DESIGN AND OPERATION
OF AN
ENGINE POLLUTION TEST FACILITY

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ABSTRACT

The gasoline-powered automobile, employing an internal combustion reciprocating engine, has been known for many years to be a major source of air pollutants. The major pollutants emitted by the automobile engines are: unburned hydrocarbons, carbon monoxide and oxides of nitrogen. Wall quenching, short period of time for combustion and the high temperature reached in the cylinder are the primary reasons for high pollutant levels in the engine exhaust.

The aim of this work was to develop a facility capable of testing automobile engines under controlled low temperature conditions. With a modification of the ventilation system, the test facility could be used for testing automobile engines at low temperature conditions. Tests conducted however, were priliminary in nature and were onlv carried out at room temperature of 70°F.

An automobile engine and dynamometer were installed in a test cell along with the necessary instrumentation to control and measure the various parameters of interest. A cooling water facility for controlled temperature testing of engines was designed and incorporated. Tests were conducted to check the operation of the systems assembled.

Measurements were made of exhaust composition resulting from advancing the spark timing of the engine at different loads and speeds. Spark timing advance is necessary at part throttle operation (for fuel economy) and is accomplished

through manifold vacuum advance to the distributor. This spark advance increases the amount of hydrocarbons and carbon monoxide emitted from the engine.

Results also indicate that, at low mixture temperatures in the manifold, exhaust pollutant levels are high. Increasing the mixture temperature beyond a certain point, however, results in insignificant reduction in the amount of pollutants emitted from the engine.

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1. INTRODUCTION

Automobile vehicles employing internal combustion engines contributed about 60% of the total mass of air pollutants in the U.S. in 1966 (1)*. Many effects of air pollution on the human respiratory system are irreversible and, thus, irreparable (2). Flora and fauna are similarly subjected to a deteriorative process due to air pollution.

The U.S. federal legislation aims to reduce the concentration in the air of those solid, liquid and gaseous components of auto exhaust known to influence health or limit visibility: unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO and NO_2) and particulates (3).

A particular test sequence, based on the traffic surveys in a Los Angeles county, is used as a standard for testing engines for exhaust emissions. Pollution standards used today are derived from these California conditions and are primarily aimed at reducing pollutants that tend to form photo-chemical smog. Concentrations of HC, CO and nitrogen oxides NO_x in the atmospheric air are largely dependant upon the traffic and weather conditions. Traffic patterns, however, vary with time of day and location as shown by the example of the four locations in United States of fig.1.1 (2). Similarly, the weather conditions are also quite different at different places.

The climatic conditions in Canada, are generally colder than in the U.S. Hence, especially in the winter,

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* Numbers in parenthesis designate References on pp. 74 - 76.

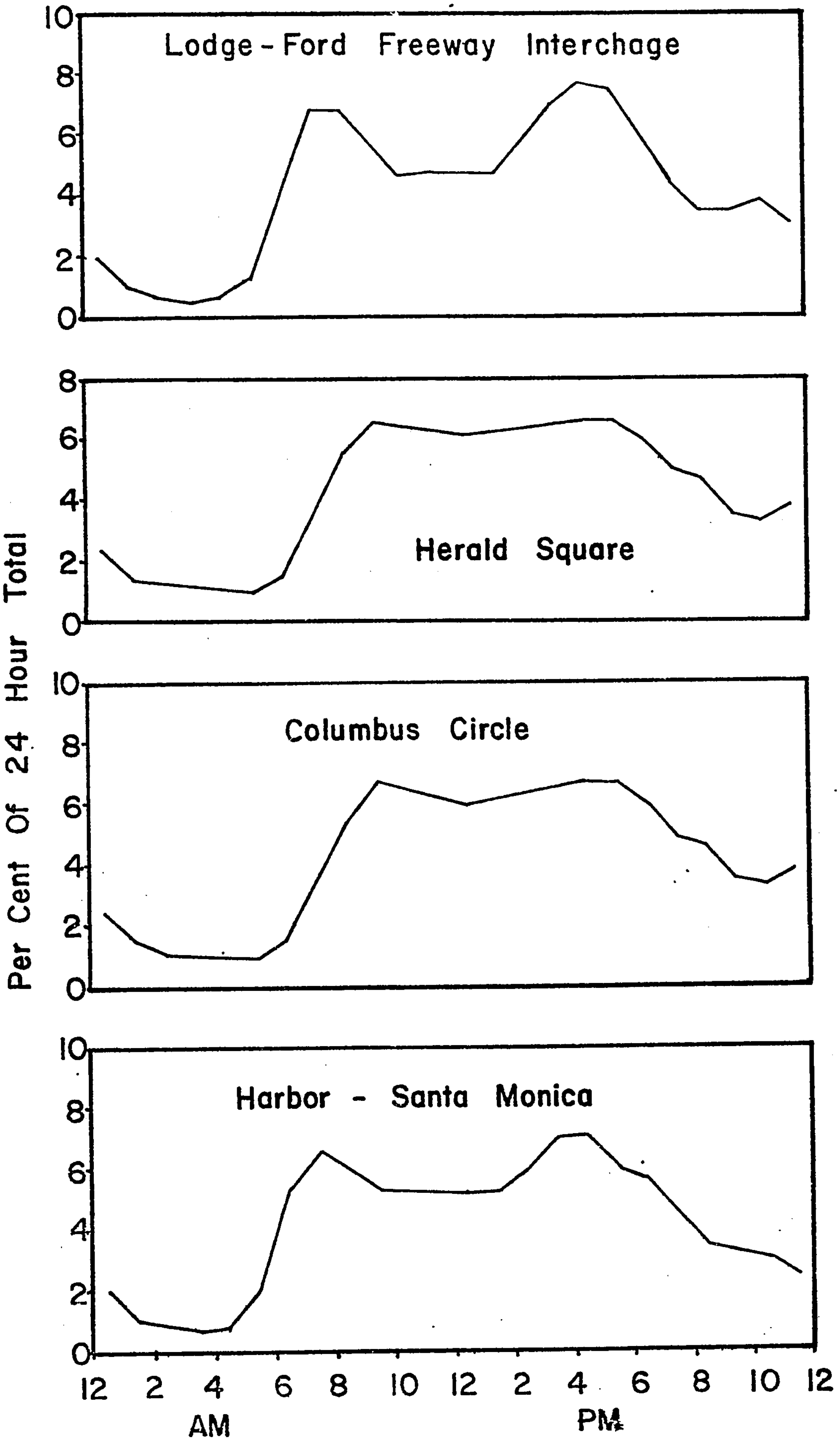


Fig. 1·1 TRAFFIC PATTERNS DURING THE DAY due to cold temperature operation of engines, more unburned hydrocarbons are emitted. Thus the testing standards should be altered where necessary, for grossly different weather and traffic conditions.

Information about cold temperature engine operation and pollutant levels is needed. The aim of this work is to set up a facility capable of testing automobile engines under controlled low temperature conditions. A preliminary set of experiments were conducted to check the operation of the systems assembled and to find the effect of advancing the spark timing on exhaust emissions at a room temperature of 70°F.

This work begins with a review of 'emissions and emission control devices'. Generation of pollutants, federal test procedures and standards and emission control devices are discussed.

An automotive engine (350 cu.in., V - 8, Chev., 1971 model) with necessary instrumentation to control and measure the engine operating conditions was installed. An eddy-current absorption dynamometer (Dynamatic type to absorb 450 HP) was also installed. The installation and the instrumentation designed are described in the third chapter.

Engine and dynamometer operations were checked. The experiments conducted are described in chapter 4. Data recorded, results observed and suggestions for future work are given in the final chapter.

2. EMISSIONS AND EMISSION CONTROL DEVICES

The combustion process in the cylinder has associated with it incomplete combustion, backward reactions, dissociation reaction and wall quenching. Due to these phenomena, exhaust gases of the engine contain unburned hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NO and NO_2). These are the main pollutants emitted by the automobile engine.

2.1. REASONS FOR HC EMISSIONS: Liquid drops or gaseous fuel are often present between the piston and the cylinder and behind the top piston ring. Also the flame is extinguished 0.002 to 0.015 in. before it reaches the walls of the combustion chamber because of heat loss to the wall (wall quenching). Consequently, a boundary layer of unburned or partially burned fuel envelops the products. These are the reasons why hydrocarbons are present in the engine exhaust and can be decreased by (4):

A. Higher temperature of the exhaust gas
   1. By decreasing the compression ratio
   2. By retarding the spark
   3. By increasing charge and coolant temperatures
   4. By increasing speed (hotter exhaust)
   5. By increasing the charge pressure

B. More oxygen in the exhaust
   1. By leaning the mixture
   2. By adding oxygen or air to the exhaust

C. Smaller mass in the quenched envelope
   1. By decreasing the area of combustion chamber walls
      a. Higher volume/surface ratio

- b. Greater displacement per cylinder with fewer cylinders
- c. Smaller bore/stroke ratio

2. By increasing the turbulence
3. By increasing the charge and coolant temperatures
4. By increasing the compression ratio (but note A.1)

D. More time for reaction

1. By decreasing speed (but note A.4)
2. By a more-homogeneous mixture
   - a. Premixing
   - b. Higher charge temperature
   - c. More volatile fuel

2.2. PRODUCTION OF CO: Excess amounts of carbon monoxide are formed primarily due to the incomplete combustion of the fuel especially when the mixture is rich. It has been found that the concentrations of CO correspond more nearly to the equilibrium concentrations of CO at peak cycle temperature than those existing at the end of expansion (due to slow rate of destruction of CO during the exhaust stroke) (2). Generally the methods used for reducing HC reduce CO as well.

2.3. FORMATION OF NO: The concentration of the oxides of nitrogen (NO_x) in the exhaust from a spark ignition engine is primarily a function of peak cycle temperature and air-fuel ratio of the intake mixture and can be reduced by (4):

A. Decreasing the combustion temperature

1. Decreasing the compression ratio
2. Retarding the spark
3. Decreasing the charge temperature

4. Decreasing the speed
5. Decreasing the mixture pressure
6. Adding an inert gas (for example, exhaust gas to the fresh charge)

B. Decreasing the oxygen available

1. Decreasing the air-fuel ratio
2. Decreasing the homogeneity of the mixture

However, it is to be noted that, generally any change in the engine or operating variables that reduce oxides of nitrogen tend to increase hydrocarbons and carbon monoxide concentrations in the automobile exhaust.

2.4. EMISSION CONTROL DEVICES: To reduce the pollutants emitted from the automobile, emission control devices have been designed and incorporated.in car models from time to time. The control devices that are already in use in automobiles, with particular reference to GM engines, and those that are being studied are described below:

2.4.1. Positive Crankcase Ventilation: In gasoline engines, blowby occurs during the compression and power strokes. These gases contain some unburned fuel-air mixture as well as the products of combustion like carbon monoxide, carbon dioxide, water and oxides of nitrogen. (Blowby gases are the gases that leak from the combustion chamber past the piston rings into the crankcase). If the blowby gases are allowed to remain in the crankcase, the combustion products react with O_2, fuel, sulfur and oil vapor to form products that are harmful to the engine (6). (The harmful effects are engine corrosion, oil dilution due to raw gasoline and engine deposits).

These blowby gases were originally vented to atmosphere. It was estimated that blowby gases constituted 15 to 40% of the total unburned HC emitted from the engine prior to 1961 (6), making desirable the reduction or elimination of these emissions. 1961 model cars sold in California and 1963 model cars in the United States were equipped with positive crankcase ventilation systems that would recirculate most of the blowby gases back to the engine where they would have another chance to burn.

In GM engines, engine manifold vacuum pulls the blowby gases from the crankcase into the intake manifold. Other systems used by different manufacturers are: (i) A large vent tube connected from the crankcase to the air filter. (ii) A system that provides two paths for blowby gases to return to the engine: one through an orifice or control valve to the manifold and the other through a tube connected to the air cleaner.

2.4.2. Controlled Combustion System: This system is used on GM engines and is similar to the 'Cleaner Air Systems' of Chrysler, 'Improved Combustion' of Ford and 'Engine Mod' of American Motors. General features shared by these systems are calibrated carburetors that provide relatively lean fuel-air mixtures for idle and cruise operation, higher idle speed and refined control of spark timing. In addition to these, GM engines are fitted with special air cleaners and ducting designed to supply heated air at a nearly constant temperature of 100^{o}F to the carburetor, thus allowing leaner mixture settings (7).

2.4.3. Evaporation Emission Control: This system is designed to reduce the fuel vapor emission that normally vents to the atmosphere from the gasoline tank and carburetor fuel bowl (7). A 'separator' mounted on the tank separates the fuel and vapor and the vapor is returned to the tank. The vapor from the carburetor fuel bowl is directed to the air filter. These are standard devices on GM, Ford, Chrysler and American Motors cars.

2.4.4. Combination Emission Control System: Engines are equipped with two types of spark advance mechanisms, centrifugal and vacuum. These mechanisms vary the spark timing for different engine operating conditions (8).

(i) Centrifugal: When the engine is idling, the spark is timed to occur just before the piston reaches the top dead center on the compression stroke. At higher speeds, it is necessary to deliver the spark to the combustion chamber somewhat earlier. This gives the mixture ample time to burn and deliver power to the piston. To provide this advance, a centrifugal advance mechanism is used.

(ii) Vacuum: Under part throttle, a partial vacuum develops in the intake manifold. This means that less air and fuel are admitted into the cylinder and the mixture is less highly compressed. The mixture burns slowly when ignited and in order to realise more power from it, the spark should be advanced. To secure this advance of spark, a vacuum advance mechanism is used.

Contrary to these requirements, it has been found that advancing the spark also results in increasing HC and CO levels in the exhaust(7). Consequently, retard in spark timing in GM engines is now utilised and is achieved by a combination emission control (C.E.C.) system which eliminates the distributor vacuum advance in the low forward gears.

The control of distributor vacuum advance is accomplished by using a solenoid valve. The vacuum line from the engine intake manifold to the distributor is connected through the solenoid valve (refer fig.4.4.). When the solenoid is in the non-energized position, the plunger in the solenoid valve covers the manifold vacuum port at the solenoid valve. Thus vacuum to the distributor vacuum-advance unit is shut off and the distributor is vented to atmosphere through a 'Clean Air Filter' in the solenoid valve. Hence when the solenoid is unenergized, the distributor has only centrifugal advance.

When the solenoid is energized, the plunger is pulled to the right (refer fig.4.4.) and this uncovers the manifold vacuum port at the solenoid valve simultaneously covering the clean air vent in the solenoid valve. The distributor now acts with both centrifugal and vacuum advance. The periods for which the solenoid is energized are given in table 2.3 below:

TABLE 2.3 (Ref. 7):

			GEAR	
TRANSMISSION	I	II	III	IV
3-speed manual	---	---	x	
4-speed manual	---	---	x	x
2-speed automatic (Torquedrive and Powerglide)	---	x		
3-speed automatic (Turbohydramatic)	---	---	x	

2.4.5. Air Injection Reactor System: The air injection systems are called 'Air Guard' at American Motors, 'Thermactor' at Ford and 'Air Injection Reactor' at GM. Air injection has not been used on Chrysler cars (10).

Air injection systems reduce exhaust emissions by injecting air into the exhaust ports of an engine to promote oxidation in the exhaust manifold (13). The oxygen in the air reacts with the exhaust gases, resulting in further combustion of unburned HC and CO that would otherwise be exhausted. Optimum reduction of emissions by this method depends on proper air injection rates, temperature, composition of the reacting mixture and residence time of the exhaust gas - air mixture (13).

The A.I.R. system as used in GM car engines consists of: an air injection pump (with necessary brackets and drive attachments), air injection tubes (one for each cylinder), an air pump relief valve, check valves and air manifold assemblies and hoses necessary to connect the various components (7).

The air injection pump with an integral filter compresses the air and injects it through the air manifolds, hoses and injection tubes into the exhaust manifold in the area of exhaust valves. The air pump relief valve located in the discharge line of the air pump allows pump outlet air to bypass the air injection system at high engine speeds and loads (8). The check valves prevent exhaust gases from entering and damaging the air injection pump.

Similar air injection systems with check valves are used by other automobile manufacturers. Spark retard during idle or idle and deceleration periods are generally used with the air injection systems.

It has been found that, due to the introduction of air into the high temperature exhaust gases at the exhaust port, the unburned HC and CO are oxidized. Simultaneously, experiments have also shown that NO_x concentration increases during periods of acceleration, regardless of inlet mixture ratio, and during periods of cruise with carburetors set for rich mixtures (9).

2.4.6. Exhaust Gas Recirculation: These systems reduce the nitrogen oxides in the exhaust. Nitrogen oxides are formed during the high temperature portion of the burning of the fuel and air in the cylinders of the engine. Since the amount of NO produced in the engine cylinders is an exponential function of temperature, even a moderate decrease in the combustion temperature should result in a significant decrease in NO formed.

One of the methods which can be used is to dilute the fuel-air mixture with some inert material (10). Accordingly, recirculation of a part of the exhaust gases to the engine intake system dilutes the fuel-air mixture and effectively reduces the formation of nitric oxides.

The system that is normally used for recirculating the exhaust consists of tapping the exhaust gases from the exhaust pipe between the exhaust manifold and the muffler and directing these gases into the carburetor between the venturi section and the throttle plate. The amount of exhaust that enters the carburetor is metered by an orifice located in the recirculation line. A simple vacuum-operated on-off valve cuts off the recirculation at idle to give smooth engine operation (10). Also at full throttle, the flow of exhaust gas is shut off and thus maximum power is not reduced.

Exhaust recycle has been credited with reducing oxides of nitrogen by 75 to 90%. However, there have been reports of adverse side effects in some of the vehicles equipped with exhaust gas recycle. One of these is the build up of deposits in the engine intake system over a long period of time. Another effect is on the so-called 'vehicle driveability'. Also if there is no other engine modification, the concentrations of unburned HC and CO increase.

2.4.7. Exhaust Manifold Reactors: The reactor provides a high temperature 'holding zone' in which CO and unburned HC in the exhaust are thermally oxidized to form carbon dioxide and water. Reactors are mounted on the engine in place of conventional exhaust manifolds.

The reactor consists of an outer shell in which is mounted a tubular core and a shield to insulate the hot core from the cooler outer shell. Exhaust gases, mixed with air supplied by an air injection system, first enter the tubular core which is designed to promote mixing and to initiate oxidation. The reacting gases then pass through the spaces between the core and the shield and finally between the shield and the outer shell. Oxidation is to be completed before the gases exit into the exhaust system.

However, theoretical calculations based only on CO oxidation rates (using reaction kinetics) indicate that CO oxidizes rapidly above 1100°K (11). In practice, in reactors operating above 1100°K, completion of CO oxidation is limited primarily by the mixing of exhaust gases with the air injected.

2.4.8. Catalytic Converter System: Catalytic converters are being considered for the oxidation of unburned HC and CO as well as for the reduction of the oxides of nitrogen. The catalytic converter contains a compartment, the catalyst bed, which is filled with a catalytic material. The catalytic material itself does not enter into the reaction, but only promotes the reaction process (12).

One of the catalysts being considered is vanadium pentoxide. This material has been proved to be effective for the oxidation of unburned HC but does not oxidize CO. Platinum catalysts have been developed for oxidizing both HC and CO.

One primary disadvantage associated with the use of catalytic converters is that the catalyst requires a certain initial warm up time before it can convert effectively. During the initial idling periods of the engine (where HC and CO concentrations in the exhaust are high), the converter is not operative. Secondly, no catalyst meets the requirement of maintaining oxidation performance for extended mileage. Any lead in the fuel affects the catalyst efficiency greatly.

As the reduction catalysts for the oxides of nitrogen, nickel-copper alloys (Monel) have been found to be extremely active. At temperatures above 1300°F and under net reducing conditions, 90% or more of the NO in automotive exhaust is reduced (14). In conjunction with engines using unleaded fuel, Monel catalysts have shown good chemical activity for at least 31000 miles (12). But again, for the reduction of NO, the catalyst has to be warmed up and also the presence of lead substantially increases the deterioration of the catalyst.

