CHAPTER-IV

EXPERIMENTAL WORK AND FINDINGS

A project on environmental study of waste disposal was taken up in the Chemistry Department of Shivaji University for tne first time and as per our need special proto-type equipments were designed and fabricated by us. This chapter describes details of experimental method and the equipments designed, their working and results and discussion.

The municipal solid waste is heterogeneous in nature comprising paper, rags, vegetable and food discards, plastics, wood barks, animal excreta and all other sorts of waste materials. The bulk density of tne solid waste is very low and the particle size of the components is widely varied. To pyrolyze or disposal of solid waste it is better to grind it into powder by which more material can be accomodated in less space. The bulk density increases due to minimizing the voids.

Hetch et al.[1] nave discussed the pulverizing tecnnique to improve the quality of fuels derived from organic fractions of solids waste.

Brun et al.[2] have discussed the preparation of domestic waste for incineration, composting and disposal by selectively crushing the waste in an impact pulverizer.

In the view of ease of handling of the solid waste and preparation of briquettes for pyrolysis the solid wastes collected from

different parts of Kolhapur Municipal area are disintegrated in a disintegrator to a fine powder after removing the stones and metallic pieces present in the waste.

PART A : EQUIPMENTS

A.4.1.1 DISINTEGRATOR

Disintegrator is a unit of equipment which shatters the large pieces of materials into smaller ones by shearing and not by pounding. This is advantageous because even wet and moist materials can be disintegrated which is not possible in equipments using pounding technique. The photographs of the equipment are included as photograph No.1 and 2.

It is having a hollow rotary drum of 30 cm diameter made up of sheetmetal mounted on a steel shaft. The width of the rotor is 20 cm. The steel blades are of 12 cm length and 3.5 cm width with their side edges sharpened. These blades are welded to the surface of rotary drum radially at equal distance in two rows. The outer drum is a stationary and made up of sheet metal. The diameter of this stationary drum is 57 cm. The blades which are welded to the inner surface of this drum are of the same size as that of rotary drum blades. These blades are welded radially at equal distance in three rows. The side edges of these blades are also sharpened but in reverse direction, so that when the rotor rotates there will be shearing action on the solid waste caught between the blades. A clearance of two mm is provided between the blades errected on rotor and stator.

The stator is closed at one side by welding a circular plate of same diameter as that of stator drum. At the other end a circular sheet metal plate with a diameter 63 cm is fixed by nuts and bolts. There is arrangement to fix this lid to stator. In between the stator drum and lid a rubber gasket is fixed to prevent any leakage of material. This arrangement enables the cleaning of internal parts of disintegrator and for maintenance. To these circular side plates of stator are fixed bearing housings in which the ball bearings are housed. The main shaft carrying the rotor passes through these ball bearings.

A feed chute (with opening 9.5 cm x 5 cm) is provided radially in the surface at the top portion through which solid waste can be fed continuously and manually. At the bottom of the stator drum there is rectangular discharge hole (10 cm x 4 cm) which can be closed by a thin perforated metal plate to sieve out the powdered material.

At one end of the shaft, towards the fixed closure of stator, a coupling flange is mounted. This flange is coupled with a correspond ing flange mounted on motor shaft by four nuts and bolts with flexible coupling. The motor is of 0.5 H.P. capacity with a rotational speed of 1440 rpm. It is AC single phase induction type and is directly coupled.

Entire disintegrator is supported by L- shaped angular stru-
                    base frame
ctural steel and it is rigid enough to withstand the operational vibra
            ∧
tions. The motor is also mounted on the structural baseframe which is made as an integral part of the disintegrator baseframe so that there is proper alignment between the rotor and motor shafts.

A.4.1.2 OPERATION

Before disintegrating any batch of solid waste the interior of the disintegrator is cleaned well. The motor is switched on and the solid waste is fed through the feed chute. A small amount of waste is fed every time and allowed to become powder before next batch of waste is fed. The bigger components which cannot pass through chute hole should be cut into small pieces using shear. At the end of disintegration of a batch of solid waste the detachable lid is removed and any fibrous material which cannot pass through perforated discharge plate is removed and disintegrator is made ready to accept the next batch of solid waste.

