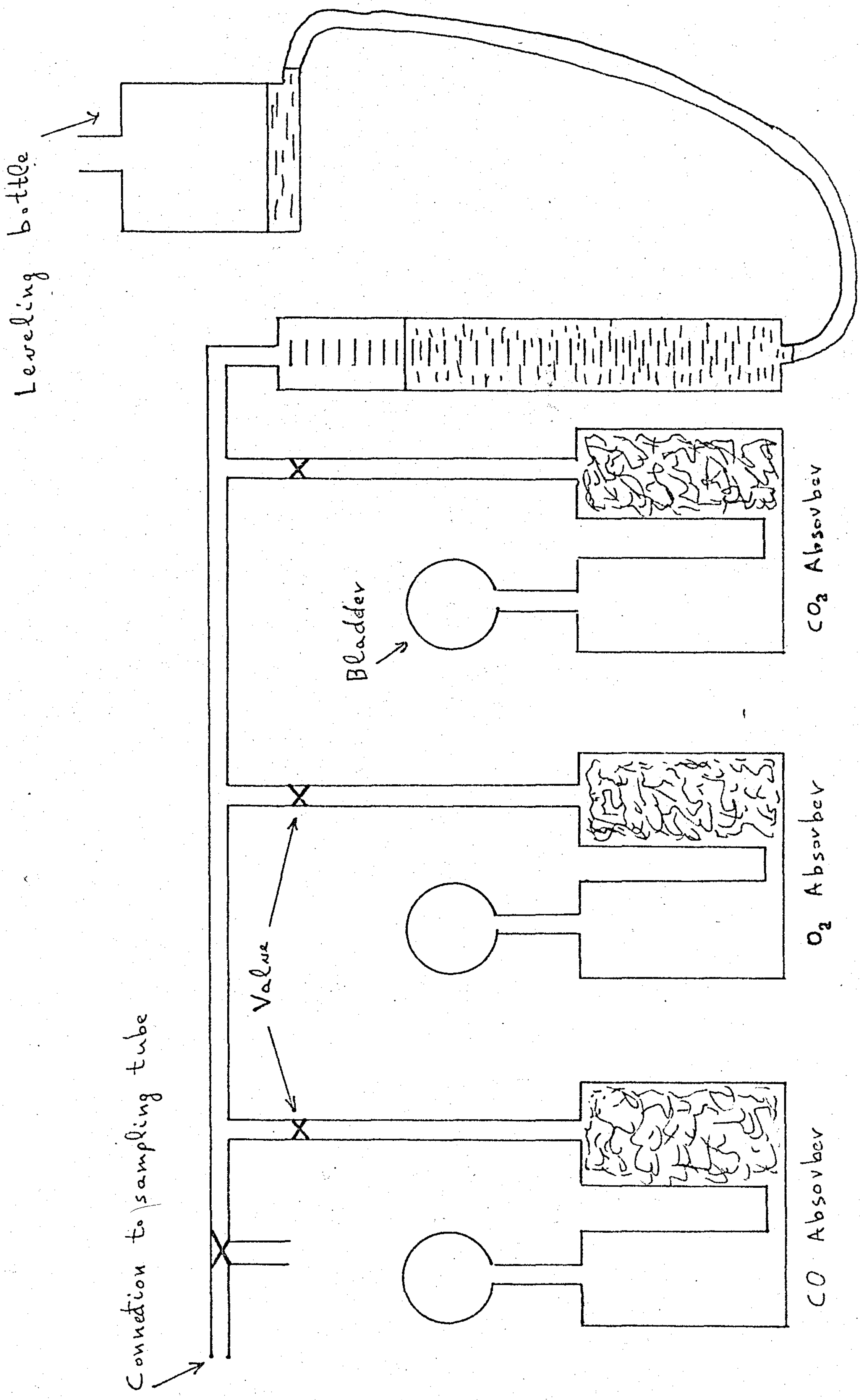
4.- The water in the burette and leveling bottle should be saturated with gas before a sample is taken in for analysis.

5.- The analysis must always be carried out in the proper sequence, i.e., CO_2, then O_2, then CO, as the oxygen solution will also absorb carbon dioxide and the carbon monoxide solution will absorb oxygen. For this reason it is also very important that the absorption be carried to completion in each pipette before admitting the gas into the following one.