Recently, a dual bed catalyst system consisting of a bed for NO_x reduction followed by a bed of oxidation catalyst was experimented upon (14). To provide net reducing conditions in the NO_x reduction catalyst bed, the engine was operated on the fuel rich side. Air was subsequently injected between the beds to change the exhaust composition from net reducing to net oxidizing. Monel was used as the reduction catalyst and platinum as the oxidation catalyst.

The problems with the dual bed catalytic converter system are:

(i) Under normal operating conditions, roughly 10% of NO in the untreated exhaust reacts with H_2 to form NH_3 in the Monel bed. NH_3 thus formed is oxidized to NO in the oxidation bed. Exhaust gas recycle is suggested as the remedy for the reduction of NO in the untreated exhaust.

(ii) Placing the NO_x reduction catalyst ahead of the oxidation catalyst slows the warm up time of the later. Also under road conditions, it would take engine operation equivalent to a 40 mph cruise to maintain Monel temperatures at 1400°F (which is required for the effective reduction of NO_x).

(iii) The presence of lead in gasoline has been proved to cause back pressure build up in the exhaust (due to lead deposits on the catalyst bed). Also lead increases the deterioration of the catalyst.

2.5. FEDERAL AIR POLLUTION STANDARDS: Restriction on the amount of pollutants emitted have been imposed from time to time by the federal government. Canadian air pollution standards are the same as the U.S. standards and are given in table 2.1 below:

TABLE 2.1. AIR POLLUTION STANDARDS IN U.S. (Ref. 5)

Year	CO (gm/mile)	HC (gm/mile)	NO_x (gm/mile)	PARTICULATES (gm/mile)
Pre-1966*	80	11	4.0	-
1968^1	36	3.5	-	-
1970^1	23	2.2	-	-
1971^1	23	2.2	-	-
1972^2	39	3.4	-	-
1973^2	39	3.4	4.0	-
1974^2	39	3.4	3.0	-
1975^3	3.4	0.41	3.0	0.1^P
1976^3	3.4	0.41	0.4	0.03^P

* - Typical average emissions from engines before 1966.
1 - According to FTP cycle
2 - According to CVS-1 cycle
3 - According to CVS-2 cycle
P - Proposed values

2.6. FEDERAL TESTING PROCEDURE: The federal air pollution standards have also established a particular sequence of engine operating conditions. Till 1971, a 7-mode cycle based primarily on the Los Angeles traffic pattern was used. The test sequence for this is given in table 2.2 below:

TABLE 2.2. SEVEN-MODE CYCLE FOR TESTING (Ref. 6)

	FRACTION OF TIME	SPEED
Idle	0.042	---
Acceleration	0.244	0 to 25 mph
Cruise	0.118	30 mph
Deceleration	0.062	30 to 15 mph
Cruise	0.050	15 mph
Acceleration	0.455	15 to 50 mph
Deceleration	0.029	50 to 20 mph

Exhaust gas for analysis was sampled by a continuous sampling method or bag sampling method. In the continuous sampling method, the exhaust gas is sampled and analysed continuously throughout the test. In the bag sampling method, the exhaust gas is collected in a bag and analysed after the gases (collected during the different modes) are mixed.

Presently, the emission test consists of starting the vehicle and driving it for 23 minutes through a non-repetitive sequence of acceleration and deceleration at speeds varying from 0 to 65 mph. This trip simulates a typical 7.5 mile trip in city traffic. The sequence is listed in reference 15.

During the entire 23 minute test, the exhaust gases are diluted with filtered ambient air and accurately metered. A small sample of this mixture is continuously taken and stored in a special bag for analysis. The remainder of the mixture is exhausted to the outside atmosphere.

2.7. DEFECTS WITH THE FEDERAL TESTING PROCEDURE: The pollutant emissions and their effects are severe in Los Angeles, California. Testing procedure devised have been based on the traffic survey made in Los Angeles. Accordingly, the testing procedure requires the engine to be run at an ambient temperature of 68°F to 86°F(15).

Traffic conditions in other cities could be entirely different. Moreover, the weather conditions, especially in Canada, are colder for a large portion of the year. During cold temperature operation of engines, more hydrocarbons are emitted. Also future emission control devices which require warming up, like the catalytic converter and thermal reactor, may not rapidly reach operating temperatures (and hence may not convert effectively) at cold temperatures.

Hence a testing procedure which takes into account the traffic as well as the weather conditions ofeach city would be ideal. Or, at least a testing procedure which takes into account the running of engines in cold temperatures is in order. As a first step to achieve this goal, an engine and dynamometer were set up to test automobile engine under controlled cold temperature conditions. The installation is described in the following chapter.

3. EXPERIMENTAL SET-UP

The experimental set-up consists of an engine connected to a braking device (an engine dynamometer) by means of a driveshaft. The engine used was a 350 cu.in., V-8, Chevrolet (1971) engine. The dynamometer was of the eddy-current type with a rating of 450 HP for a speed range of 1800 rpm to 6000 rpm. Both the engine and the dynamometer were water-cooled.

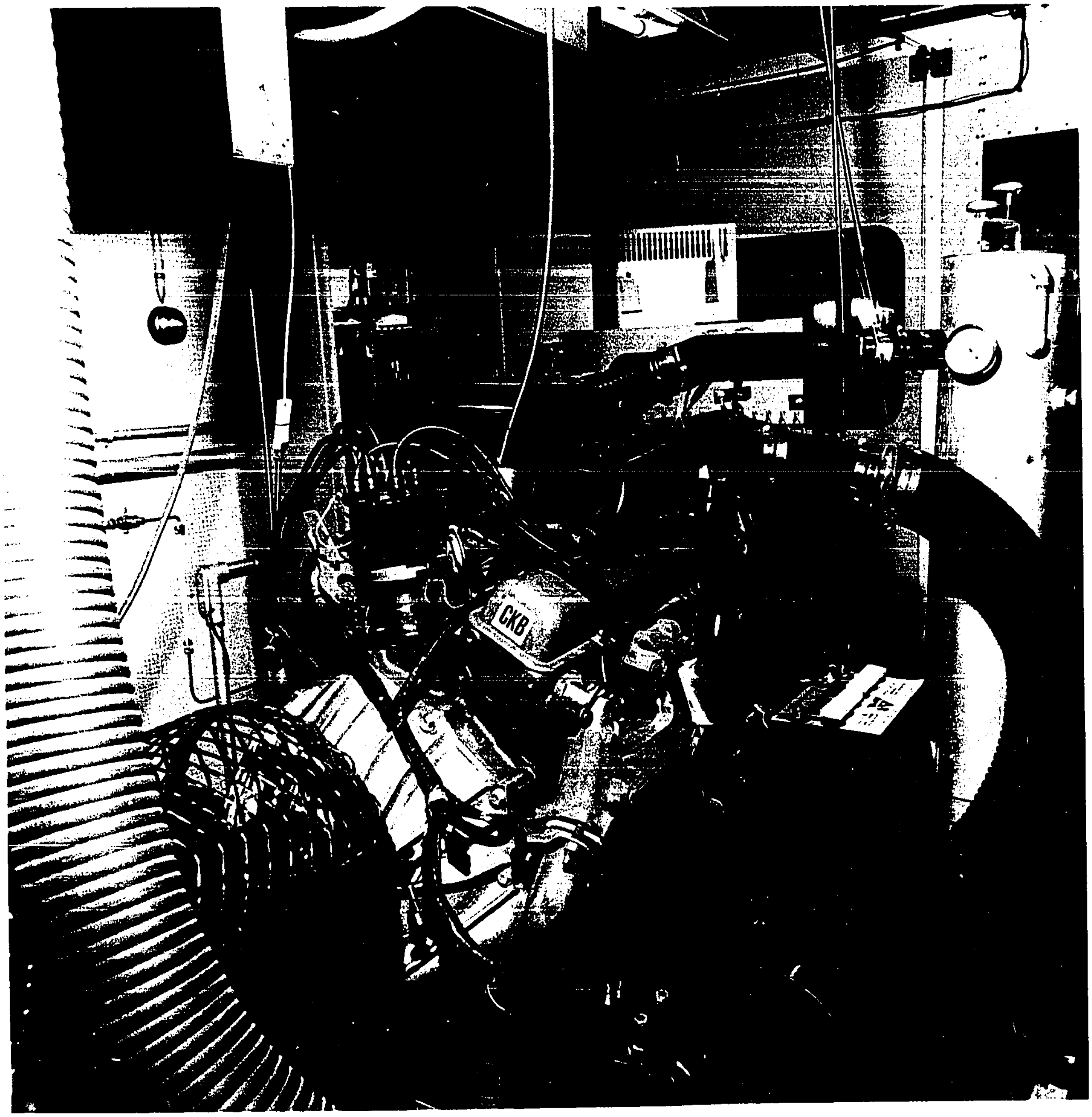
Before experiments could be performed, the following requirements were necessary:

a. Mount the engine and the dynamometer
b. Provide engine combustion air at relatively constant temperature
c. Supply water for engine and dynamometer cooling
d. Provide instrumentation to control the engine and dynamometer.

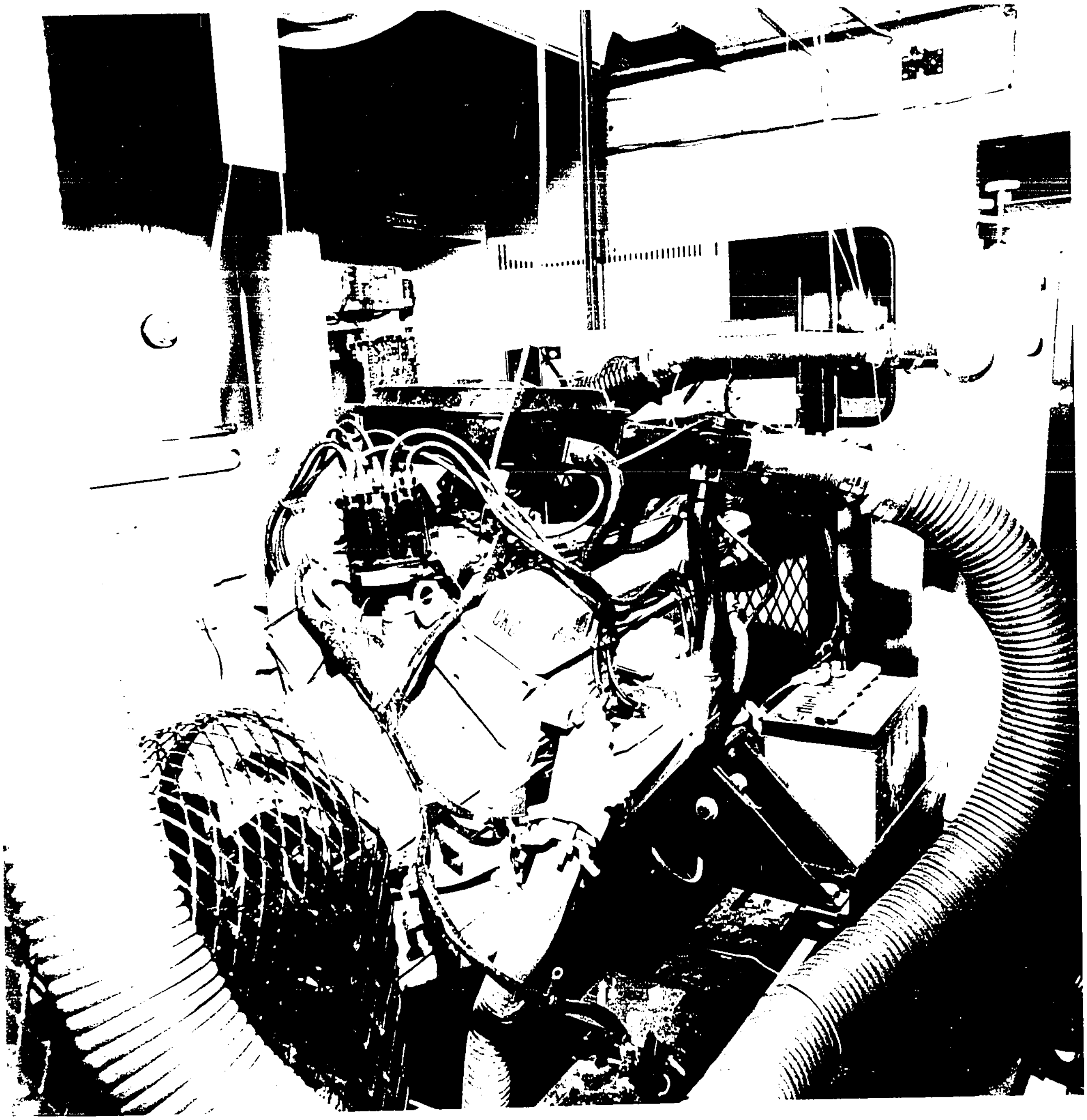
3.1. MOUNTING THE ENGINE AND DYNAMOMETER: An engine test facility was utilised. It consists of a serviced engine cell and an adjoining instrumentation and control room. An exhaust line, a heat exchanger and fuel tanks were provided in the facility. The dynamometer was mounted on a test-bed plate provided in the cell. An engine stand which could be adjusted for mounting automobile engines of any size, was designed. The stand assembly is shown in fig.3.1. The engine was mounted on the stand such that the carburetor axis was vertical.

Two supports (on the sides of the engine) were provided by this test stand. The supports were standard rubber mounts which absorb the vibration. For the engine mounting to be stable,

PLATE 1



ENGINE TEST CELL SHOWING 350 cu.in. V-8 ENGINE INSTALLATION



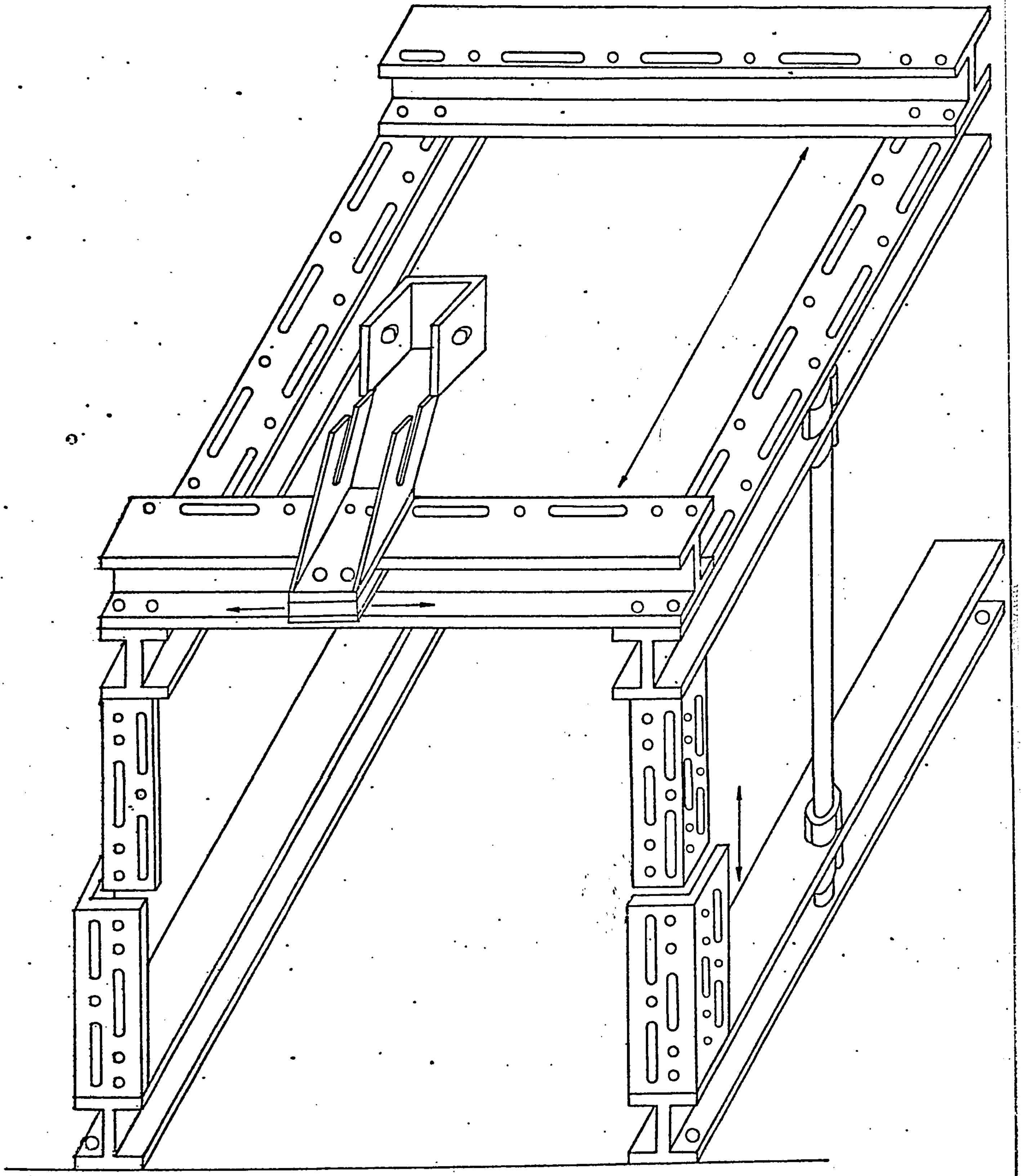


Fig. 3·1 ENGINE STAND ASSEMBLY

a third support was required at the engine flywheel side (where the transmission is usually attached). The engine was not equipped with a transmission; so, a flywheel cover called the clutch housing assembly was fixed on the engine. The housing was mounted on the test stand using two angle bars.

A driveshaft, with two unversal joints, was used to connect the engine to the dynamometer. The height of the engine was adjusted so that the angle between the driveshaft and the engine was the same as that between the driveshaft and the dynamometer to minimise loss in transmission. A flange was mounted on the dynamometer shaft and the driveshaft was connected to this flange. To connect the other end of the driveshaft to the engine flywheel, an adapter was fabricated. It was light in weight and statically balanced. A driveshaft guard was fabricated of thick wire mesh.

3.2. VENTILATION: Combustion air to the engine was provided by the ventilation system in the test facility. This system took atmospheric air, heated it (if necessary) using a hot water heat exchanger, then forced it into the engine cell through louvers in the ceiling. Temperature of the air in the cell was controlled and maintained constant by the amount of air supplied. Excess air was exhausted through the floor to the atmosphere by means of an exhaust fan.

3.3. COOLING SYSTEMS: A cooling water circuit was designed for cooling the dynamometer and engine. The water pressure and temperature requirements for the dynamometer were specific.

The pressure range is 35 psi to 125 psi and the temperature of water entering the dynamometer should not exceed 90°F. Also the discharge from the unit should not be restricted. The maximum flow required for the dynamometer is 45 GPM while absorbing 450 HP.

The water discharged from the engine is mixed with cold water in a cooling column. It is thermostatically controlled to maintain any desired water temperature in the engine. Cold water for mixing has to be supplied to the column from the cooling water circuit.

The maximum flow requirement to the column was determined using the formula suggested by the manufacturers:

$$GPM^{*} = \frac{HP \times Btu}{8.33 \times td} \qquad \text{where}$$

HP - Actual maximum horsepower to be absorbed (For the engine used, it is 245 HP)

Btu - Engine heat rejection rate in Btu/HP/min. (Since no specific value on the heat rejection rate was available, 55 Btu/HP/min. as suggested by the manufaturer was taken as the value).

td - Temperature differential in °F between inlet and outlet (The maximum outlet and minimum inlet water temperatures were assumed to be 210°F and 75°F respectively).

* For safety, this flow value was increased by 15%.

The maximum flow requirement for a 450 HP engine was calculated to be 25 GPM. Hence the maximum flow required from the cooling circuit is 70 GPM. For the present engine-dynamometer set-up however, the cooling water required is much less. To satisfy the present and future requirements, 60 GPM was assumed as a reasonable figure.

The ½ in. water supply line provided in the cell was insufficient for open-loop (once-through) cooling. Hence an appropriate closed-loop (recirculating) circuit was designed. The arrangement is shown in fig.3.2.