A.4.2.1 BRIQUETTE PRESS

In any engineering project the involvement of powdery material is a great nuisance. The powders are difficult to handle, produce dust and clogging and take more time for precipitation. Eventhough grinding is used to prepare uniform sample the powdered material cannot be used further as such. The material can be compressed using hydrolic press to give suitable sized, rod like briquettes and this work can be conveniently prepared by a device called briquette press (Photograph No.3 and figure 4).

This consists of a steel case of 10.5 cm in height cylindrical in shape with inner diameter of 5 cm. The thickness of the steel case is 3 mm. This case has got a anvil stub at the bottom which can be secured to the base platform of the briquette press by nuts and bolts. A steel rod of diameter 5 cm and length 13 cm serves as plunger and

presses the material poured in the die (case) into briquettes. This plunger is fixed to a screw rod with acme threading which can be operated using a horizontal drive rod to impart verticle movement. The screw rod is accomodated in a culindrical casing which has got threading to suit the screw rod tnreading. This cylindrical casing is fixed firmly to the upper platform of the briquette press. Botn the upper and lower platforms made up of U- shaped angular structural steel are held together in position by guide rods. The platforms along with guide rods make tre main frame of oriquette press.

At the junction of plunger and screw rod a cylindrical neck is provided which enables the screw rod to rotate without rotating the plunger. To this neck a metalic plate is welded at tne both ends of which semicircular construction are present wnich slide over tne guide rods and restrict tne movement of plunger in vertical fashion only.

A rectangular groove is machined in the base of tne die to accomodate a rectangular metallic sliding strip. This strip consists of a circular hole which is larger in diameter than the plunger dia- meter. The base platform is also having a circular hole of size equal to that present in sliding strip.

A.4.2.2 OPERATION

The powdered waste is poured into briquette die keeping the sliding strip in position so that the die is closed from bottom. The plunger is lowered down into breiquette case and the material is pressed hard. This operation is done manually. When the briquette is

formed the sliding strip is moved so that the case opening, the holes in the sliding strip and platform are in alignment. Then the plunger is pushed down to oust the briquette formed through the bottom into a tray.

A.4.3.1 RETORT

The anaerobic distillation of the waste can be carried out in standard retorts prepared by machining cost iron master casting.

The retort is a cylindercal vessel made up of cast iron with a 13 cm height, 8.5 cm diameter and 3 mm wall thickness and having a torispherical bottom. It consists of a neck flange with a thickness 1.5 cm and 15 cm diameter. A lid made up of cast iron is also of 15 cm diameter, consists of a central hole of 1.25 cm diameter. A copper bent tube of length 75 cm (40 cm vertical, 35 cm inclined at an angle of 70°) is brazed in this hole of the lid which serves as outlet for the gas. Another copper tube of same diameter, length 10 cm with lower end closed is also brazed besides the central tube as shown in the figure 2. This serves as thermowell (Photograph No.4 and Figure 2).

The lid consists of a circumferential tongue of width 4 mm and the neck flange consists of a corresponding groove. Asbestos thread is packed in this groove which serves as a gasket and prevents the leakage of the gas. The lid can be secured to the retort vessel using machine nuts and bolts, in the holes provided circumferentially in the neck flange and lid at equal distance.

A.4.4.1 GAS HOLDER

The gas holders of various kinds were designed for collecting the pyrolysis gas. These are (1) Drum type gas holder (Photograph 5 and figure 1) and (2) Bottle gas holder.

The drum type gas holder is simple in construction having two cylindrical drums placed in one another and of volume approximately 25 L. These are made up of galvanised sheet. The inner drum is of size 28 cm in diameter and 30 cm height. It is inverted and to the wall of which four pulleys are fixed. These pulleys slide over the guide rods welded to the outer drum of size 40 cm height and 35 cm diameter. These guide rods assist in the vertical movement of the inner gas holder drum. Two bent copper tubes are fixed to the outer drum as shown in figure 1 which extend upto the base of the inner drum. Taps are provided at the ends of copper tubes. These copper tubes serve as inlet and outlet for gas. The water is poured into the gas holder until the water level touches the base of inner drum so that no air is trapped inside the drum. The water serves as liquid seal. An indicator point is fixed to the outer drum and a calibrated scale, in volume, is fixed to the inner drum by which one can read the volume of gas collected in the drum.