6.- When there is any doubt about the strength of the solutions, they should be renewed. The CO_2 solution will last for 100 to 200 analyses, but the other solutions may be exhausted after 10 or 15 analyses. (The oxygen solution is always exhausted first and light also has a deteriorating effect on it).

7.- Care must be used not to allow either the burette water or the reagents to enter the capillary manifold above the stopcocks. If the solutions are allowed to mix in this manner, they must be renewed before further analyses can be made.

8.- The first pipette, for absorbing carbon dioxide, contains a solution of potassium (or sodium) hydroxide, KOH, in the proportions of 2 parts by weight of water to 1 part of the caustic compound. The second pipette, for absorbing oxygen, contains potassium pyrogallate. An easy way to prepare the solution is to put 5 g of the dry pyrogallic acid int a funnel, insert the funnel in the mouth of the pipette, and pour over the acid a sufficient amount of caustic potash solution to fill the pipette. The same caustic potash solution is used as in the CO_2 pipette. The third pipette, for absorbing carbon monoxide, contains a cuprous chloride (Cu_2Cl_2) solution. There are several ways of preparing this solution, but it is rather difficult to prepare a solution that is satisfactory. A common method and one for which the materials are easily obtained is as follows: Pour about 50 g of black copper oxide (scale) into a 500 cu. cm. flask, and insert also several strips or wires of copper, long enough to reach up to the mouth of the flask. Fill the flask with 1.10 gravity hydrochloric acid, and insert the stopper. Let the solution stand until it is colorless, then pour off the clear liquid. This liquid may be stored in full bottles containing copper strips, provided that the bottles are well sealed from air and protected from strong light.



The Orsat Analyzer

DETERMINATION OF COMBUSTION LOSSES

OBJECT:

This experiment deals with the methods of determining the energy losses associated with the products of combustion.

INTRODUCTION:

The largest cost in the production of power (or heat) is the cost of the fuel itself. Large energy losses will result if the proper relation is not maintained between the fuel demand and the supply of air for combustion. Effective controls are available to maintain automatically the desired air-fuel ratio, in spite of wide fluctuations in load and operating conditions. The excellent air and fuel metering systems of automotive and airplane carburetors are the result of long and intensive development.

Automatic combustion control seldom involves complete chemical analysis of the combustion products, except when the control instrument is being calibrated or checked. The control detector or continuous monitor is a simple device employing one of the following methods:

1.- The thermal conductivity cell utilizes the higher electrical conductivity of CO_2 as an indicator of the CO_2 content of the products, employing a Wheatstone bridge circuit.

2.- Chemical absorption cells are an adaptation of the principle of the Orsat, and the measured quantity is a pressure difference.

3.- The density method is based on the higher density of CO_2 as compared with the other gases. A pair of fans, one handling exhaust gases and the other air, may be mounted in a balance so that the position of the unit indicates the percentage of CO_2.

4.- A combustion cell may utilize the residual ozygen in the products of combustion, and the oxygen content is then indicated by a temperature rise. Unburned combustibles are also detected by means of combustion cells.

5.- Flowmeters can be arranged to measure air flow and fuel flow, or quantities proportional thereto, providing signals that are used for maintaining the desired air-fuel ratio.

One of the disadvantages of many combustion controls is the time lag inherent in their operation. Another practical difficulty is that of securing and maintaining a true average sample of the products of combustion.

CALCULATIONS:

The combustion losses may be separated into 6 items:

1) Loss to dry products

This is given by:

$$q_1 = \frac{\text{lb dry products}}{\text{lb fuel}} X\ C_p\ X\ (t_g - t_a)$$

where:

t_g = exit temperature of gaseous products of combustion, °F

t_a = entering temperature of air supply, °F

C_p = specific heat of the dry exhaust gases, usually about 0.245 Btu/lb °F

q_1 = heat loss to dry exhaust gases, Btu/lb fuel.

2) Loss due to incomplete combustion of carbon

The heating value of 1 lb of carbon when contained in carbon monoxide is 10160 Btu, and since the same weight of carbon is contained in a volume of either CO or CO_2, the loss may be computed by:

$$q_2 = \frac{CO}{CO + CO_2} X\ C\ X\ 10160 \qquad , \frac{\text{Btu}}{\text{lb fuel}}$$

where the symbols CO and CO_2 represent volumetric percentages of the Orsat analysis, and C is pounds of carbon (burned) per pound of fuel.