The circuit consists of a tank, pump, heat exchanger and valves. The reservoir tank had a capacity of 40 gallons. If the water level in the reservoir decreased, make-up water controlled by a float in the tank, was introduced from the supply line. Overflow and bottom drains were fitted on the tank. A vented lid was provided on the tank to keep the dirt out.

A single stage centrifugal pump with a capacity of 63 GPM at a head of 100 ft. of water was used to transfer the water to the heat exchanger. A check valve was placed in the circuit ahead of the pump to prevent draining of the system back into the tank.

The heat exchanger was of shell and tube design. Water was pumped into the tubes and cooled by glycol circulating in the shell. Glycol was cooled by atmospheric air in the ventilation system. The cooled water from the heat exchanger was led through control valves both to the dynamometer and

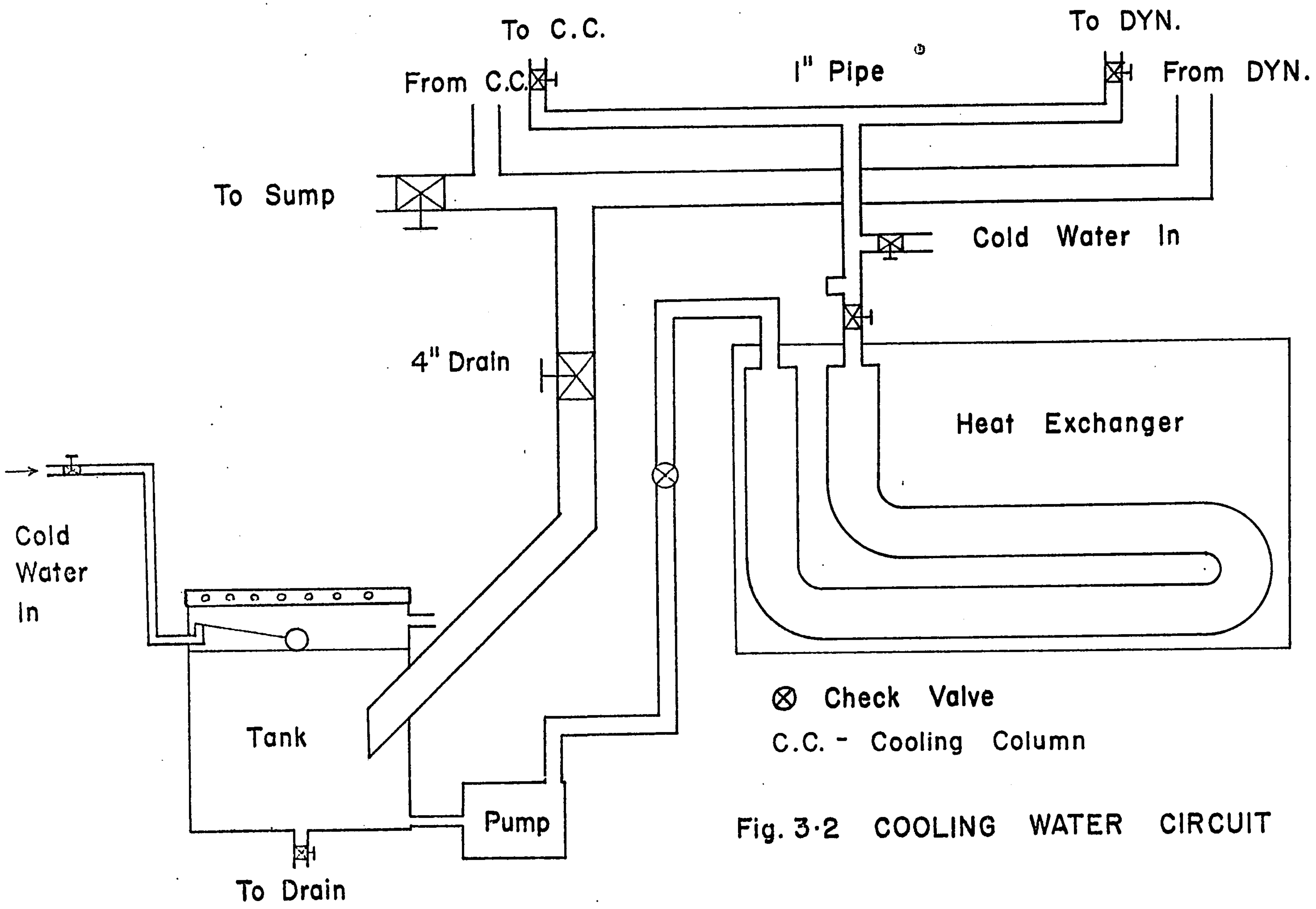


Fig. 3·2 COOLING WATER CIRCUIT

engine cooling column. A 4 in. drain pipe carried the discharged water from the dynamometer and cooling column back to the tank.

This closed-loop cooling water system has the following limitations: The temperature of glycol is above atmospheric temperature. Hence, during the summer months, the glycol temperature is often around 80°F or higher. Under such circumstances coolant water for the dynamometer would be at a temperature higher than the 90°F specified for operation. However, this cooling water circuit would work satisfactorily during the winter months, when the atmospheric temperature is sufficiently low.

This closed-loop system has the major advantage that if the engine cell is cooled to temperatures below freezing, anti-freeze could be easily introduced and circulated.

To overcome the limitation of the closed-loop system for warm weather operation, an open-loop system was also included. A valve and tee were installed in the line just after the heat exchanger. A larger (1 in.) water supply was introduced to separate the two cooling systems. A valve and a tee in the discharge pipe directed water to a drain in the cell.

3.4. INSTRUMENTATION: The dynamometer installation consisted of a brake unit, controller and control unit. The brake unit consisted of a rotor (dynamometer shaft), a magnet as a stator and necessary cooling water circuit for the brake unit. Control of current through the magnet was provided by 'SPEED CONTROL' and 'CURRENT CONTROL' potentiometers, mounted in the control room. The speed control potentiometer operates such that the speed of the rotor (same as engine speed) is kept constant, while the excitation (and the braking torque) varies to hold the speed relatively constant. The current control potentiometer holds the excitation current (current flowing through the rotor) and thus the braking torque relatively constant.

A controller located in the engine cell housed the necessary electronic circuitary to control the amount of excitation in the dynamometer brake unit.

The braking torque on the rotor was measured by a load cell positioned on the brake unit. This load cell was connected electrically to a strain gage instrument mounted in the control room. The speed of the rotor (same as the engine speed) was sensed by means of an alternating-current generator. A tachometer, which indicated the speed, was connected to the generator.

The ignition switch of the engine was connected through terminals provided in the controller for safety purposes, so that the engine could not be started without excitation in the dynamometer. In addition, oil pressure and water temperature gages as well as tachometer were installed on the engine so that the readings could be observed during engine start-up or during operation.

Fig. 3.3. shows the connections made.

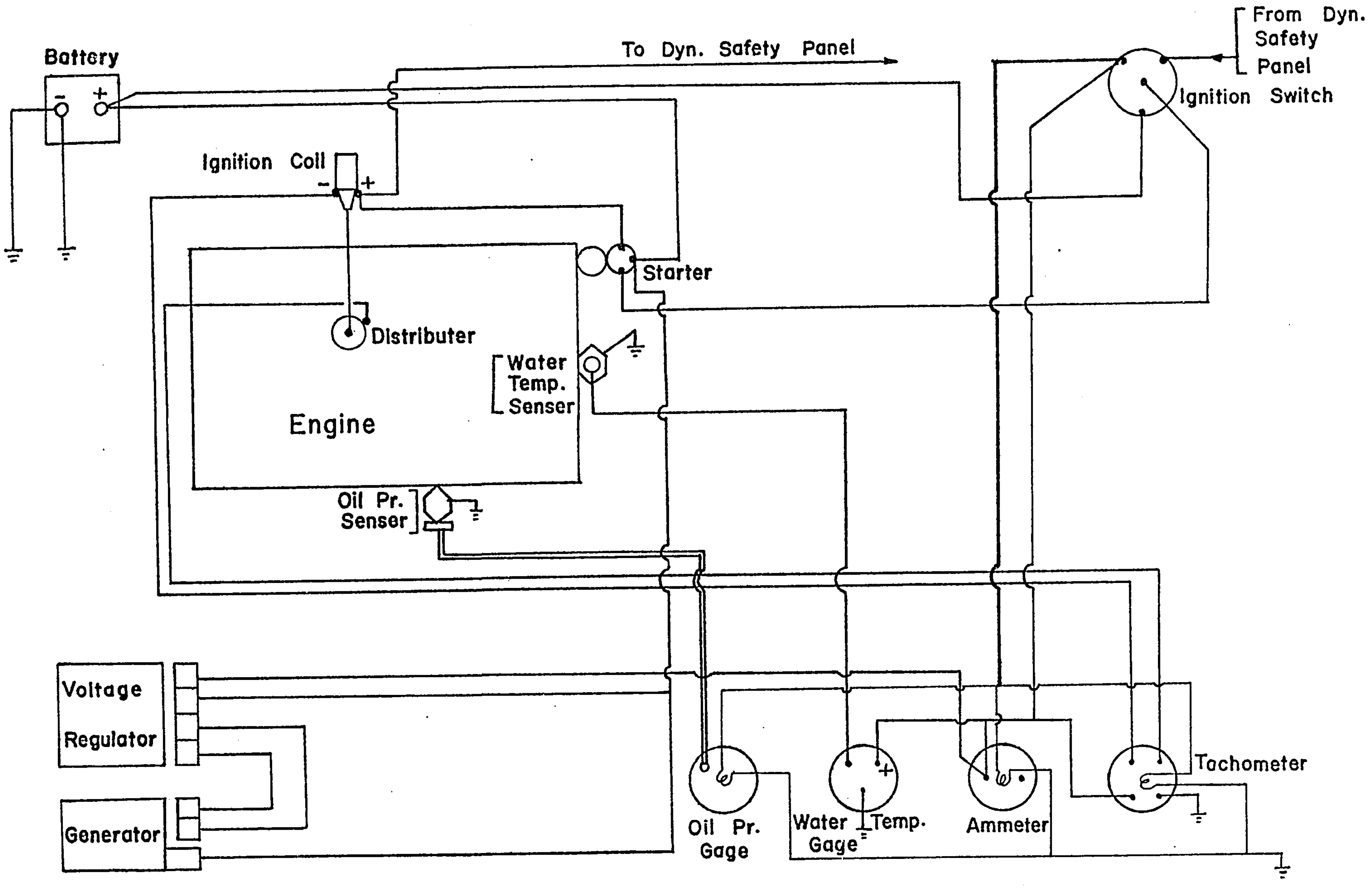
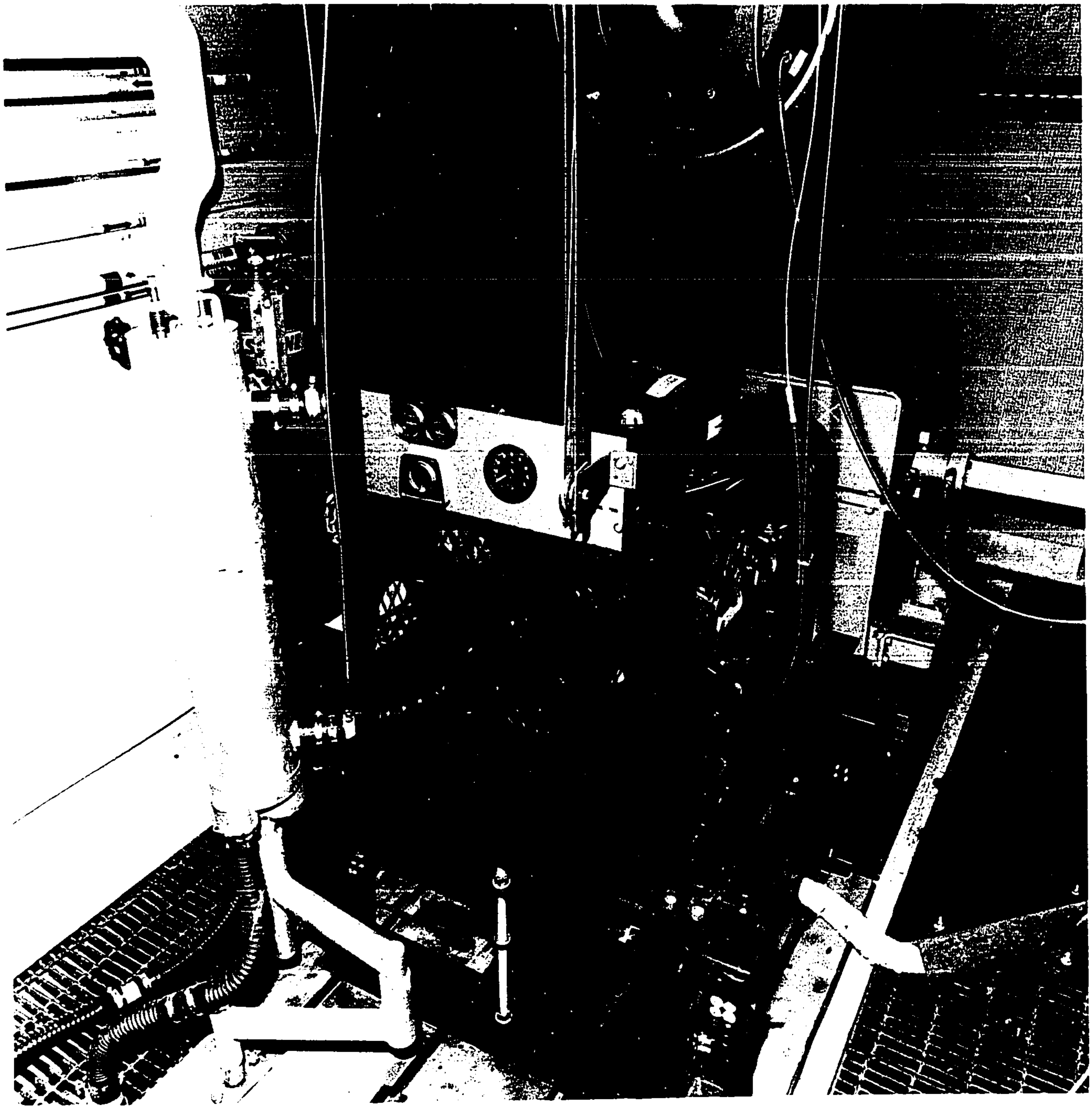
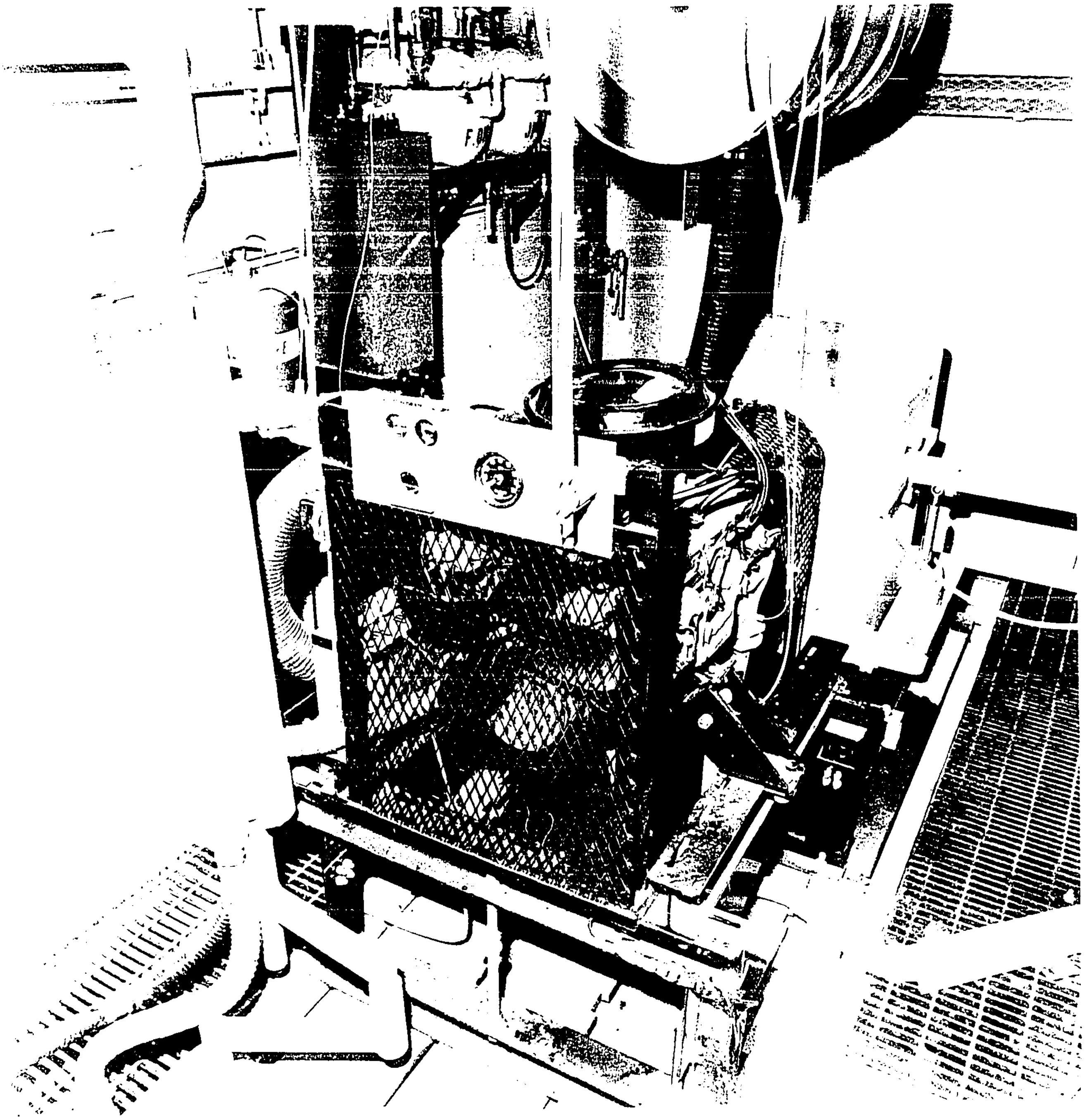


Fig. 3·3 ENGINE ELECTRICAL CONNECTIONS

PLATE 2



ENGINE TEST CELL SHOWING ENGINE, DYNAMOMETER, COOLING COLUMN AND FUEL AND AIR FLOW MEASURING EQUIPMENT.



Operating temperatures such as air and fuel flow and some specific temperatures were to be measured. Consequently instrumentation for measuring these was installed.

An air flow meter (Model M-5000), manufactured by Go-Power Systems, was used. Air flow was measured by drawing the engine air through a precision long-radius flow nozzle into a pulse-damping drum, and then out through a flexible hose to the engine air filter. By measuring the pressure difference across the flow nozzle by means of a water manometer, the air flow rate could be determined. Fuel flow was measured by drawing the engine fuel out of a fuel can through a rotameter, and then into the engine fuel pump.

During tests, six temperatures were measured using thermocouples. They were:

(1) Inlet air temperature before entering the air filter.

(2) Intake manifold mixture temperature before entering the engine cylinder.

(3) Oil temperature at the oil pan.

(4) Engine cooling water inlet temperature at the line connecting the cooling column to the engine.