While collecting the gas the inner drum is lowered till water level touches its base and drum rests on the tips of copper tubes. It should be ensured the no air is trapped inside the drum. By closing the tap of one copper outlet and connecting the another copper tube to the gas outlet of condenser bulb, the gas can be easily collected.

As the gas collects in the inner drum it rises vertically and indicates the amount of gas collected.

A.4.4.2 BOTTLE GAS HOLDER

The gas holder previously explained is not used because of the small size of charge. An alternative arrangement, a gas holder made from Aspirator bottle is used. This also helps to collect the gas at atmospheric pressure and temperature (Figure No. 3)

The gas holder is an Aspiratory bottle of 13 L capacity. It is fitted with a cork with a central hole. A tubular arrangement, comprising of two concentric tubes is fixed in the cork and tightly secured. The outer glass tube serves as gas inlet which ends at the lower end of cork. The other glass tubing which is smaller in diameter than the first one runs upto the bottom of the gas holder. This serves as outlet for water which is displaced by incoming gas. It can also be used to fill up the gas holder with water wnile displacing the gas. A flexible rubber tubing is fixed to the open end of this inner glass tube. This rubber tube facilitates in adjusting the height of discharge end to maintain atmospheric pressure conditions during the gas colle- ction. The gas holder is graduated in markings of quarter of a litre.

A.4.5 BHASKARE'S CALORIMETER

This is a suitable equipment meant for measuring the calori- fic valve of a gas. It is fabricated using two copper calorimeters of different sizes. The larger calorimeter is of height 10 cm and diameter 7.5 cm at the base of which a circular hole of 5 cm is made. Another calorimeter of diameter 5 cm and height of 6 cm is brazed to

the larger calorimeter with its base upwards as shown in the figure 5. The base of inner calorimeter is having a hole of 1.9 cm in which a copper tube of same diameter and length 12 cm is brazed which serves as chimney. To the inner wall of the inner calorimeter a conical spiral copper coil of 2 mm diameter is brazed in such a fashion that the ends of coil open into the annular space between the two calorimeters. The water taken in the calorimeter flows through this coil from bottom to top due to the natural convection currents induced by buoyancy forces and helps in absorbing the heat efficiently. A thin copper foil is also brazed horizontally to the coil to distract the hot gases and to distribute the heat energy of flame. Water taken in the calorimeter occupies the annular space between the two calorimeters and absorbs the heat energy. The amount of water taken should be sufficient enough to submerge the inner calorimeter.

A thin copper wire stirrer is provided for the agitatiion of water. A ring shaped fibre sheet cover with holes to accomodate stirrer and thermometer serves as lid. The thermometer used is of range 0-100°C with graduations in 0.2°C.

PART B : METHODOLOGY

B.4.1 Sampling

The powdered material obtained in the disintegrator is free flowing in nature. The colour is brownish black. While taking 200 g of powdered solid waste, the CONE & QUADRANT technique of sampling is used to get true representation of entire amount in a batch.

The powdered solid waste is intimately mixed to get the uniformity in composition. It is poured in the form of a cone. This cone is divided into four equal quadrant bisecting the apex. One quadrant portion of the material is taken and three quadrants rejected The procedure of pouring into cone and making quadrants is repeated, till required amount of charge is obtained. The same sampling technique is adopted to all the batches of powdered solid waste.

B.4.2 Screening Analysis

200 g of powdered material is taken from each batch of waste. It is analyzed for particle size distribution using Indian Standard screens of mesh size 4.75 mm, 2.36 mm, 1.18 mm, and 1.0 mm alongwith pan. The 200 g of material is poured on the top screens arranged in their decreasing order of mesh size. This entire stack is mounted on a gyrating shaking machine to impart gyrating motion on horizontal plane on a verticle axis. The different fractions of the powdery material, according to size distributiion in weight percent is given in the table No. 4.1. The particles with dimensions greater than 4.75 mm screen opening are mostly fibrous in nature which do not pass through screen opening by gyrating action . This fraction forms very less percentage compared with finer powdery material.

B.4.3 Production of Gas

B.4.3.1 Experimental set up

200 g of powdered solid waste is charged into retort in the form of briquettes. Asbestos is packed in the groove of the neck flange of the retort. The lid is tightly secured to the retort with nuts and bolts. The retort is placed in the muffle furnace.