3) Hydrogen-moisture loss

This represents the heat lost in the enthqlpy of the water formed from the burning of combustible hydrogen. To calculate this loss, the superheated vapor at the temperature of the gaseous products t_g (^oF) would be cooled, condensed at around 150 ^oF, and subcooled to the entering fuel temperature t_f (^oF), or approximately:

$$q_3 = \frac{18}{2} H \left[0.46 (t_g - 150) + 1008 + (150 - t_f) \right] =$$

$$= 9 H (1089 + 0.46 t_g - t_f) \quad , \frac{Btu}{lb\ fuel}$$

where H is the weight of combustible hydrogen in 1 lb of fuel.

4) Loss due to moisture in the fuel

This is given by:

$$q_4 = W \left[0.46 (t_g - 150) + 1008 + (150 - t_g) \right] =$$

$$= W (1089 + 0.46 t_g - t_f) \quad , \quad Btu/lb\ fuel$$

where t_g, t_f have the same meaning as before and W is the weight of moisture in 1 lb of fuel by analysis.

5) Loss due to heating moisture in air

Since the combustion equations assume dry air, any moisture in the air supplied for combustion is merely superheated to the temperature of the exhaust gases, and this heat is lost.

$$q_5 = W_s \times \frac{\text{lb air}}{\text{lb fuel}} \times 0.46\,(t_g - t_a) \quad , \quad \frac{\text{Btu}}{\text{lb fuel}}$$

where:

W_s = humidity ratio of entering air, $\frac{\text{lb moisture}}{\text{lb dry air}}$

t_a = temperature of entering air , ^{o}F

t_g = temperature of exhaust gases , ^{o}F

6) <u>Miscellaneous losses</u> (including radiation)

These are composed of the heat rejected by the cooling system of the engine, radiation and convection losses from the engine body, etc.

7) <u>Useful heat</u>

This is the balance of the heat supplied, when all losses, items 1 to 6, have been subtracted. Since the input basis is 1 lb of fuel, the useful heat is the heating value of 1 lb of fuel minus all losses (1 to 6).

RESULTS:

For at least three sets of engine speed and torque (and/or carburetor adjustment) obtain the following data:

1.- Orsat analysis of exhaust gases

2.- Temperature of fuel

3.- Dry-bulb and wet-bulb temperatures of the air supplied for combustion

4.- Brake horse power of engine

5.- Identification of fuel so that its analysis may be approximated

6.- Approximations of cooling losses, (jacket losses etc.) by available methods.

Note: See experiment: Analysis of exhaust gases using the Orsat analyzer.

PART FOUR

A.- Equipment

B.- Location and Layout of the I. C. Engine Laboratory

EQUIPMENT

At present the I.C. engine laboratory equipment is installed in the power laboratory. The following exist there:

1.- Single-cylinder two-stroke marine diesel engine coupled to a cradle mounted electric dynamometer.

2.- Six-cylinder four-stroke Chevrolet gasoline engine coupled to a hydraulic dynamometer.

3.- Single-cylinder Japy gasoline engine coupled to an electric generator.

4.- Hot-bulb engine. A single-cylinder two-stroke semi-diesel engine, equipped with a Prony brake.

5.- Single-cylinder four-stroke, variable compression ratio engine coupled to a cradle-mounted D.C. dynamometer. The engine may be run either as a spark-ignition or compression-ignition engine, by changing its head.

All the above engine-dynamometer sets are properly installed, and tests may be run on any of them. However, the most flexible and the most useful of all is the variable compression ratio engine-dynamometer set. With this set almost all usual engine tests can be carried out with the engine operating either as a gasoline or diesel engine at various compression ratios. Comprehensive instrumentation is provided on the set. (For detailed information refer to: Thesis by Fevzi Taşçı, "Analysis of Pressure Variations in a Variable Compression Engine Cylinder" June 15, 1964, Robert College, Graduate School).

In addition to the equipment mentioned above, there are the following I.C. engines in the power laboratory:

6.- A nine-cylinder radial aircraft engine.

7.- Two, six-cylinder four-stroke in line gasoline engines,

8.- A V-8 Ford gasoline engine

9.- A four-cylinder inclined Pontiac gasoline engine.

10.- A cut-away model of a two-stroke single-cylinder gasoline engine.

Items 6-10 above can not be used to perform experiments, in the condition they are. The nine-cylinder radial aircraft engine and the two six-cylinder in line gasoline engines are old and they have many missing parts and accessories. One of these two six-cylinder engines may be used to make a cut-away model, and the other should be kept for practicing engine dismantling and reassembling by students. The nine-cylinder radial aircraft engine can not be used for any useful purpose.