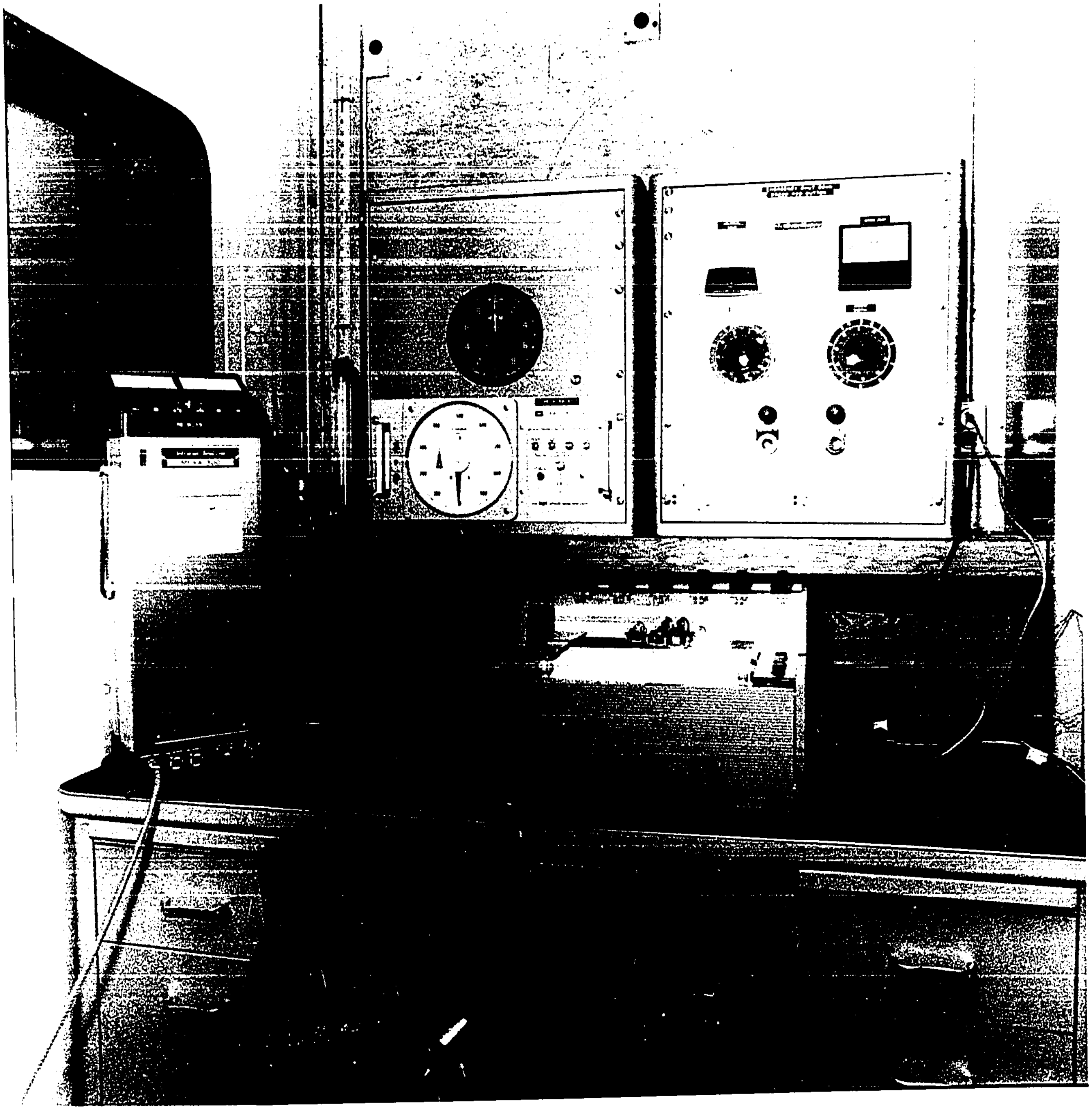
(5) Engine cooling column outlet temperature at the line connecting the engine to the cooling column.

(6) Exhaust gas temperature at a point just after the exhausts from four cylinders in one bank mix.

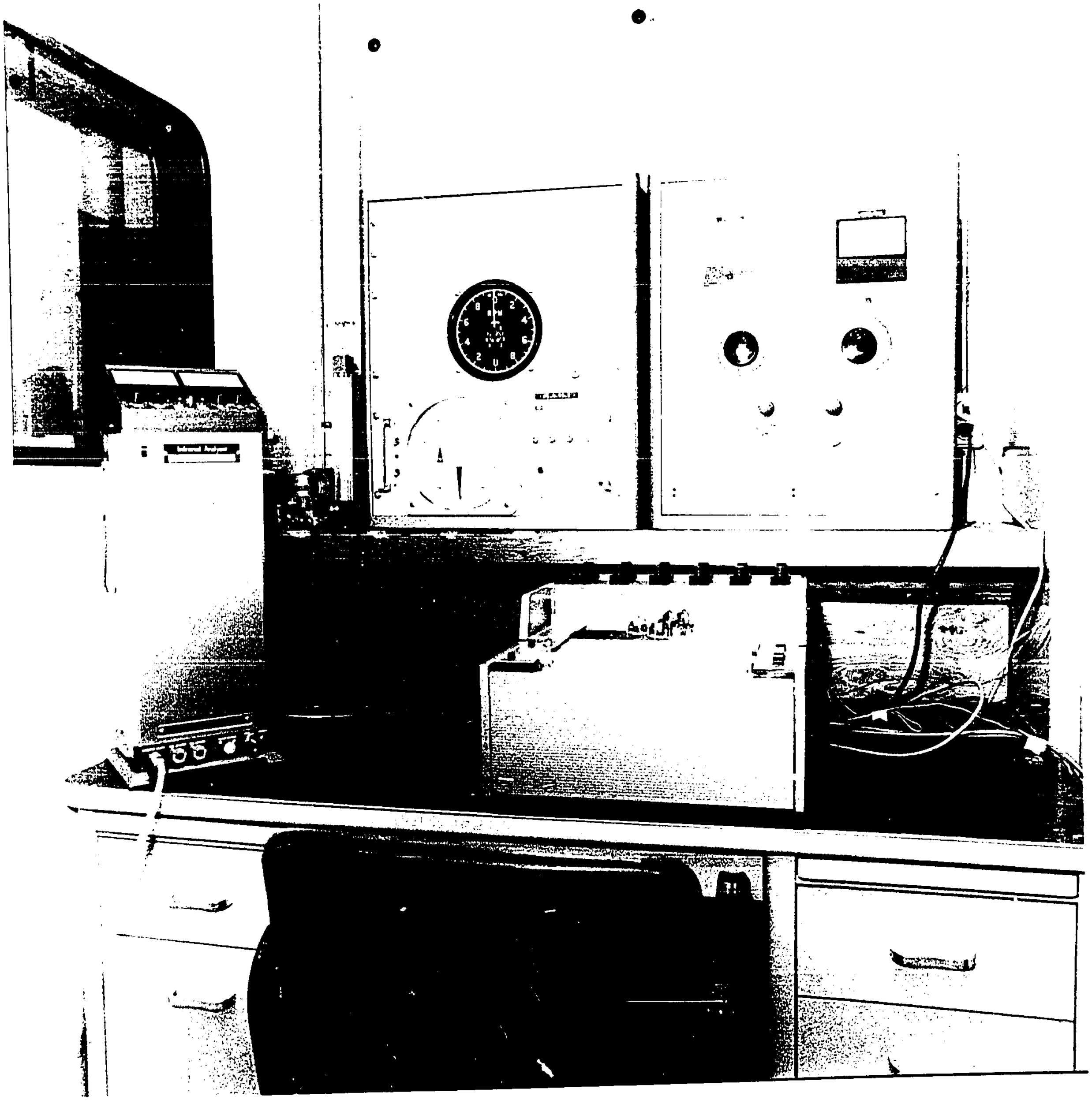
The first five thermocouples were of the copper-constantan type and the last was of the chromel-alumel type.

The output of these thermocouples were read in millivolts. Four temperatures, namely, cooling water inlet, cooling

PLATE 3



ENGINE CONTROL AND MONITORING PANEL


Infrared Analyzer
RPM

[illegible]

water outlet, manifold air, and exhaust gas temperatures were measured continuously with a recorder. The other temperatures, namely, inlet air and oil temperatures were measured periodically using a potentiometer.

3.5. EXHAUST GAS SAMPLING AND ANALYSIS INSTRUMENT: The sampling system for continuous measurement of the exhaust components (hydrocarbons, carbon monoxide etc.) consisted of a sampling probe, sampling line, cooler, dryer, particulate filter, pump, by-pass flow regulator and flow meter. Fig. 3.4. shows the complete sampling system.

The sampling probe was fixed in the engine exhaust in such a way as to minimise induction of ambient air. The probe was a ¼ in. O.D. stainless steel tube placed parallel to the flow, facing upstream.

A tee and valves were located near this probe to allow purging of the system or the introduction of calibration gas. The purging could be done with either prepurified dry nitrogen or clean dry air.

From this point, the exhaust sample was carried through a ¼ in. I.D. teflon tube to the cooler. Here water contained in the exhaust gas sample was condensed and removed. This was necessary since many analysers have a strong response to water vapor which can lead to erroneous results. The exhaust gas in the cooler was carried through a 10 ft. length of ¼ in. O.D. stainless steel tube contained in a chilled water bath.

Further downstream a gas drying unit consisting of

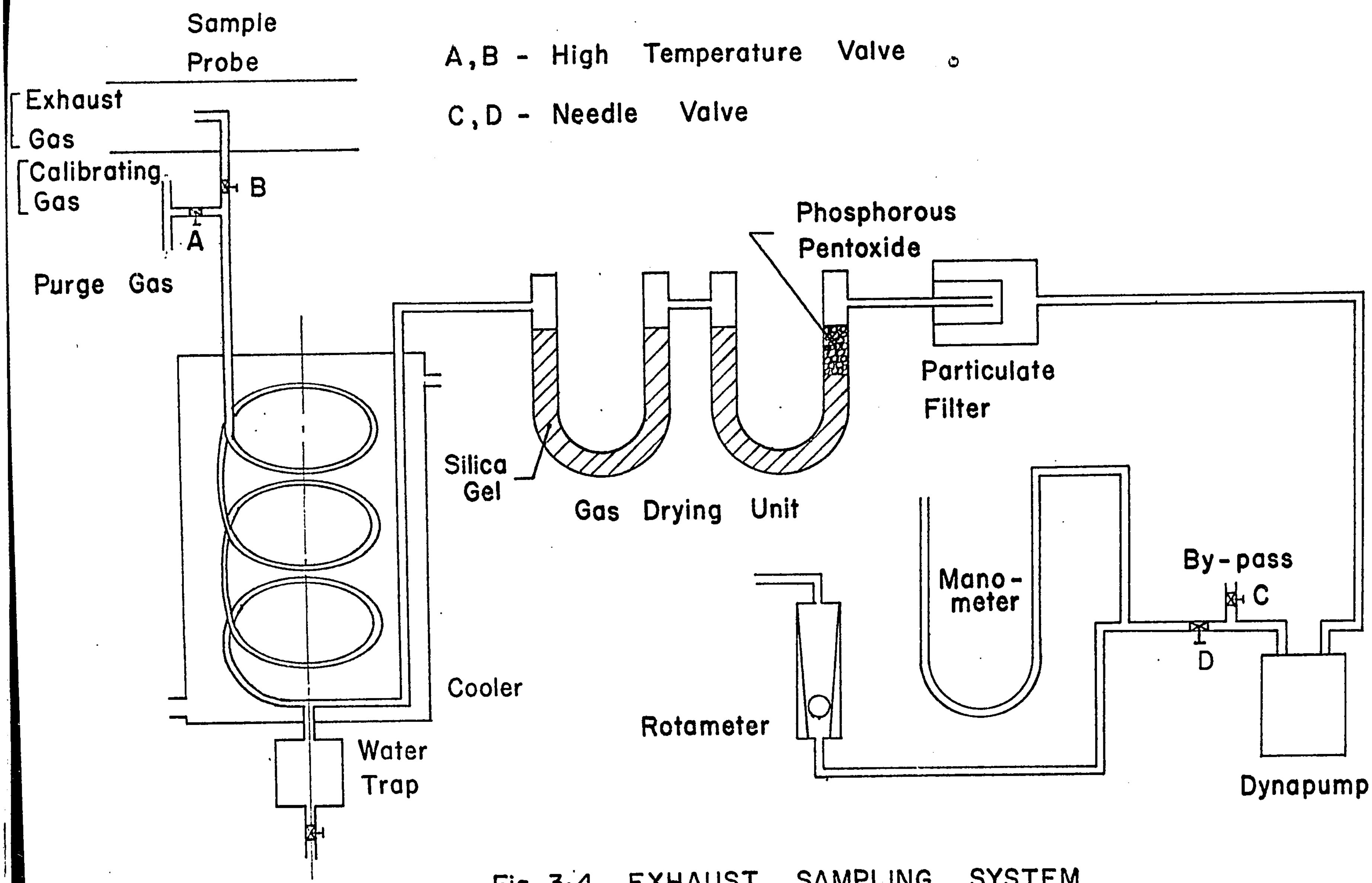


Fig. 3·4 EXHAUST SAMPLING SYSTEM

two 'U' tubes filled with silica gel further dried the exhaust gas. A small amount of phosphorous pentoxide was added to the final 'U' tube to dry the exhaust gas thoroughly.

The cool, dry exhaust gas was then led through a particulate filter where carbon as well as other particles in the exhaust were removed. An easily replaceable 7 micron filter was used as the filtering element.

A low-head positive displacement pump (Dyna pump Model 3) was used to transfer the exhaust gas to the analyser. It was a diaphrgm type pump with a neoprene (non-reactive)diaphragm.

A by-pass line, controlled by a needle valve, was provided to dump excess exhaust gas pumped to a waste system. Sample flow through the analyser was regulated by another needle valve. A rotameter, with float of inert material, measured the constant flow rate. Further, sample pressure was regulated to be constant and monitored with a water manometer.

The analyser used for measuring hydrocarbons and carbon monoxide was a non-dispersive infra-red type (model MEXA - 300) manufactured by Olson - Horiba Inc. Details are given in Appendix D. This instrument measures HC as equivalent n-hexane in parts per million (ppm) and CO in percent (%).

The set-up was ready for operation under cold temperature conditions. However, the ventilation without modifications could not deliver air below 70°F. Hence, some experiments of preliminary nature were carried out to find the effect of advancing the spark timing on exhaust emissions. This is described in detail in the following chapter.

4. EXPERIMENTAL PROCEDURE

Initial experiments were designed to verify reliability of the complete system. Initially, the cooling water and sampling systems were checked for operation. Then all measuring instruments were calibrated. Finally the operation of the engine and dynamometer were checked along with the combination emission control system installed on the engine.

4.1. COOLING WATER CIRCUIT OPERATION: The operation of the closed-loop cooling water system was checked first. This included checking for the capacity of the tank, operation of the pump and water level control in the tank. The open-loop system was then operated. The discharge sump could not handle the amount of water discharged, but this was rectified. Both the systems were finally made to operate properly.

4.2. SAMPLING SYSTEM OPERATION: The sampling system, consisting of probe, condenser, filter and flow regulating valves, was checked for leaks. Then the system was checked for its ability to deliver exhaust gas to the analysis instrument at constant pressure and constant flow rate over a long period of time.

4.3. STRAIN GAGE INDICATOR CALIBRATION: The strain gage indicator was calibrated according to the procedure described below:

A number of 50 lbs. weights provided with the dynamometer were placed on the calibrating arms for calibration. A calibration

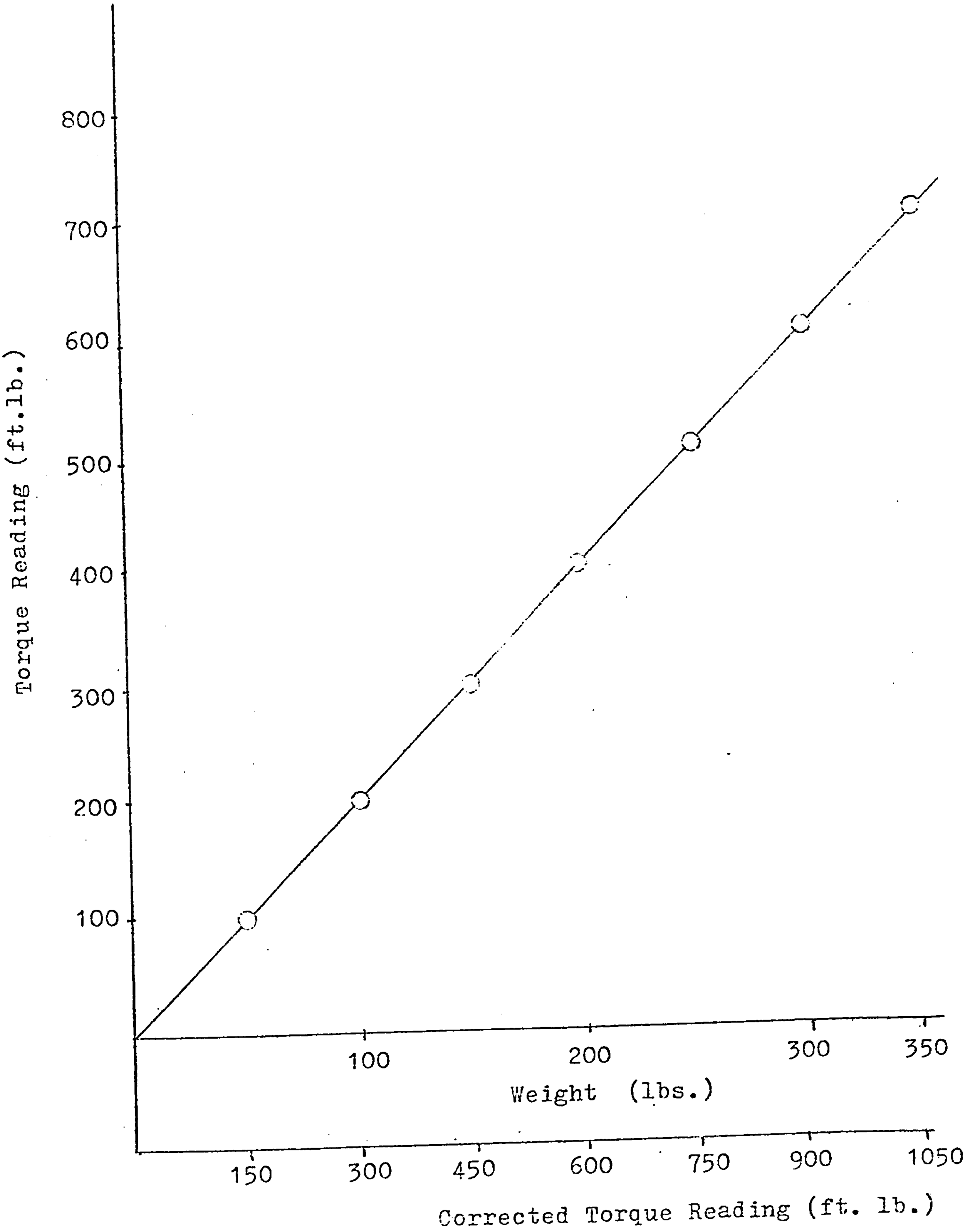


Fig. 4.1. CALIBRATION OF TORQUE METER

graph of torque reading versus corrected torque reading (and the weights) is shown in fig. 4.1.

4.4. FUEL FLOW METER CALIBRATION: Following manufacturers' instructions, the fuel flow rotameter was calibrated as follows: The full fuel tank was pressurised slightly and flow from it regulated by means of a needle valve. Several flow rates were then measured by allowing the fuel to collect in a container set on a balance (drop-of-beam method was used). A line paasing through the experimental points gives the calibration graph shown in fig.4.2.

4.5. MEXA - 300 INFRARED ANALYSER: (Fig. 4.3.) This analysis instrument was calibrated before every test. A half hour warm-up period was allowed before the calibration. The sampling probe was removed and placed in clean air. The 'CO zero' and 'HC zero' controls were adjusted to indicate zero on the scales. The 'pump' was switched off and the nozzle of the calibration gas can (containing a mixture of 9.15% CO, 3660 ppm C_3H_8 and the rest N_2 or 1.77% CO, 735 ppm C_3H_8 and the rest N_2) was pressed against the 'Gas Checker' inlet. The 'CO span' and 'HC span' knobs were adjusted, if necessary, to bring the meter reading to a point corresponding to the concentration of the span gas. The pump was switched on and the meters were checked again for zero reading. 'CO check' and 'HC check' were carried out, to check whether the meter readings were within the allowable range (i.e.) 1.5±0.1 % CO and 300±10 ppm HC. If necessary, the CO (or HC) check adjustment screw (at the back of the unit) was rotated to bring the appropriate meter reading within the specified range.

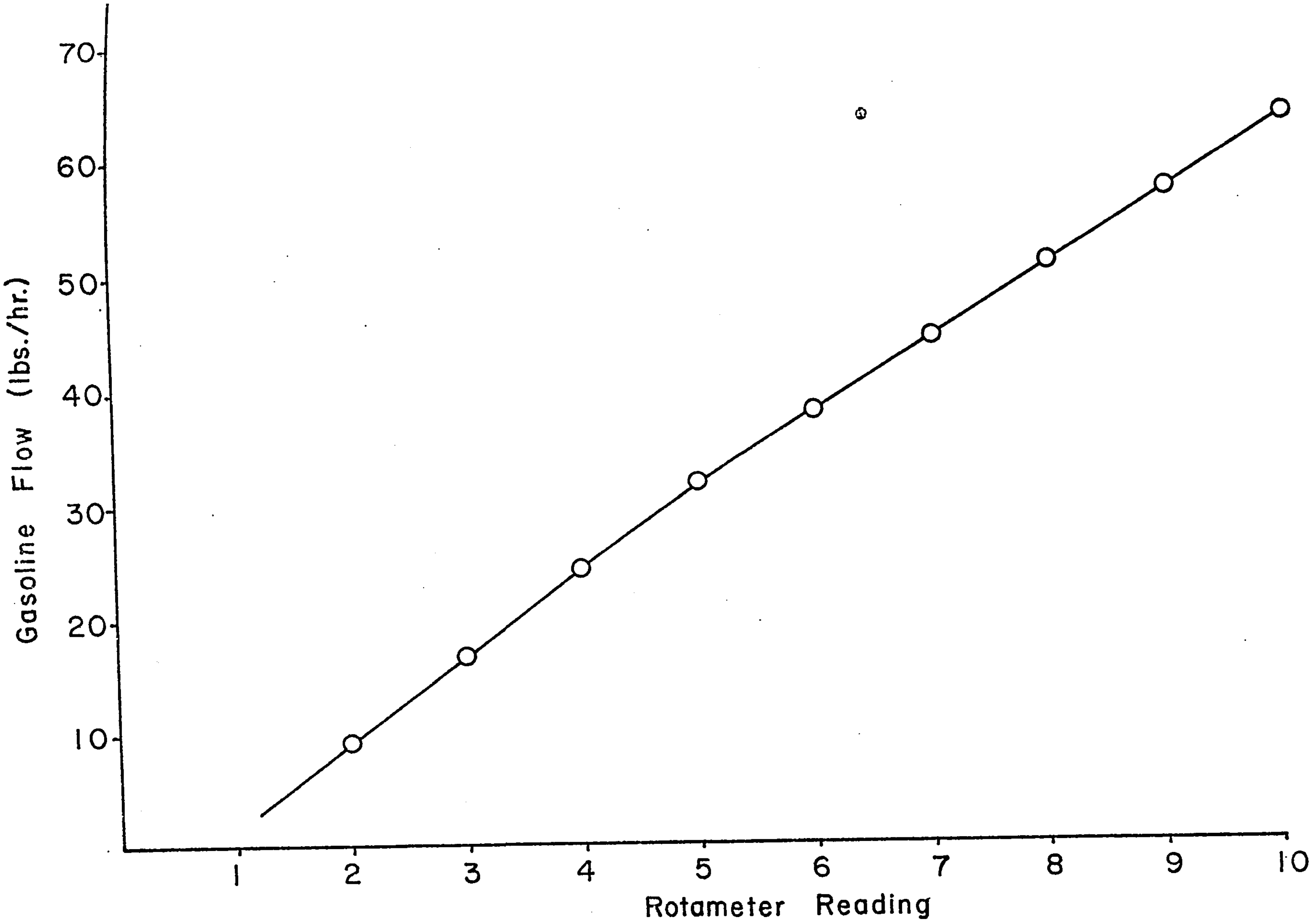


Fig. 4·2 CALIBRATION OF FUEL FLOW METER

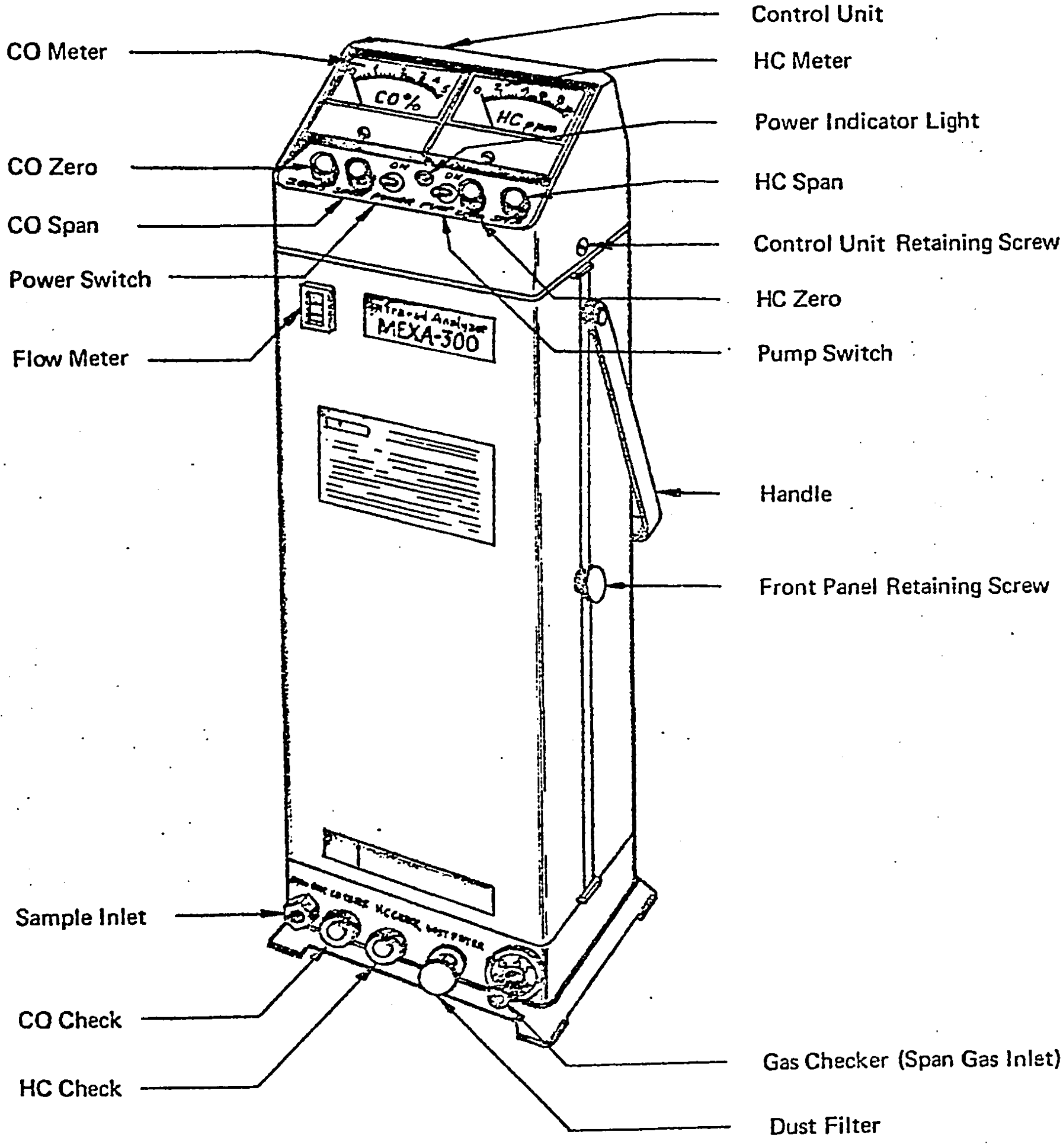


FIG. 4.3. MEXA - 300 INFRARED ANALYSER

When this adjustment was necessary, the calibration procedure was repeated two or three times till no adjustment in zero, span or gas check was needed.

4.6. ENGINE AND DYNAMOMETER OPERATION: Initially the operation of the engine and dynamometer was checked over a range of speeds and loads. A combination emission control (C.E.C.) system (refer section 2.4.4.) was installed on the engine. The solenoid valve of the C.E.C. system was connected for manual operation as shown in fig. 4.4, since the engine was tested without transmission.

The C.E.C. system makes use of a solenoid valve to cut off manifold vacuum advance to the distributor at low forward gear operation of the automobile. The operation of the C.E.C. system as connected, was checked while operating the engine. The engine operating procedure is described in Appendix E.

4.7. PRELIMINARY EXPERIMENTS:

4.7.1. Speed versus Spark Timing: The first experiment conducted on the engine consisted of determining spark timing at different engine speeds with the solenoid of the C.E.C. system in the unenergized as well as in the energized condition. A spark timing light was used for this purpose.

4.7.1.1. Centrifugal Advance: The hose connecting the distributor and the C.E.C. system was disconnected at the solenoid valve of the C.E.C. system and plugged. The spark timing was checked and adjusted by loosening the distributor

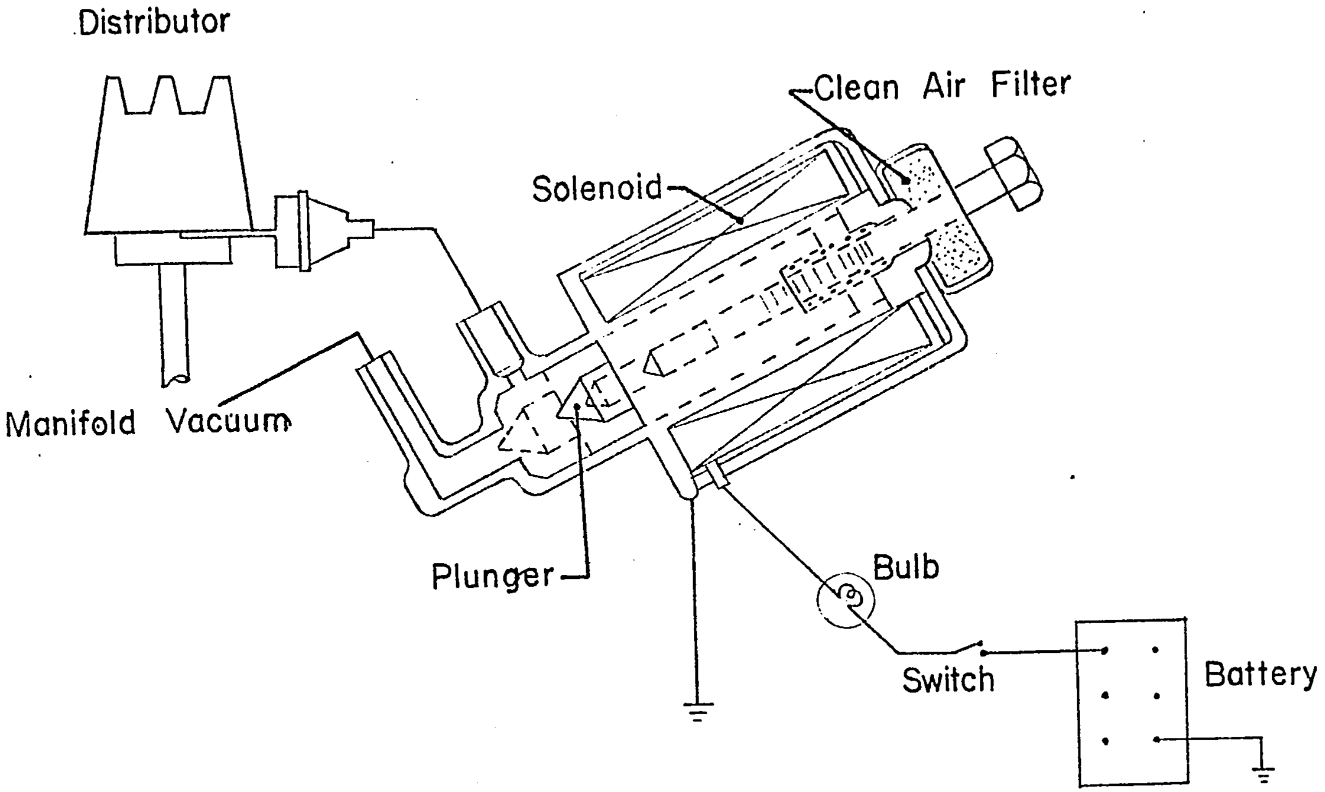


Fig. 4·4 SOLENOID VALVE CONNECTION

locking screw and rotating the distributor to set a spark timing of 6°BTDC at 550 rpm.

The engine speed was varied and the spark timing at different engine speeds was found.

4.7.1.2. Centrifugal and Vacuum Advance: The distributor was connected to the C.E.C. system by a rubber hose and the solenoid was energized. The engine was run at different speeds and the spark timing at these speeds was found.

A graph of spark timing against the engine speed for centrifugal advance and centrifugal and vacuum advance is shown in fig.4.5. It may be noted that spark timing is more advanced with centrifugal and vacuum advance than that with the centrifugal advance alone.

While finding the spark timing at the different engine speeds, the following variables were observed: air and fuel flow and the various temperatures mentioned earlier. It was observed that around 1650 rpm, there was a sudden increase in the pollutants emitted. It was decided to investigate this further (Refer to conclusion 2, page 66).

4.8. CORRECTION FACTORS FOR AIR FLOW AND HORSEPOWER: To compare the air flow rate and horsepower absorbed between any two days, correction factors depending upon the humidity, temperature and pressure of the ambient air on each day, are needed. These correction factors for air flow rate and HP absorbed can be found by knowing the dry bulb and wet bulb temperatures of the ambient air. The dry bulb and wet bulb temperatures were found by using

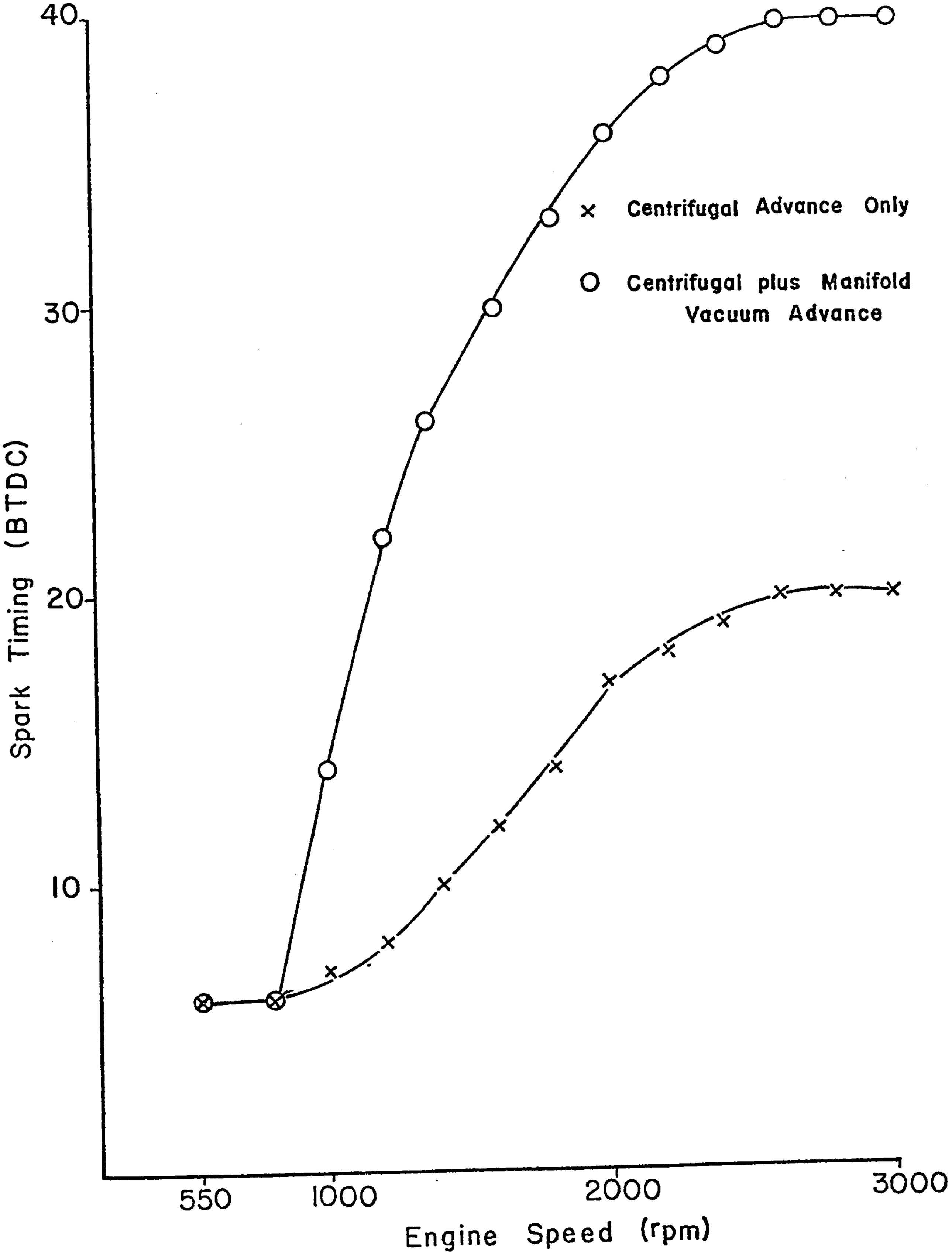


Fig. 4·5 ENGINE SPEED VERSUS SPARK TIMING a psychrometer.

Charts (figs. 4.6. through 4.9) give the correction factors for air flow and horsepower absorbed in terms of wet and dry bulb temperatures.

4.9. TESTS CONDUCTED: The operation of the dynamometer was checked finally. The engine was run at different speeds (chosen at random) and the engine was loaded. The 'Speed Control Potentiometer' was used to adjust the engine load. While running the engine at high speeds (about 2500 rpm) and at moderate loads (about 100 HP), an over-temperature switch in the dynamometer would cut off the excitation to the dynamometer (as well as ignition to the engine). The reason for this was not resolved, but it was felt that sufficient useful results could be obtained by running the engine only on loads up to 50 HP.