The V-8 Ford engine, as well as the four-cylinder Pontiac gasoline engine, should be properly installed and coupled to cradle mounted electric dynamometers of suitable capacity.

The cut-away model of a two-stroke single-cylinder gasoline engine should be mounted on a stand.

Apart from the two new cradle mounted electric dynamometers required, the following additions to the equipment in the I.C. engine laboratory are suggested;

1.- A two-stroke spark-ignition engine, preferably a single-cylinder or a two-cylinder model, coupled to a cradle mounted electric dynamometer.

2.- An electric motor-generator set of proper capacity to generate D-C for the electric dynamometers (when they are used for starting or motoring).

In addition to usual laboratory equipment like:

a) temperature and pressure gages

b) voltmeters and ammeters

c) graduated cylinders

d) sensitive balance

e) stop-watches

f) tachometers

g) hydrometer

h) callipers

i) planimeter

j) oscilloscope

k) Sling psychrometer

the following special equipment is necessary:

a) Orsat apparatus	1 ea
b) compression gage with check valve	1 ea
c) spark-plug thermocouples	8 ea
d) combination spark plug and quartz piezo-electric pick-up	8 ea
e) Bouncing-pin device with water electro-lysis apparatus	1 ea

LOCATION AND LAYOUT OF THE I. C. ENGINE LABORATORY

It is preferable to leave the I. C. engine laboratory where it is in the Power Laboratory, at present. Utilities like water and electricity are available there, and there is no problem of objectionable noise from the exhaust of engines.

The layout of the existing equipment is satisfactory. A suggested layout is shown on the drawing in the pocket inside the back cover of this volume.

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APPENDIX

A.- Formulae Used in I. C. Engine Test Calculations

B.- The Report

FORMULAE USED IN I.C. ENGINE TEST CALCULATIONS

1.- HORSEPOWER, THERMAL EFFICIENCY, FUEL-AIR RATIO:

Thermal efficiency is defined by:

$$\eta = \frac{\text{work output}}{\text{fuel energy input}} = \frac{\text{work output}}{e_c \times w_f \text{ input}} \qquad (1)$$

where: e_c = heating value of fuel, Btu/lb

w_f = pounds of fuel

Obviously both output and input must be measured in the same convenient time interval, and in the same units.

$$\eta = \frac{W}{J e_c w_f} = \frac{W}{778\ e_c w_f} \qquad (2)$$

where:

W = work output in ft-lb

e_c = heating value of fuel, Btu/lb

w_f = pounds of fuel consumed.

$$W = w_f\ 778\ e_c \eta \qquad (3)$$

Since $hp = \frac{W/min}{33000}$

then, $$hp = \frac{(w_f/min)\ 778\ e_c\ \eta}{33000} \qquad (4)$$

Fuel-air ratio, $F = \frac{w_f}{w_a}$ (5)

where, w_a = lb of air mixed with w_f lb of fuel.

Substituting eq (5) in eq (3) and (4)

$$W = w_a \; J \; Fe_c \eta \qquad (6)$$

$$hp = \frac{(w_a/min) \; J \; Fe_c \; \eta}{33000} \qquad (7)$$

2.- Specific-fuel and specific-air consumptions;

From eq (4);

$$\frac{1}{\eta} = \frac{(w_f/min) \; J \; e_c}{hp \times 33000} \quad \frac{(w_f/hr) \; Je_c}{hp \times 33000 \times 60} \qquad (8)$$

$\frac{(w_f/hr)}{hp}$ is the pounds of fuel used per hour for ~~each~~ each horsepower developed, or the pounds of fuel required per horsepower-hour of work done. This is called the specific fuel consumption, sfc

From eq (8)

$$sfc = \frac{33000 \times 60}{J \; e_c \eta} = \frac{2545}{e_c \eta} \text{ , lb of fuel/hp-hr} \qquad (9)$$

Similarly from eq (7)

$$\frac{1}{\eta} = \frac{(w_a/min) \; F \; J \; e_c}{hp \times 33000} = \frac{(w_a/hr) \; F \; J \; e_c}{hp \times 33000 \times 60} \qquad (10)$$

$\frac{(w_a/hr)}{hp}$ is the pounds of air used per hour for each horsepower developed, or the pounds of air required per horsepower-hour of work done. This is called the specific air consumption, sac

From eq (10):

$$sac = \frac{33000 \times 60}{F\,J c_c \eta} = \frac{2545}{F\,c_c \eta} \text{ , lb of air/hp-hr} \qquad (11)$$

3.- Indicated and brake thermal efficiencies:

If the work output W in eq (2), (3), or (6) is the work at the engine output shaft, it is shown as W_b, and the corresponding efficiency is called the brake thermal efficiency, η_{bth}

If it is the work done by the cylinder gases on the piston, it is known as indicated work W_i, and the corresponding efficiency is called the indicated thermal efficiency, η_{ith}.