After running the engine under loaded conditions the dynamometer should be cooled before the tests are run at different speed and load conditions. Thus the following sequence was formed for conducting experiments:

SPEED (rpm)	TORQUE (ft.lb.)
Idle	---
1000	0
1000	165
1650	15
1650	120
2500	0
2500	100

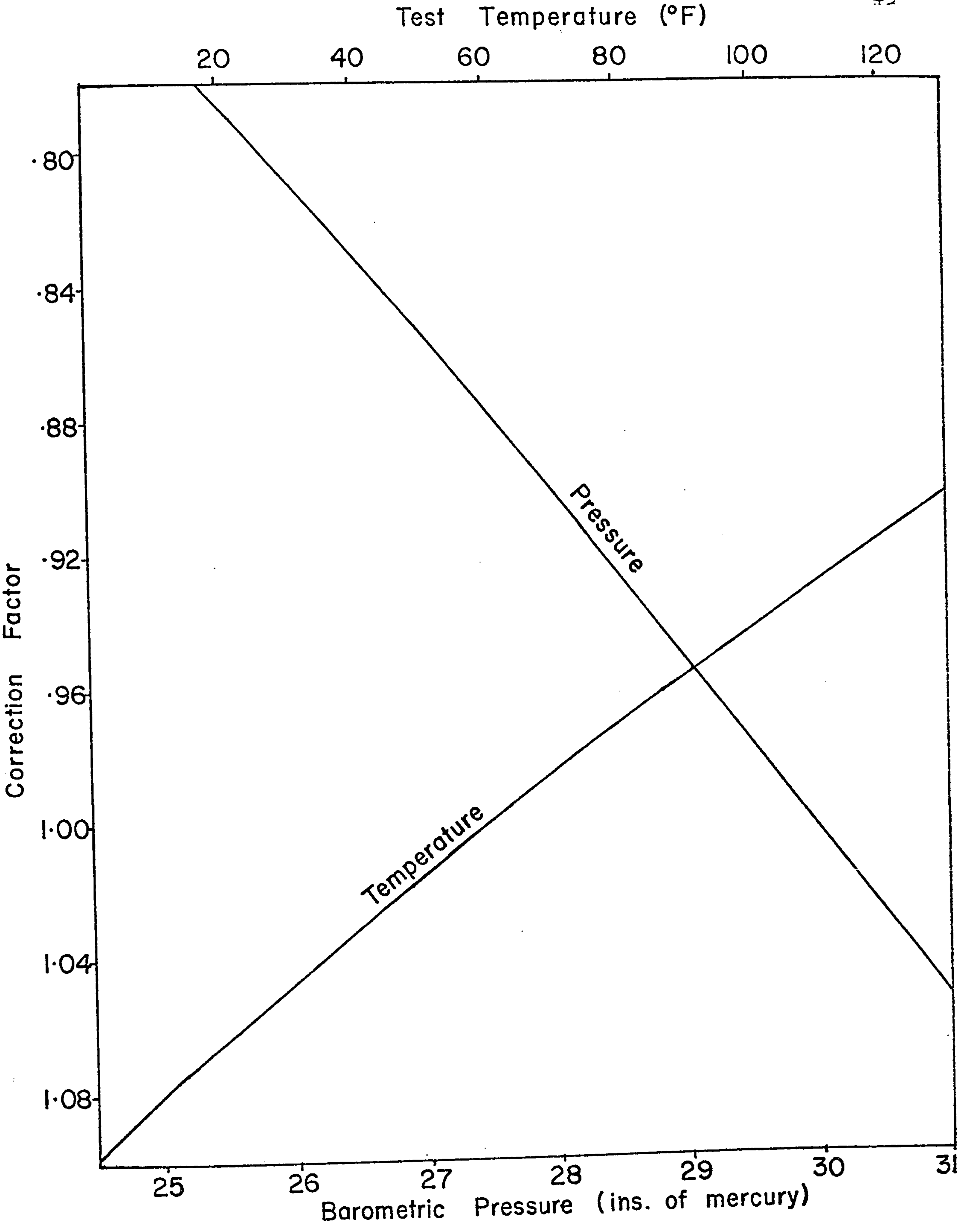


Fig. 4·6 AIR FLOW RATE CORRECTION FACTOR FOR TEST TEMPERATURE AND PRESSURE

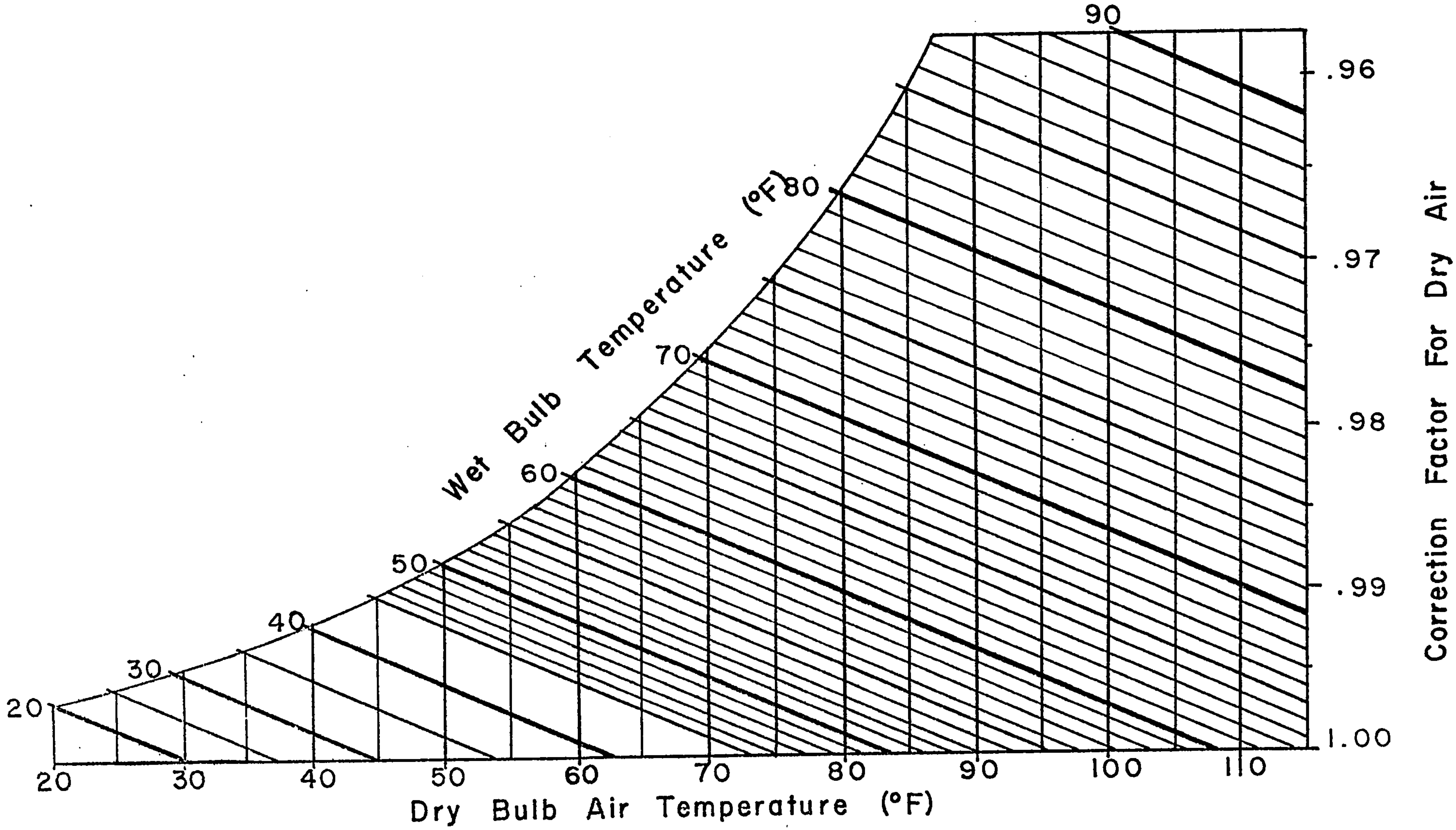


Fig. 4.7 AIR FLOW RATE CORRECTION FACTOR FOR HUMIDITY

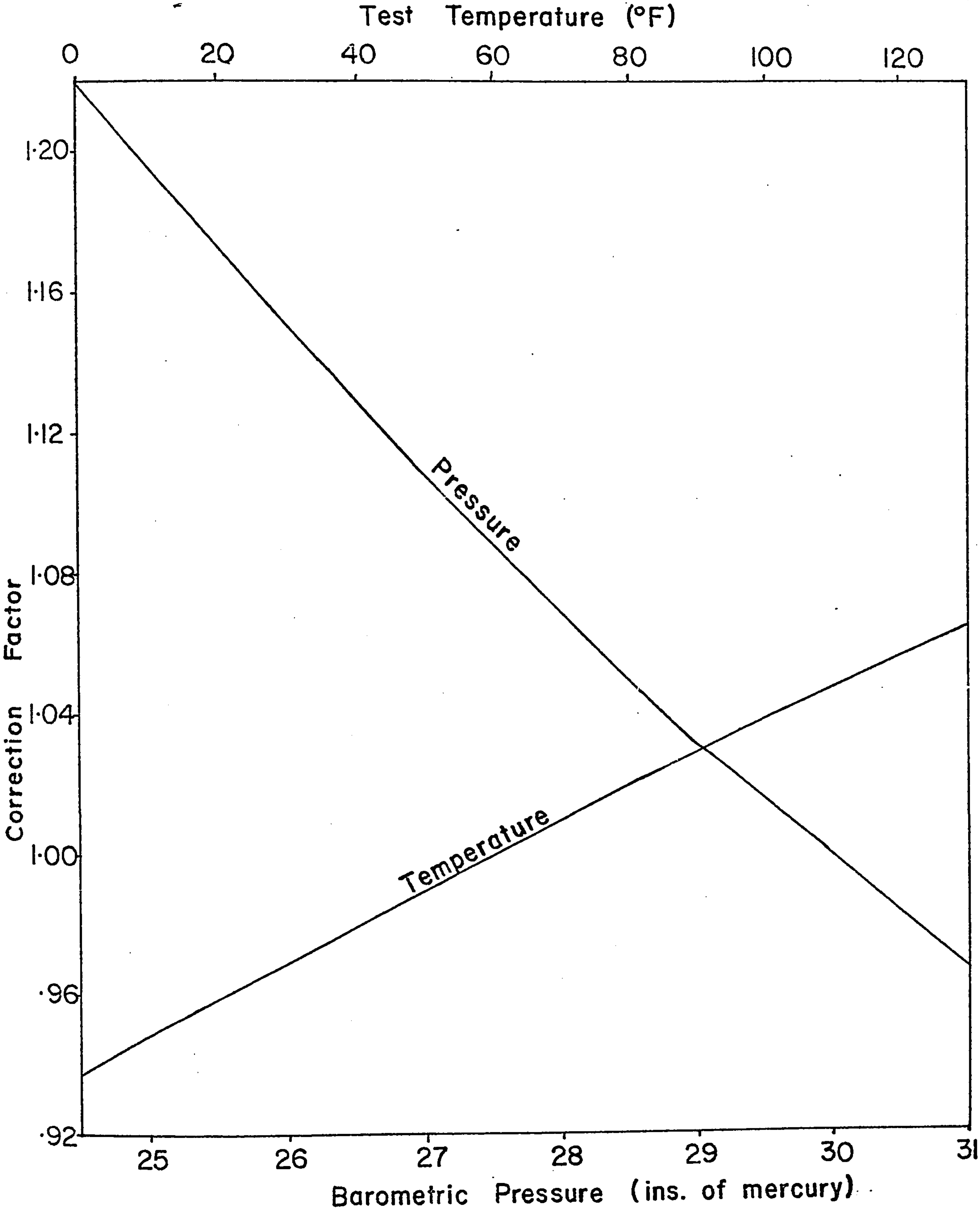


Fig. 4·8 HORSEPOWER CORRECTION FACTOR FOR TEST TEMPERATURE AND PRESSURE

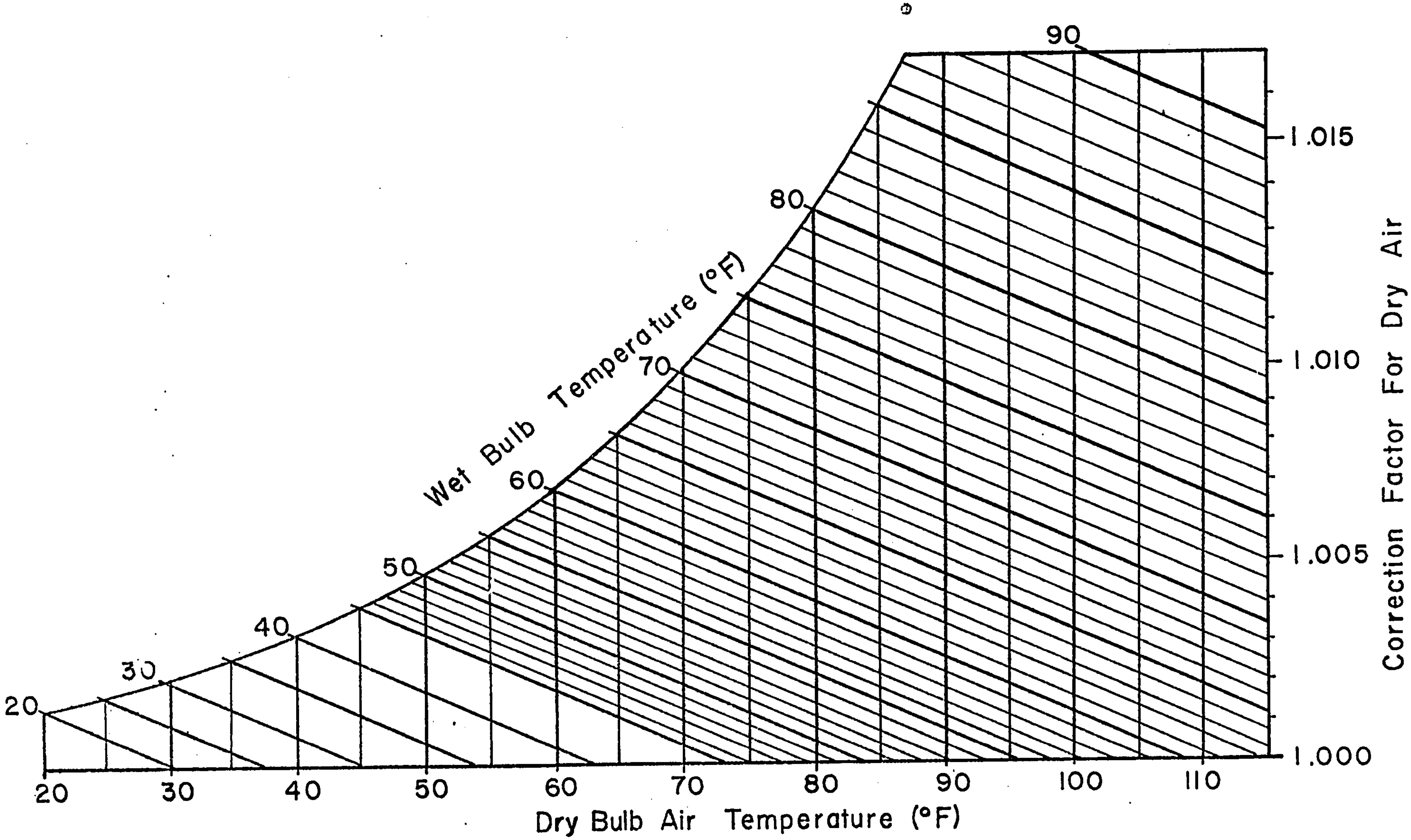


Fig. 4.9 **HORSEPOWER CORRECTION FACTOR FOR HUMIDITY**

SPEED (rpm)	TORQUE (ft. lb.)
2800	0
2800	85
1650	15
1650	130
Idle	---

In an automobile, under actual running conditions, the solenoid of the C.E.C. system is energized only during high gear acceleration. However, the effect of its operation on the performance of the engine should be experimented upon. Hence, two series of tests, one with the solenoid in the unenergized position and the other in the energized position, were conducted. A third series of tests were conducted to find the effect of energizing the solenoid while the engine was under loaded conditions. The three series of tests were repeated with the carburetor set at four different idle speeds, viz. 500, 550, 600 and 650 rpm.

The concentrations of the pollutants, hydrocarbons (as ppm hexane) and carbon monoxide (as percentage), were analysed continuously throughout the tests. The temperatures and fuel and air flow rates were recorded for each running condition of the engine. The dry bulb and wet bulb temperatures were recorded at the beginning and at the end of each test. Each reading of the concentration of HC and CO, and the temperatures was taken under steady state conditions, that is, when the exhaust and the manifold air temperatures were constant. The data recorded are tabulated and presented in tables 4.1

through 4.12. The fuel used during the experiments was SHELL ULTRA GASOLINE.

The results revealed that the manifold mixture temperature might have an effect on the exhaust emission levels. Hence it was decided to compare the results at constant test conditions except for the manifold mixture temperature. The engine conditions at which the results were to be compared, was arbitrarily chosen to be 1000 rpm and 75 ft.lb. The following sequence of operation was carried out:

SPEED (rpm)	TORQUE (ft.lb.)
600	no load
1000	75
800	no load
1000	75
1000	no load
1000	75
1650	30
1000	75
2000	no load
1000	75
2400	no load
1000	75
2800	no load
1000	75
600	no load

Comparing the test results at the engine conditions of 1000 rpm and 75 ft. lb., it was found that there was a change of 10°F in manifold mixture temperature with little variation in the other parameters. The results are tabulated in table 4.13.

The conclusions derived from the data are discussed in the following chapter.

TABLE 4.1

SOLENOID UNENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs./hr)	CORR HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	500	-	1.8	-	400 to 600	0.14	189.5	64	77.5	143.4	162.5	671
2	1000	-	7.0	-	25 to 60	0.1	197.4	65	79.7	148.7	181.7	1006
3	1000	165	18.5	32.12	80	0.7	199.3	68.6	83.7	131.9	191.1	1158
4	1650	15	18.5	4.82	127	7.0	195.5	67.7	83.7	128.9	208.6	1073.5
5	1650	120	38.5	38.55	200	10	203.2	67.7	84.1	99.2	214	1153.7
6	2500	-	20	-	140	6.0	193.5	69.4	86.3	120.6	222.5	1128.5
7	2500	100	42	48.68	130	7.0	201.3	66.3	87.5	106.6	230.8	1393.7
8	2800	-	26	-	135	8.0	205.1	71	91	120.6	233.5	1218
9	2800	85	44.8	46.34	115	4.6	203.2	71	91	107.8	236.1	1286
10	1650	15	18.5	4.82	200	7.0	195.5	70.3	89.7	124.6	225.1	1052.5
11	1650	130	40	41.77	160	7.8	199.3	69.4	87.5	99.2	220.9	1137
12	500	-	1.8	-	400 to 600	0.15	189.5	66.3	81	153.6	184.0	745.7

TABLE 4.2

SOLENOID UNENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs./hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	550	-	2.5	-	100 to 340	0.135	182	64	82.8	153	127	777.5
2	1000	-	5	-	40	0.11	201.3	65	94	169.7	193	1031.5
3	1000	165	17	31.42	77	0.825	189.5	69.4	83	169.7	177	745.7
4	1650	15	15.5	4.71	200	>10	201.3	67.7	84.5	119	198	1137
5	1650	120	37	37.71	150	9.3	205.2	71	85	105.7	215.5	1190
6	2500	-	19	-	80	3.2	193.2	69.4	87	133	223	1247.7
7	2500	100	42	47.619	80	3.0	195.5	73	89.8	116.7	232	1376.5
8	2800	-	26	-	80	4.1	199.3	71	93	124.7	237.6	1286
9	2800	85	44.8	45.33	90	3.4	193.5	73	94	135.1	242	1327
10	1650	15	15.5	4.71	180	>10	201.3	68.6	91.5	126.9	224.4	1115.7
11	1650	130	37	40.857	145	7.8	205.2	71	89	110	223	1200.7
12	550	-	2.5	-	100 to 350	0.15	185.5	66.3	83	159.7	187	777.5

TABLE 4.3

SOLENOID UNENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL.	EXH.
1	600	-	3	-	80 to 340	0.14	193.5	61.9	73.9	141.4	159.7	799
2	1000	-	6.2	-	25 to 55	0.1	200.1	64	78.3	152.8	188	1052.5
3	1000	165	18.5	32.11	85	0.95	201.3	64	80.6	133.1	192.7	1194
4	1650	15	15.5	4.81	200	3.4	197.4	68.6	81.9	128.9	206.7	1105.3
5	1650	120	39	38.53	140	> 10	201.3	68.6	83.7	101.4	216	1158
6	2500	-	18.5	-	88	3.6	209	71	85.4	132.2	224.4	1247.7
7	2500	100	43	48.66	120	5.7	205.1	68.6	86.2	113.0	230.4	1307.5
8	2800	-	26	-	165	> 10	209	71	88.4	120.6	233.9	1254
9	2800	85	44.8	46.32	125	6.2	205.1	71	88	111.2	238	1329
10	1650	15	15.5	4.81	200	> 10	201.3	66.3	87.1	127.7	224.4	1094.5
11	1650	130	40	41.75	140	5.0	201.3	71	85.4	107.8	221.8	1277.5
12	600	-	3	-	100 to 320	0.14	189.5	72.1	82.3	159.7	192.3	820

TABLE 4.4

SOLENOID UNENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppmHex.	CO %	TEMPERATURES (°F) C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	650	-	3	-	70 to 280	0.14	189.5	65	84.5	141.4	161.3	782
2	1000	-	7	-	28	0.11	197.4	67.2	83	153.6	179.6	1010.3
3	1000	165	20	31.832	103	1.65	201.3	71	85	133	193.5	1147.5
4	1650	15	18	4.82	90	3.95	201.3	68.7	87	142.1	205.2	1107.3
5	1650	120	40	38.58	170	>10	205.2	71	87	112.1	215.6	1105.3
6	2500	-	19	-	85	4	197.4	66.4	89.8	133	225.1	1179.5
7	2500	100	43	48.718	92	4.6	209	71	90.2	116.7	233.5	1329
8	2800	-	26	-	148	>10	197.4	68.7	93	123.9	236.5	1183.5
9	2800	85	44.8	46.38	90	3.2	209	73	93	113	241.7	1350.5
10	1650	15	18	4.82	107	5.0	201.3	71	91	137.2	222.4	1088.5
11	1650	130	43.5	41.8	95	5.65	209	73	89.3	119.3	221.3	1286
12	650	-	3	-	80 to 290	0.14	193.5	67.2	85.9	161.7	190.7	782

TABLE 4.5

SOLENOID ENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	500	-	1.8	-	400 to 800	0.15	189.5	68.6	76.1	139.7	155.2	713.7
2	1000	-	5	-	60 to 90	0.12	197.4	68.6	77	137.2	173.3	951
3	1000	165	21	32.08	100	0.78	199.3	66.3	81	123.4	184.9	1194
4	1650	15	17.0	4.81	230	7.6	197.4	71	81	128.9	205.9	983
5	1650	120	38.5	38.5	300	>10	201.3	71	82.3	88.4	213.7	1067.3
6	2500	-	18.5	-	157	6.4	204.4	68.6	84.3	135.2	233.5	1078
7	2500	100	40	48.62	172	8.0	205.1	68.6	88.9	107.8	240.6	1209
8	2800	-	25	-	175	9.1	205.1	71	91.5	124.6	238	1243.5
9	2800	85	44	46.29	155	5.4	205.1	73	94.1	113	244	1372
10	1650	15	17	4.81	225	7.8	201.3	73	90.6	133.1	225	1094.5
11	1650	130	40	41.72	170	8.2	207.9	71	89.3	107.8	223.2	1222
12	500	-	1.8	-	400 to 750	0.15	189.5	68.6	83.7	161.5	189.5	692.3

TABLE 4.6

SOLENOID ENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	550	-	2.5	-	100 to 370	0.14	182	64	77.5	153	140.5	777.5
2	1000	-	5	--	40	0.12	197.4	67.7	80.1	169.7	175	904.7
3	1000	165	17	33.31	85	1.35	189.5	71	82.8	131	186.4	1147.5
4	1650	15	17	4.997	355	>10	193.5	68.6	83.7	126.9	207.5	915.3
5	1650	120	36	39.977	290	>10	201.3	71	84.1	101.4	212.9	999.6
6	2500	-	18.5	-	105	3.7	197.4	69.4	85	122.6	226.6	1094.5
7	2500	100	41	50.476	120	3.6	189.5	73	86.2	112.1	235.4	1286
8	2800	-	25	-	100	5.9	195.5	71	90.6	135.1	239.5	1158
9	2800	85	44	48.05	100	5.4	189.5	73	89	149.5	241.7	1073.5
10	1650	15	17	4.997	345	>10	195.5	68.6	87	119	224	926
11	1650	130	37	43.309	270	>10	199.3	71	84.5	99.2	222	1021
12	550	-	2.5	-	100 to 400	0.15	189.5	66.3	81.7	157.6	192	777.5

TABLE 4.7

SOLENOID ENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	600	-	3	-	100 to 360	0.14	197.4	64	79.7	139.7	156.4	767
2	1000	-	7	-	38 to 70	0.13	205.1	66.3	81.0	152.4	184	904.7
3	1000	165	21	32.08	100	1.25	205.1	66.3	86.3	133.1	195	1147.5
4	1650	15	15.5	4.81	375	8.0	204.4	68.6	84.5	140.1	214.4	989.3
5	1650	120	40	38.5	175	> 10	201.3	68.6	85.8	99.2	219	1004
6	2500	-	17	-	110	3.8	209	71	87.1	140.1	229	1063
7	2500	100	42.0	48.61	145	6.2	205.1	66.3	88.9	112.1	238.4	1211.3
8	2800	-	25	-	242	> 10	209	71.2	90.6	124.7	239.5	1094.5
9	2800	85	Not steady	46.28	142	6.7	209	71.2	91.5	108.7	247	1232.7
10	1650	15	15.5	4.81	360	> 10	201.3	69.4	90.2	127.2	229.7	926
11	1650	130	43.5	41.71	195	7.9	209	68.6	89.3	103.6	225.9	1137
12	600	-	3.0	-	100 to 360	0.14	197.4	68.6	84.1	119.7	192.3	735

TABLE 4.8

SOLENOID ENERGISED

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	650	-	3	-	90 to 270	0.15	177.7	61.9	77.5	143.4	163.6	820
2	1000	-	6	-	48	0.11	185.5	63.1	79.2	149.5	188	947
3	1000	165	21	31.832	105	2.3	193.5	64	81.7	127.7	194.3	1190
4	1650	15	17	4.82	235	5.65	199.3	64.6	86.2	144.7	204.4	1073.5
5	1650	120	40	38.58	260	> 10	201.3	64.6	82.8	105.7	218.2	1052.5
6	2500	-	17	-	118	4.2	195.5	66.4	85.9	137.2	228.9	1094.5
7	2500	100	42	48.718	120	5.0	201.3	64.6	88	110.9	239.1	1286
8	2800	-	25	--	190	9.8	195.5	66.4	88	126.9	238.7	1107.3
9	2800	85	43	46.38	100	3.2	201.3	64.6	87.1	112.1	244	1307.5
10	1650	15	17	4.82	148	5.0	195.5	68.7	85.45	133	223.6	1035.7
11	1650	130	44	41.8	105	6.0	201.3	64.0	85	118.4	222.8	1342
12	650	-	3	-	70 to 310	0.14	189.5	64.0	82.8	161.7	193.9	820

TABLE 4.9

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	500	-	1.8	-	370 to 700	0.16	193.5	64	79.7	133.1	144.6	698.7
2	1000	-	5	-	25	0.14	201.3	66.3	83.3	149.5	180.9	1048.3
3	1000	165	23	31.42	115	1.9	199.3	65	86.3	132.2	191.1	1190
4	1000	171	24.5	32.57	120	2.0	203.2	66.3	88.0	131.8	194.3	1200.7
5	1650	15	20	4.71	185	9.6	199.3	69.4	86.2	126.8	216	1086.3
6	1650	120	38.5	38.78	200	> 10	203.2	69.0	88.0	107.8	220.9	1158
7	1650	129	40	41.69	240	> 10	203.2	68.6	88.4	104.9	222.1	1120
8	2500	-	21.7	-	138	7.7	209	71	89.3	129.8	228.6	1179.5
9	2500	100	43	48.97	122	5.3	209	68.6	90.2	112.1	233.1	1324.7
10	2500	106.5	43.5	52.15	135	5.6	209	68.6	90.6	110.4	237.2	1286
11	2800	-	26	-	125	8.1	207	71	92.3	128.9	237.2	1243.5
12	2800	85	46	46.62	115	6.7	205.1	71	92.3	113.3	240.2	1324.7
13	2800	94.5	48.5	51.83	142	6.9	205.1	68.6	92.8	110.9	243.2	1282
14	1650	15	21	4.84	150	7.8	199.3	71.2	90.6	136	225.9	1099
15	1650	130	38	42.02	170	8.0	205.1	69.4	90.2	107.8	225.1	1192
16	500	-	1.8	-	400 to 950	0.25	189.5	68.6	84.5	161.5	187.2	692.3

TABLE 4.10

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	550	-	2.5	-	100 to 350	0.135	182	64	77.5	153	160.5	777.5
2	1000	-	5.0	-	11	0.09	197.4	71	80.1	155.6	186	1031.5
3	1000	165	17.0	33.3	78	1.35	189.5	71	83.7	135.2	192.7	1200.7
4	1650	15	11.4	4.997	210	>10	201.3	71	85	121	207.5	1115.7
5	1650	120	38.5	39.997	175	9.5	193.5	71	85	103.6	211.3	1222
6	1650	138	40	45.974	185	>10	193.5	71	85	103.6	211.3	1222
7	2500	-	21	-	80	3.7	197.4	71	87.1	133	226.6	1226.3
8	2500	100	42	50.476	110	7.4	189.5	71	88.9	112	229.3	1256.3
9	2500	108	43.5	54.514	145	8.1	189.5	71	88.9	112	229.3	1256.3
10	2800	-	26	-	130	9.5	197.4	71	89.8	126.8	232.7	1222
11	2800	85	44	48.05	65	5.7	185.5	71	89.8	124.7	236.9	1481
12	2800	96	46	54.27	70	6.0	185.5	71	89.8	124.7	236.9	1481
13	1650	15	11.4	4.997	190	>10	201.3	71	90.2	129	225.9	1105.3
14	1650	130	38.5	39.997	145	6.6	199.3	71	87.1	112	222	1190

TABLE 4.11

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	T E M P E R A T U R E S (^{o}F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	600	-	3.0	-	80 to 340	0.14	189.5	61.9	77.5	137.2	144.6	799
2	1000	-	6.2	-	25 to 55	0.1	201.3	64	79.2	155.6	182.1	1021
3	1000	165	18.5	32	80	0.75	201.3	61.9	82.8	137.2	192.7	1179.5
4	1000	171	20	33.17	85	0.77	201.3	61.9	84.5	137.2	195	1190
5	1650	37.5	27.5	12	335	> 10	205.1	68.6	84.5	116.3	207.9	1126.3
6	1650	120	41	38.41	248	> 10	205.1	68.6	87.1	100.2	218.2	1153.7
7	1650	138	43	44.17	260	> 10	205.1	68.6	87.1	99.2	220.9	1105.3
8	2500	-	21	-	98	4.4	209	69.4	88	130.1	226.7	1239
9	2500	100	44.8	48.5	120	5.0	209	66.3	88	112.1	233.1	1346.3
10	2500	105	47	50.93	135	5.2	209	66.3	88	112.1	235	1346.3
11	2800	-	25	-	125	8.4	209	71	90.6	127.6	236.9	1247.7
12	2800	85	46	46.17	100	4.6	209	71	89.7	112.1	238.7	1307.5
13	2800	93	48.5	50.5	115	4.8	209	71	92.3	112.1	242.1	1307.5
14	1650	37.5	27.5	12	260	> 10	201.3	72.1	89.7	120.6	224.4	1115.7
15	1650	130	36.0	41.61	220	9.6	204.4	69.4	88.9	103.6	224.4	1141
16	600	-	3.0	-	100 to 400	0.22	193.5	66.8	84.5	157.6	192.7	792.7

TABLE 4.12

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	TEMPERATURES (°F) C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	650	-	3	-	70 to 310	0.14	189.5	61.8	76.7	141.4	159.8	782
2	1000	-	5	-	28	0.11	197.4	64	79.2	153.6	184.8	1027
3	1000	165	17	31.832	78	0.6	203.2	64	81	137.2	193.5	1188
4	1000	171	18.5	33.32	85	0.75	203.2	64	84.5	137.2	195.8	1200.7
5	1650	15	10	4.82	500	>10	201.3	68.7	85	108.7	203.6	1179.5
6	1650	120	38.5	38.58	280	>10	207.1	68.7	85	95	215.2	1147.5
7	1650	135	41	43.408	320	>10	207.1	68.7	85	92.8	219.8	1084
8	2500	-	18.5	-	100	3.9	197.4	71	88	133.1	229.7	1237
9	2500	100	40.5	48.718	52	0.4	201.3	71	90.6	110	237.8	
10	2500	108	42.0	52.616	60	1.1	203.2	68.7	91.5	157.7	238.7	
11	2800	-	29	-	150	9.3	197.4	71	92.3	166.9	237.6	1243.5
12	2800	85	43.5	46.376	110	4.8	203.2	71	92.3	112.2	239.8	
13	2800	96	44.8	52.38	125	5.0	203.2	73	92.8	110.3	242.5	
14	1650	15	10	4.82	228	>10	197.4	71	90.2	122.2	221.7	1115.7
15	1650	130	38.5	41.8	165	5.6	201.3	71	88.9	107.8	221.7	1243.5
16	650	-	3	-	70 to 320	0.16	189.5	68.7	85	159.7	194.2	820

TABLE 4.13

NO	SPEED (rpm)	TORQUE (ft.lb.)	FUEL FLOW (lbs/hr)	CORR. HP (BHP)	HC ppm Hex.	CO %	T E M P E R A T U R E S (°F)					
							C.OUT	C.IN	INLET AIR	MAN. AIR	OIL	EXH.
1	1000	75	14	14.53	100	1.65	201.3	61.9	80.1	141,4	191.9	1190
2	1000	75	14	14.53	102	1.85	201.3	64	81.4	140.2	200.5	1172.5
3	1000	75	14	14.53	105	2.1	201.3	64	81.4	138.1	200.5	1140.5
4	1000	75	14	14.53	108	2.35	201.3	64	81.4	136.5	201.3	1109
5	1000	75	14	14.53	112	2.7	201.3	66.3	81.9	135.16	203.6	1086.3
6	1000	75	14	14.53	120	2.95	201.3	66.3	81.9	134	203.6	1069.2
7	1000	75	14	14.53	130	3.2	201.3	64	81.4	133.08	201.3	1052.5

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The observations made during the experimentation and the conclusions derived from data obtained are discussed in this chapter.

5.1. ACCURACY OF MEASUREMENT: The parameters measured were: speed, torque, air flow, fuel flow and temperatures. The variation in the engine speed could be kept within ± 10 rpm. At the lowest speed tested namely 500 rpm, this represents a control to within ± 2 %. Accuracy of the tachometer was ± 5 rpm. Torque variation was not controlled since the speed control potentiometer was used for loading the engine. It was observed, however, that the variation was ± 2 ft. lb. (approximately 2.35% at 85 ft. lb. torque). Torque meter accuracy was 0.25% of full scale.

The air flow measurement seems to be faulty. The probable reason for the faulty measurement and suggestions to obtain accurate air flow are discussed in Appendix F.

The fuel flow meter was calibrated. The accuracy claimed by the manufacturers is ± 5 %, but since it was calibrated under test conditions of pressure and temperature, it is expected to be better than 5%. The repeatability claimed for the measurement of concentration of pollutants is ± 1% of full scale reading.

5.2. REPEATABILITY OF CONDITIONS AND MEASUREMENTS: Repeatability of the operating conditions between two days was very good, except for the temperature of ambient air and humidity.

Due to malfunctioning of the ventilation system in the test facility, the temperature and humidity could not be kept controlled within a day as well as between two days.

In each set of experiments, one test condition (1650 rpm and 15 ft. lb.) was repeated and reproducability of the measurements was good. Some experiments were replicated to check the repeatability. Speed versus spark timing curves were obtained twice and were found to be identical. Two sets of experiments with an idling speed of 550 rpm were also repeated.

5.3. CONCLUSIONS DERIVED FROM DATA:

(1) When the engine is operating under idling conditions, the hydrocarbon level fluctuates. (Personal communications with the research associates at Shell Research Center confirmed this.) This is believed to be due to ± 10 rpm variation in engine speed which is continuously oscillating between the maximum and minimum speeds. When the engine decelerates from the maximum to minimum speed, the concentration of hydrocarbon increases.

(2) When the engine speed reaches around 1650 rpm, there is a noticeable increase in the concentrations of the pollutants (HC and CO). On further increase of speed, the HC and CO levels return to a lower level.

The reason for this may traced to the operation of the carburetor. At part throttle, the low pressure in the intake manifold encourages low air-vapor ratios, but even under this condition, part of the fuel passes to the cylinder as a liquid film on the manifold walls (4). Thus the mixture entering the cylinder is made up of air, vaporised fuel and liquid fuel. This liquid fuel does not take part in combustion, but evaporates as a result of combustion. This causes an increase in the concentration of pollutants. At higher speeds (when the throttle is opened), the fuel is atomised well even though a rich mixture is supplied to the cylinders. Thus, there is a reduction in concentration of pollutants.

This reasoning is only speculative and positive conclusion or reasoning cannot be given unless a study on the carburetor characteristics is undertaken.

(3) Under similar speed-torque conditions, the engine with its solenoid (of the C.E.C. system) unenergized produces less pollutants than the engine with the solenoid energized.

In the past, the distributor had both centrifugal and manifold advance. Now due to the introduction of the C.E.C. systems in GM engines, only centrifugal advance to the distributor is present (solenoid in the unenergized position) till high speeds are reached. At high speeds, the solenoid is energized and the distributor has both centrifugal and manifold vacuum advance.

Table 5.1. compares the concentration of the pollutants (at similar engine operating conditions) with the solenoid off (unenergized) and on (energized).

Introducing manifold vacuum advance to the distributor

TABLE 5.1

SPEED	TORQUE	SOLENOID	HC with carburetor set at idle speeds of (rpm)				CO with carburetor set at idle speeds of (rpm)			
			500	550	600	650	500	550	600	650
1000	0	OFF	25 to 60	40	25 to 55	28	0.1	0.11	0.1	0.11
		ON	60 to 90	40	38 to 70	48	0.12	0.12	0.13	0.11
1000	165	OFF	80	77	85	103	0.7	0.825	0.95	1.65
		ON	100	85	100	105	0.78	1.35	1.25	2.3
1650	15	OFF	127	200	200	90	7.0	>10	3.4	3.95
		ON	230	355	375	235	7.6	>10	8.0	5.65
1650	120	OFF	200	150	140	170	>10	9.3	>10	>10
		ON	300	290	175	260	>10	>10	>10	>10
2500	0	OFF	140	80	88	85	6.0	3.2	3.6	4.0
		ON	157	105	110	118	6.4	3.7	3.8	4.2
2500	100	OFF	130	80	120	92	7.0	3.0	5.7	4.6
		ON	172	120	145	120	8.0	3.6	6.2	5.0
2800	0	OFF	135	80	165	148	8.0	4.1	>10	>10
		ON	175	100	242	190	9.1	5.9	>10	9.8
2800	85	OFF	115	90	125	90	4.6	3.4	6.2	3.2
		ON	155	100	142	100	5.4	5.4	6.7	3.2
1650	15	OFF	200	180	200	107	7.0	>10	>10	5.0
		ON	225	345	360	148	7.8	>10	>10	5.0
1650	130	OFF	160	145	140	95	7.8	7.8	5.0	5.65
		ON	170	270	195	105	8.2	>10	7.9	6.0

advances the spark (fig.4.5.). Retarding the spark reduces the HC and CO levels (4). Thus the increase in the levels of the pollutants could be attributed to the spark advance.

(4) Engines without the C.E.C. systems, as compared to the present GM engines, emit more pollutants (HC and CO) at low gear operations and consume more fuel.

At low gears, the present GM engines operate with their solenoids (of the C.E.C. systems) unenergized (off).

Typical values of fuel consumption and pollutant levels are given in the table below as examples (from table 4.9):

SOLENOID	SPEED rpm	TORQUE ft.lb.	FUEL CONSUMPTION lbs./hr.	HC ppm	CO %
ON	1000	171	24.5	120	2.0
OFF	1000	165	23.0	115	1.9
ON	1650	129	40.0	240	> 10
OFF	1650	120	38.5	200	> 10

The 'Speed Control Potentiometer' controlled the engine-dynamometer operation, so that energizing the solenoid increased the load on the engine. The increase in fuel consumption accounts for increased load on the engine. The increase in HC and CO levels while energizing the solenoid is due to the spark advance.

(5) As the mixture temperature at the manifold increases,

the concentrations of the pollutants decrease. The effect on CO is more pronounced.

A graph of manifold mixture temperature versus HC and CO levels is shown in fig. 5.1.

The increase in manifold mixture temperature results in more complete evaporation of the fuel and thorough mixing. As a result, more complete combustion takes place, causing lower pollutant levels. Also increasing the intake mixture temperature beyond a certain point results in lower percentage reduction in HC level. In other words, beyond a certain point, pollutant reduction tends to level off with increased engine intake mixture temperatures. This is in agreement with Fleming and Eccleston (19). They have found that the effect of mixture temperature on exhaust emissions is insignificant from 160°F up to a maximum temperature tested of 280°F.

The measured concentrations of CO has been compared with theoretical computations of CO as a function of the extent of expansion of the gases, and it has been shown that the concentrations of CO correspond more nearly to the equilibrium concentrations of CO at peak cycle temperatures rather than those existing at the end of expansion (due to slow rate of oxidation of CO in the exhaust stroke) (2). As the mixture temperature increases, the peak cycle temperature also increases. Hence more complete combustion takes place resulting in reduced CO levels.