4.- bhp , bsfc , bsac

Similarly, if in eq (4), (7), (8), (9), (10), or (11), η_{bth} is used for efficiency, then, the corresponding horsepower is called brake horsepower (bhp), the specific fuel consumption is called brake specific fuel consumption (bsfc) and the specific air consumption is called the brake specific air consumption (bsac).

5.- ihp , isfc , isac

If in eq (4), (7), (8), (9), (10), or (11), η_{ith} is used for efficiency, then, the corresponding horsepower is called indicated horsepower (ihp), the specific fuel consumption is called indicated specific fuel consumption (isfc), and the specific air consumption is called the indicated specific air consumption (isac).

6.- Mean effective pressure:

Mean effective pressure for a cylinder is defined as:

$$mep = \frac{W/cycle}{V_d} , \frac{in\text{-}lb}{in^3} = psi \qquad (12)$$

$$\text{Work of engine} = hp \times 33000 \times 12 , \frac{in\text{-}lb}{min}$$

$$\text{Work of engine/cycle} = \frac{hp \times 33000 \times 12}{n} , in\text{-}lb$$

where: n = total number of cycles per minute
(for a four-stroke cycle engine

$$n = \text{number of cylinders} \times \frac{rpm}{2} \Big)$$

From eq (12), therefore

$$mep = \frac{hp \times 33000 \times 12}{n\ V_d} , psi \qquad (13)$$

where: V_d = displacement volume of one cylinder, in^3

or,
$$hp = \frac{mep \times n \times V_d}{33000 \times 12} \qquad (14)$$

7.- imep , bmep :

Again, if ihp is used in eq (13) or (14) for horsepower, the corresponding mep is called indicated mean effective pressure (imep). If bhp is used for horsepower, then, the corresponding mep is called brake mean effective pressure (bmep).

The imep can also be calculated from an indicator diagram, if the area of the diagram {pressure x volume , $(lb/in^2) \times in^3 = in\text{-}lb$} is divided by the length of the diagram (which represents the displacement volume).

8.-Mechanical Efficiency

It is defined as

$$\eta_{mech} = \frac{bhp}{ihp} = \frac{bmep}{imep} \qquad (15)$$

On the other hand,

$$bhp = ihp - fhp \qquad (16)$$

where: fhp = friction horsepower

Combining eq (16) with (15)

$$\eta_{mech} = \frac{ihp-fhp}{ihp} = 1 - \frac{fhp}{ihp} \qquad (15a)$$

From eq (4)

$$ihp = \frac{(w_f/min)\ J\ e_c\ \eta_{ith}}{33000} \qquad (17)$$

where: η_{ith} = indicated thermal efficiency and

$$bhp = \frac{(W_f/min)\ J\ e_c\ \eta_{bth}}{33000} \qquad (18$$

where: η_{bth} = brake thermal efficiency

Dividing (18) by (17)

$$\frac{bhp}{ihp} = \eta_{mech} = \frac{\eta_{bth}}{\eta_{ith}} \qquad (19$$

Similarly from eq (9)

$$isfc = \frac{2545}{e_c\ \eta_{ith}} \qquad (20$$

where: isfc = indicated specific fuel consumption

and

$$bsfc = \frac{2545}{e_c\ \eta_{bth}} \qquad (21$$

where: bsfc = brake specific fuel consumption.

Dividing eq (20) by (21)

$$\frac{isfc}{bsfc} = \frac{\eta_{bth}}{\eta_{ith}} = \eta_{mech} \qquad (22$$

From eq (19) or (22)

$$\eta_{bth} = \eta_{ith} \times \eta_{mech} \qquad (2$$

so that eq (21) could be written

$$bsfc = \frac{2545}{e_c\ \eta_{ith} \times \eta_{mech}} \qquad (2$$

9.- Ideal efficiency:

It is defined as

$$\eta_{ideal} = 1 - \left(\frac{1}{r}\right)^{k-1} \qquad (25)$$

where: r = compression ratio

$k = (c_p/c_v)$ for air (= 1.4)

10.- Indicated engine efficiency:

or efficiency ratio, is defined by:

$$\eta_{i\ engine} = \frac{\eta_{ith}}{\eta_{ideal}} \qquad (26)$$

11.- Brake engine efficiency:

is defined by:

$$\eta_{b\ engine} = \frac{\eta_{bth}}{\eta_{ideal}} \qquad (27)$$

12.- Air capacity and volumetric efficiency:

The ideal air-capacity for a four-stroke engine is given by

$$W_i/min = \frac{rpm}{2} \times N \times V_d \times \gamma_i \quad , \quad \text{lb of air/min} \qquad (28)$$

where: V_d = displacement volume of one cylinder

γ_i = inlet air density

N = number of cylinders

If w_a/min is the actual air consumption of the four-stroke engine, then, the volumetric efficiency is defined as

$$\eta_v = \frac{W_a}{W_i} \quad \frac{w_a/\text{min}}{\frac{\text{rpm}}{2} \times N \times V_d \times \gamma_i} \tag{29}$$

so that

$$\frac{w_a}{\text{min}} = \frac{\text{rpm}}{2} \times N \times V_d \times \gamma_i \times \eta_v \tag{30}$$

If we define

$$\gamma_{cyl} = \frac{\text{mass of air entering cylinder per suction st}}{V_d}$$

$$= \frac{w_a/\text{min}}{\frac{\text{rpm}}{2} \times N \times V_d} \tag{31a}$$

and from eq (29)

$$\eta_v = \frac{\gamma_{cyl}}{\gamma_i} \tag{32}$$

13.- Scavenging ratio, scavenging efficiency:

The ideal air-capacity for a two-stroke engine would be

$$w_i/\text{min} = \text{rpm} \times N \times V_t \times \gamma_i \text{ , lb of air/min} \tag{33}$$

where: V_t = total volume per cylinder = $V_d \times \frac{r}{r-1}$

γ_i = inlet air density

N = number of cylinders

If $\frac{W_a}{min}$ is the total air entering the engine ports per minute, then, the scavenging ratio, R_{sc}, for the two troke engine is defined by :

$$R_{sc} = \frac{W_a}{W_i} = \frac{(W_a/min) \times \left(\frac{r-1}{r}\right)}{rpm \times N \times V_d \times \gamma_i} \qquad (34)$$

If $\frac{W_{ret}}{min}$ is the total air retained in the cylinders per minute, then the scavenging efficiency, η_{sc}, for the two stroke engine is defined by:

$$\eta_{sc} = \frac{W_{ret}}{W_i} = \frac{(W_{ret}/min) \times \left(\frac{r-1}{r}\right)}{rpm \times N \times V_d \times \gamma_i} \qquad (35)$$

14.-Engine power at standard conditions:

The maximum output of a spark ignition engine is directly proportional to the weight of air or mixture inducted into the cylinder. If the engine is operated in a region of low barometric pressure, there will be a corresponding reduction in power output. Similarly, if the temperature of the air entering the engine is high, the output will be reduced. In both cases the reduction in power is due to the reduced weight of air taken into the cylinders.

The Society of Automotive Engineers (S.A.E.), agreed upon air at 60 °F and at 29.92 in. of mercury (14.696 psi with no water vapor present in the air, as representing standard conditions.

To correct the maximum power output of an engine to standard air conditions the following correction factor should be used.

$$CF = \frac{29.92}{P_a} \times \sqrt{\frac{T_a}{520}} \qquad (36)$$

where:

CF = correction factor

P_a = barometric pressure, inches Hg

T_a = absolute temperature of air entering the engine ($= 460 + {}^{\circ}F$)

THE REPORT

INTRODUCTION:

After making the experiment and obtaining the data, the student must report the results. For many students, the writing of a satisfactory report is almost as difficult as making the test. Perhaps one reason for this is that the writing of the report is not approached by these students, in a logical, engineering manner.

There is no single, all-inclusive form or set of instructions which can be given for writing an engineering report, but underlying principles can be discussed. There are many factors which affect the nature of the report. Some of these are the nature of the test, the kind of results which were obtained, etc. In general, however, the report must state the purpose of the experiment, how it was made, and what the results are, and must contain an analysis of the results.