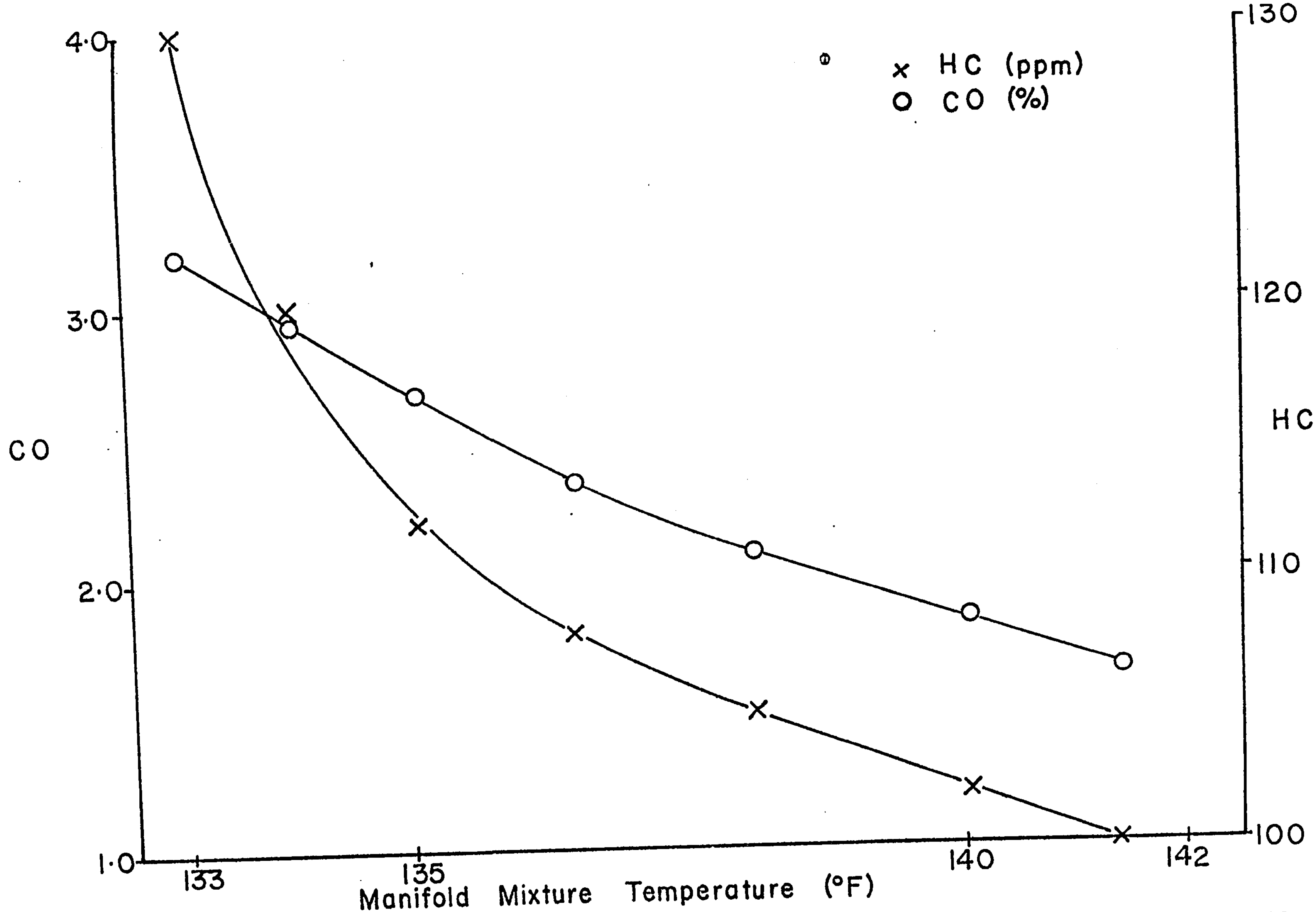


Fig. 5·1 MANIFOLD MIXTURE TEMPERATURE VERSUS POLLUTANTS

(6) Referring to table 5.2, which is a collection of data obtained from tests conducted at different idle speeds, an idle speed of 550 rpm seems to be best for reducing pollutants and for fuel economy.

This is the idle speed suggested by the manufacturer and shows the importance of maintaining the correct idle speed.

5.4. SUGGESTIONS FOR FURTHER WORK: A transmission can be installed on the engine. Then, to simulate the road load conditions of an automobile, a flywheel can also be designed and installed on the dynamometer shaft. Both these changes would produce conditions closer to those that actually occur in use but less control is then possible on the engine operation.

The cell could be cooled to low temperatures (at least to -25^{o}F) and emissions could be analysed, particularly during the first few minutes of engine warm-up. Emission control devices like exhaust recirculation, air injection, catalytic converter and thermal reactor could be installed and the performance tested at various ambient temperatures (85^{o}F to at least -25^{o}F).

The load controls on the dynamometer and the throttle control for the engine could be modified so that an automated sequence of testing (preferably adaptable to computer control) is possible.

TABLE 5.2

SPEED	TORQUE	SOL.	Fuel Consumption with Carb. set at idle speeds of 500	550	600	650	HC with carburetor set at idle speeds of (rpm) 500	550	600	650	CO with carburetor set at idle speeds of(rpm) 500	550	600	650
1000	0	OFF	7.0	5.0	6.2	7.0	25 to 60	40	25 to 55	28	0.1	0.11	0.1	0.11
		ON	5.0	5.0	7.0	6.0	60 to 90	40	38 to 70	48	0.12	0.12	0.13	0.11
1000	165	OFF	18.5	17.0	18.5	20.0	80	77	85	103	0.7	0.825	0.95	1.65
		ON	21.0	17.0	21.0	21.0	100	85	100	105	0.78	1.35	1.25	2.3
1650	15	OFF	18.5	15.5	15.5	18.0	127	200	200	90	7.0	>10	3.4	3.95
		ON	17.0	17.0	15.5	17.0	230	355	375	235	7.6	>10	8.0	5.65
1650	120	OFF	38.5	37.0	39.0	40.0	200	150	140	170	>10	9.3	>10	>10
		ON	38.5	36.0	40.0	40.0	300	290	175	260	>10	>10	>10	>10
2500	0	OFF	20.0	19.0	18.5	19.0	140	80	88	85	6.0	3.2	3.6	4.0
		ON	18.5	18.5	17.0	17.0	157	105	110	118	6.4	3.7	3.8	4.2
2500	100	OFF	42.0	42.0	43.0	43.0	130	80	120	92	7.0	3.0	5.7	4.6
		ON	40.0	41.0	42.0	42.0	172	120	145	120	8.0	3.6	6.2	5.0
2800	0	OFF	26.0	26.0	26.0	26.0	135	80	165	148	8.0	4.1	>10	>10
		ON	25.0	25.0	25.0	25.0	175	100	242	190	9.1	5.9	>10	9.8
2800	85	OFF	44.8	44.8	44.8	44.8	115	90	125	90	4.6	3.4	6.2	3.2
		ON	44.0	44.0	-	43.0	155	100	142	100	5.4	5.4	6.7	3.2
1650	15	OFF	18.5	15.5	15.5	18.0	200	180	200	107	7.0	>10	>10	5.0
		ON	17.0	17.0	15.5	17.0	225	345	360	148	7.8	>10	>10	5.0
1650	130	OFF	40.0	37.0	40.0	43.5	160	145	140	95	7.8	7.8	5.0	5.65
		ON	40.0	37.0	43.5	44.0	170	270	195	105	8.2	>10	7.9	6.0

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APPENDIX A

Engine

SPECIFICATIONS: (ref. 18)

Type	V - 8
Displacement	350 cu. in.
Horsepower	245 HP at 4800 rpm
Torque	350 ft. lb. at 2800 rpm
Bore	4 in.
Stroke	3.48 in.
Compression Ratio	8.5:1
Firing Order	1-8-4-3-6-5-7-2
Compression	160 psi at cranking speed, throttle wide open
Spark Plug Gap	0.035 in.
Spark Timing	6° at idle speed with vacuum advance line disconnected and plugged
Idle Speed	550 rpm
Carburetor	2 Barrel
Ignition Coil:	

Primary Resistance 1.77 - 2.05 ohms at 75°F

Secondary Resistance 3,000 - 20,000 ohms at 75°F

APPENDIX B

Dynamometer

SPECIFICATIONS:

Type	Eddy - Current Absorption
Horsepower	450 HP at a speed range of 1800 - 6000 rpm
Cooling	Water cooled - equipped with integral automatic water piping with temperature and pressure switches
Flow	45 GPM max.
Pressure Range	35 to 125 psi
Inlet Temperature	less than 90°F
Power Supply	575 V (± 10%) single phase 60 Hz.

APPENDIX C

Cooling Column

The cooling column is designed to replace the radiator and to provide adequate cooling as well as to maintain constant temperature in an engine undergoing test. Water is circulated through the coulmn by the engine pump and the temperature is maintained by sensitive modulating thermostats. Water in the column is cooled by cold water that is introduced into the cooling column at the mid-point thus mixing with the hot water before entering the engine. Thermostats are located at the outlet of the column and therefore are sensitive to the temperature of water entering the engine. Excess hot water flows out of the column through a overflow drain and is replaced by just the right amount of cold water to maintain the desired temperature.

A pressure relief valve maintains an operating pressure of 5 to 10 lbs. per square inch on the cooling column. Temperatures are varied by means of a control valve that adjusts the thermostats thus maintaining the desired temperatures. An accurate temperature gage is provided to indicate the engine operating temperature at all times. A sight gage indicates the water level in the column. The cooling column and engine are quickly drained by turning a knob located at the top of the column.

Adjustable arms which permit both vertical and horizontal adjustment support the column at any desired position for connecting to the engine. Connection to the water supply and disposal lines is through flexible hoses provided with quick connects.

The unit has a capacity for cooling engines up to 810 HP, has a maximum heat rejection rate up to 22,000 Btu per HP per minute and operates on 5 to 10 lbs. pressure.

APPENDIX D

MEXA - 300 Infrared Analyser

The analyser is designed specifically for measurement of CO and HC in automobile exhaust. It determines the concentration of CO (%) and HC(ppm) by measuring the infrared absorption by each of the components in the sample (exhaust gas) compared to a non-absorbing reference gas (atmospheric air). Two meters indicate the concentrations of HC and CO. The instrument is equipped with two zero control knobs and two span control knobs which are used for zero adjustment and calibrating respectively.

Calibration with gas sample as well as a mechanical check is possible for this instrument. The analyser is also equipped with its own sampling system.

SPECIFICATIONS:

Measuring method	Infrared analyser, non-dispersive method
Ranges	0 to 2 % CO and 0 to 400 ppm HC 0 to 10 % CO and 0 to 2000 ppm HC
Repeatability	± 1 % of full scale
Respense Time	90% of reading in 7 seconds
Read out	Two meters, each with 3 inch scale lengths, one for CO and one for HC. Electrical output points available and used for recording CO and HC concentrations.
Sampling system	Houses a complete sampling system, including a flow meter, water separator, particulate filter and pump. A tail-pipe probe and flexible sample line with prefilter are also supplied.

APPENDIX E

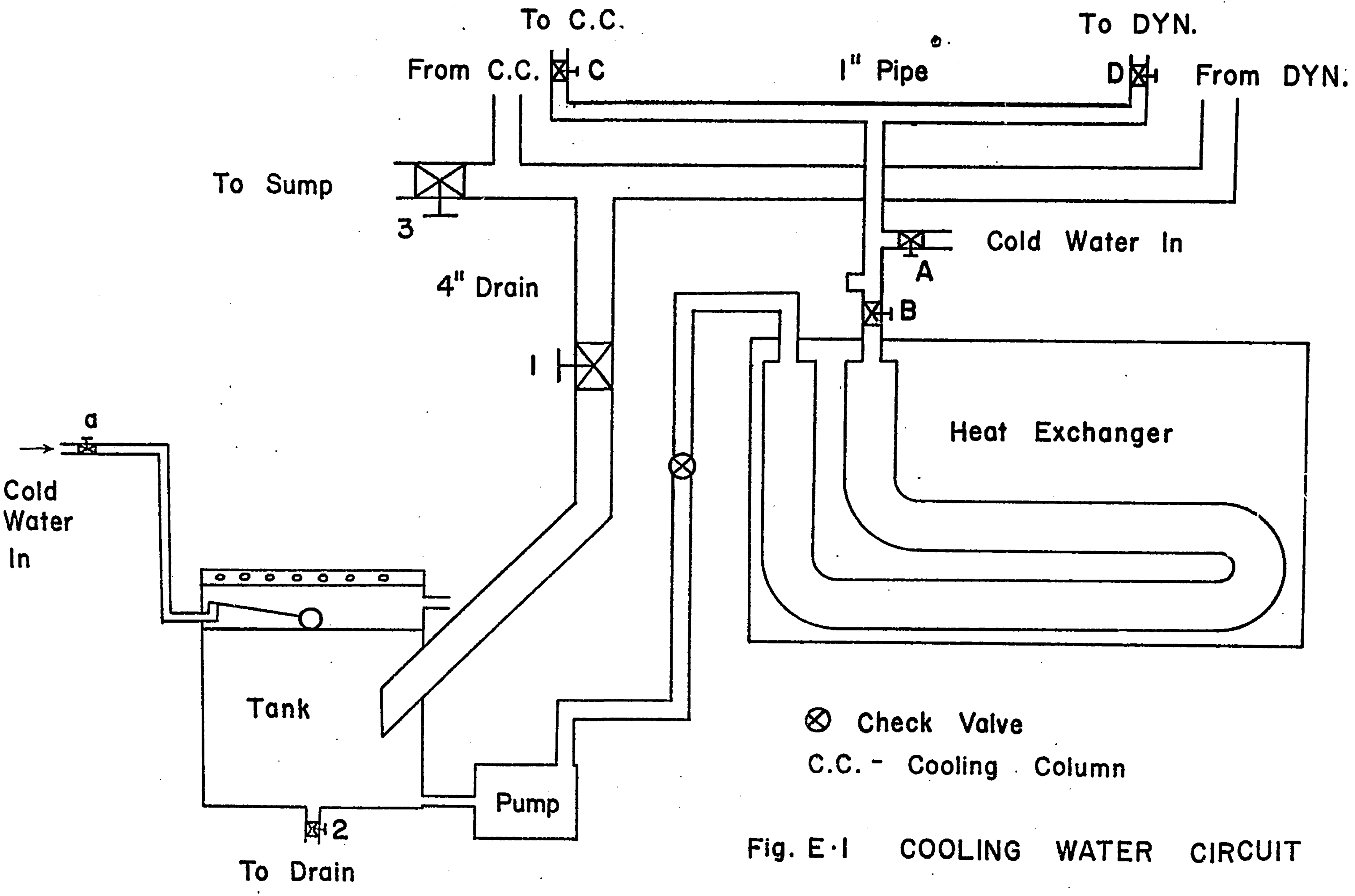
Operating Procedure

START-UP PROCEDURE:

1. Strain Gage indicator: Set at 'STAND-BY' and switch on power half an hour before engine start-up.
2. HC-CO Analysis Instrument: Switch on power and pump half an hour before engine start-up.
3. Cooling Water Circuit:
   - 3.1. If open-loop circuit is used:
     - 3.1.1. Drain valve: (Marked 3 in fig.E.1.) Open full. Close drain valve marked 1 in fig.E.1.
     - 3.1.2. Open cooling water valve (marked A in fig.E.1.)
   - 3.2. If closed-loop circuit is used:
     - 3.2.1. Drain valve: (Marked 1 in fig.E.1) open full Close drain valve marked 3 in fig.E.1.
     - 3.2.2. Tank: a) Close drain valve (marked 2 in fig.E.1), if necessary.

       b) Open make-up water supply valve (marked 'a' fig.E.1).
     - 3.2.3. Pump: When the tank is full, switch on power and start the pump. Open cooling water valve (marked B in fig.E.1)
4. Cooling Column: a) Turn the drain control knob (Refer fig.E.2) in clockwise direction until tube bottom touches the base; then turn control one full turn in counter-clockwise direction.

   b) Open water supply valve (marked C in



⊗ Check Valve

C.C. - Cooling Column

Fig. E·1 COOLING WATER CIRCUIT

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fig.E.1)

c) Turn the thermostat control (shown in fig.E.2) in clockwise direction until it is felt to be touching the thermostats. Turn 4 or 5 additional turns and allow the engine and cooling column to fill and water to stabilize. Turn control upward until stop nuts contact the bottom of the bridge.

5. Dynamometer: a) Open the water supply valve (marked D in fig.E.1).

b) Switch on power supply. Green light on the control panel marked 'A-C LINE ON' should light up.

6. Control Panel: a) Set the 'SPEED CONTROL' potentiometer to 100 and 'CURRENT CONTROL' potentiometer to zero.

b) Push the black button marked 'EXCITATION ON'. Another green light marked 'EXCITATION ON' should light up.

7. HC-CO Analysis Instrument: Calibrate.

8. Recorder: Switch on power and drive. Select the proper speed. Switch channels to 'MEASURE'.

9. Strain Gage Indicator: Switch to 'RUN'.

10. Engine: Turn the ignition key and start.

Engine could be loaded using either the 'SPEED CONTROL' or the 'CURRENT CONTROL' potentiometers.

11. Cooling Column: When the engine is operating, observe the temperature and water level. If the temperature

exceeds the desired high limit, open supply valve 'C' to make sure that the coolant supply is adequate. Operation at higher or lower temperatures could be achieved by turning the thermostat control counter-clockwise or clockwise respectively.

SHUT-DOWN PROCEDURE:

1. Control Panel: Set the 'SPEED CONTROL' potentiometer to 100 and 'CURRENT CONTROL' potentiometer to zero.
2. Engine: Operate at fast idle for 5 to 10 mins.; then switch off the ignition. Allow water to pass through the engine for 15 minutes.
3. Control Panel: Push the red button marked 'EXCITATION OFF'. The green light marked 'EXCITATION ON' should go out.
4. HC-CO Analysis Instrument: Switch off pump and power
5. Recorder: Switch channels to 'OFF'. Push the buttom marked 'DRIVE-FREE'. Paper should stop moving. Switch off drive and then the power.
6. Dynamometer: a) Switch off power supply. The green light marked 'A-C LINE ON' should go out.
   b) Close water inlet valve 'D'.
7. Cooling Water Circuit:
   7.1. If open-loop circuit is used: Close valve 'A'
   7.2. If closed-loop circuit is used: a) Close valve 'B'.
   b) Pump: Stop the pump and switch off power supply.
   c) Tank: Close make-up water valve 'a'. Open drain control valve '2', if necessary.

8. Cooling Column: Close valve 'C'. Turn drain control six to eight full turns in the counter-clockwise direction and allow the engine and cooling column to drain.
9. Strain Gage Indicator: Switch to 'STAND BY' and switch off power.

APPENDIX F

AIR FLOW MEASUREMENT

The air-fuel ratios caculated from air and fuel flow data were in the range of 8 to 11 while somewhat higher values from 9 to 15 would have been expected. Since the fuel flow meter was calibrated accurately, any error in air-fuel ratio calculation must have been due to error in air flow measurement. Such error might have been due to leakage in the hose connecting the drum to the air filter or between the lid and body of the air filter. In addition, the air flow meter could have been calibrated for test conditions of temperature and pressure.

Other methods for accurate air flow measurement:

(i) Critical flow nozzles: These are nozzles which have sonic velocity at the throat. By measuring the pressure upstream and downstream of the throat and using gas tables, air flow could be calculated accurately. Such a method reduces the effect of pressure fluctuation on the measurement but requires the use of some pressurising system.

(ii) Exhaust gas analysis: The results of an accurate exhaust gas analysis can be used as an indirect method of measuring air-fuel ratio. Using Orsat's apparatus or gas partitioner, the concentrations of CO_2, CO and O_2 are found. Knowing hydrogen to carbon atom ratio in the fuel, charts can be used to determine air-fuel ratio (20).