These are the minimum requirements. An extensive report may contain the following parts:

1.- Title
2.- Object
3.- Summary
4.- Theory and analysis
5.- Description of apparatus tested

6.- Instruments, equipment and methods.

7.- Data

8.- Results

9.- Conclusions and recommendations

10.- Discussion

11.- Appendix

The following list and comments will furnish suggestions for checking the quality and completeness of a report. It is a good practice to write the report in the third person (passive voice), past tense.

CHECK LIST FOR COMPLETE REPORT:

Title and object:

1.- A title page should be used with full identification, including names and dates.

2.- The title should be brief but fully descriptive.

3.- If the report is long or complex, a table of contents should follow the title page.

4.- The object should be concisely stated, in the past tense, using complete sentences.

This section not only informs the reader of the nature and purpose of the experiment, but also becomes the writer's own guide to all that is to follow in the report. All material in the report is related to the object, and anything unrelated can be omitted.

SUMMARY:

1.- A good rule for this section is to require that the first sentence state what was accomplished.

2.- The summary is not a condensation of the entire report, but rather a short statement of the results achieved and an indication of the scope of the report.

3.- Conclusions and recommendations should also be summarized.

4.- The summary should be informative, not simply descriptive.

This section should indicate to the reader whether or not he will be interested in the full text of the report.

THEORY AND ANALYSIS:

1.- Pertinent principles, laws and equations should be stated, and any unfamiliar terms defined.

2.- Analytical diagrams such as theoretical cycles, or energy-balance diagrams should be included.

3.- The nature and significance of coefficients, correction factors, or efficiencies should be indicated.

APPARATUS OR MACHINE TESTED:

This is an important section in performence tests.

Full and accurate identification should be given.

Photographs and sketches, together with names, ratings, classifications, and sizes, will aid for identification.

INSTRUMENTS, EQUIPMENT AND METHODS:

1.- Instrument ranges and identification numbers should be recorded.

2.- A sketch of the test set-up showing relative positions, connections and flows, and locations of instruments should be included.

3.- The nature of tests or runs should be stated.

4.- Preliminary tests, duration of runs, and frequency of readings should be indicated.

5.- Special precautions for obtaining accuracy and means for controlling conditions should be described.

6.- The independent variables should be indicated.

DATA AND RESULTS:

1.- The findings should be summarized in a few paragraphs, supported by tables and graphs as required.

2.- Tables should include pertinent material only. Original data sheets and other data should be placed in the appendix.

3.- Graphical representation of the results adds clearness.

4.- Deviations from smooth curves should be carefully checked. Apparent deviations should be pointed out and explained.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS:

1.- Conclusions are to be drawn with reference to the previously stated object of the experiment.

2.- Each conclusion should be supported by specific references to data and results, quoting numerical values, and guiding the reader from facts to conclusions.

3.- Conclusions should follow directly from the numerical results quoted. Conclusions are judgments, not happenings, but these judgments should be supported wherever possible.

4.- An analysis of the accuracy of methods, data and results is a necessary support for the conclusions. This includes examination of probable errors in observations, in sampling the various quantities (duration of runs and frequency of readings), and in the formulas and computations involved.

5.- Recommendations are often more important than conclusions. Student experiments are frequently hampered by lack of time and experience, shortcomings of methods and equipment, and insufficient attention to accuracy. Recommendations should be made for any changes or further work that would more adequately accomplish the original object.

6.- An important rule to remember when writing the discussion is that any part of it that could have been written without doing the experiment is not an evaluation of the work done, nor a conclusion therefrom.

APPENDIX:

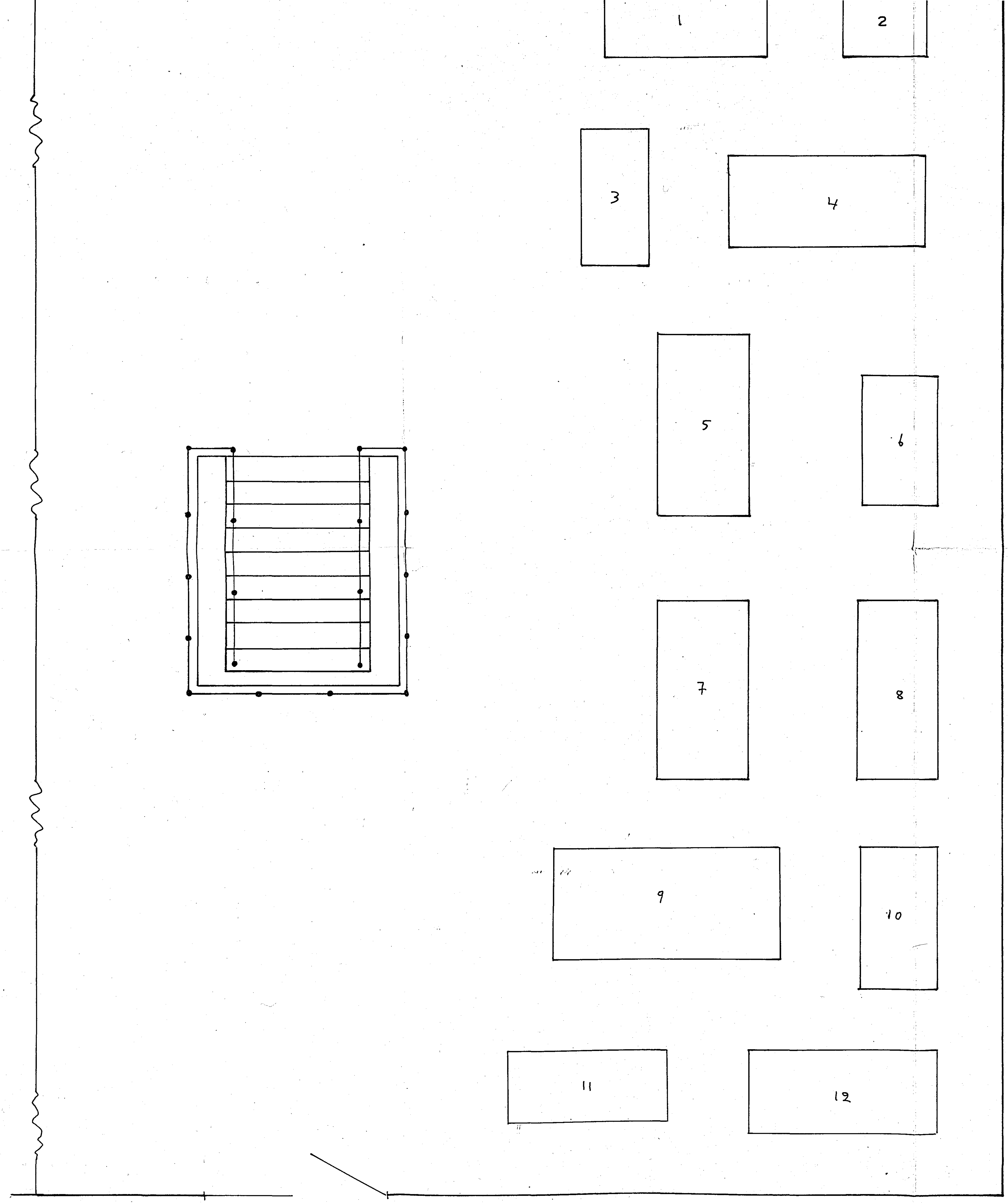
1.- All original data sheets, diagrams and sketches are preferably included in the appendix for reference.

2.- Sample calculations are important and, unless very brief, should be put in the appendix.

3.- Special descriptions, drawings and details regarding test methods may appear in the appendix if their importance is secondary to the object of the experiment.

ACKNOWLEDGMENTS AND BIBLIOGRAPHY:

Separate sections for acknowledgments and references may be included in the report. These should usually follow the body of the report and precede the appendix.



1. — Six-cylinder, four-stroke cutaway model, gasoline.
2. — Single-cylinder, two-stroke cutaway model, gasoline.
3. — Six-cylinder, four-stroke engine for practicing dismantling and reassembling.
4. — Hot-bulb engine, single cylinder, two-stroke.
5. — Six-cylinder, four-stroke Chevrolet, gasoline.
6. — Single-cylinder, Japy engine, gasoline.
7. — V-8 Ford engine, gasoline.
8. — Four-cylinder, Pontiac engine, gasoline.
9. — Single-cylinder, four-stroke variable compression ratio engine, gasoline or diesel.
10. — Electric motor-generator set for D-C supply.
11. — Two-stroke spark-ignition engine.
12. — Single-cylinder, two-stroke marine diesel engine.

Proposed Layout for the I.C. Engine Laboratory			
Drawn by:	F. P.	Scale:	Not to scale
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