At the open end of the copper gas outlet a cork is fixed as a collar. This serves to fix the condenser to the copper tube tightly. The condenser is of 35 cm length with water circulated outer jacket. At the discharge end of the condenser is a bulb of volume 60-75 ml. This bulb consists of two tubular outlets. The tubular outlet facing downwards serves as a condensate outlet, to which a rubber tubing is fixed and closed tight with a screw type pintch cork, during collection of gas. Tne other tubular outlet is connected to a gas holder using a flexible rubber tubing as shown in the figure 6.

B.4.3.2 Gas Collection

After charging 200 g of powdered solid waste in the retort, the retort, condenser and the gas holder are interconnected as shown in the figure 6 . The water is circulated in the outer jacket of the condenser to condense any condensable components of pyrolysis gas, and to reduce the temperature of the gas to room temperature. All the joints are leakproof. Before starting of heating the retort , tne gas nolder is filled with water upto its brim, and it is ensured that no air is trapped inside the gas holder.

A cromel-alumel thermocouple is placed in side the thermowell provided in the lid so that the junction of thermocouple touches the bottom of thermowell. The terminal of the thermocouple are connected to a pyrometer (Galenkamp- range 0-1200°C, graduation in 20°C) to read the temperature of the gas production.

The furnace is switched on. Throughout tne heating the water circulation in the condenser is maintained. As tne pressure builds up

in the retort due to production of pyrolysis gas it rushes through the condenser where all the condensable components of gas condense •and noncondensable gases collect in the gas holder by displacement of water. Frequently the flexible outlet of the gas holder is lowered so that the pyrolysis gas is collected at atmospheric conditions. This flexible water outlet should never be lowered below the water level in the gas holder.

The heating is continued till the maximum possible temperature is reached in the retort. When the evolution of the gas stops, the furnace is switched off. The maximum temperature reached in the retort and the volume of gas collected in the gas holder are noted. The gas holder is disconnected and closed air tight.

The condensate collected in the condenser bulb is quantitatively collected in separate dry and clean bottles. The retort is removed from the furnace, cooled to room temperature. The residue present in the retort is quantitatively collected and weighed.

B.4.4 Calorific Value of Gas

B.4.4.1 Experimental set up

Since the pyrolysis gas is collected over water any water soluble components of gas, if present in gas will dissolve in water. Sufficient time is allowed for this purpose before measuring the volume of insoluble components of gas.

The water outlet is connected to a water tap. A flexible rubber tubing is fixed to the gas inlet, at the other end of which a small burner is connected. This burner is placed directly below the

calorimeter. The calorimeter is filled with 200 ml of water. The initial temperature t_1 of water and the calorimeter is noted. The tap water is allowed at moderate flow rates into gas holder to displace the pyrolysis gas. The burner is lit, and the two litres of gas is burnt. While the gas is burnt the water in calorimeter is stirred thoroughly to assist the efficient absorption of heat (Figure 7).

After 2 litre of gas is burnt the burner is removed and the tap water is stopped. The maximum temperature attained by calorimeter and the water i.e. t_2 is noted. The same procedure is repeated to obtain concordent readings.

B.4.4.2 Water Equivalent of Calorimeter (E)

The calorimeter is filled with water and the temperature of water and calorimeter t_3 is noted. After removing this water 200 ml of water at 50°C (t_4) is poured into calorimeter and stirred well till thermal equilibrium between the water and the calorimeter is attained. The final temperature of water and calorimeter t_5 is noted. The water equivalent of calorimeter in g is calculated using the formula

$$E = \frac{200\ (t_4 - t_5)}{(t_5 - t_3)} \qquad \qquad \dots (1)$$

The procedure is repeated for concordant readings. The water equivalent (E) of calorimeter obtained is 44.554 g.

B.4.4.3 Calorific value of Gas

The calorific value of gas in $kJ - m^{-3}$ is calculated by using the formula

$$\frac{(W+E)\ (t_2 - t_1)4.184}{2} = H,\ kJ\ m^{-3} \qquad \qquad \dots (2)$$

where H = Calorific value of gas, $kJ - m^{-3}$

W = Weight of water taken in calorimeter, g

E = Water equivalent of calorimeter, g (44.554 g)

t_2 = Final temperature of water and calorimeter, °C

t_1 = Initial temperature of water and calorimeter, °C

The maximum temperature attained by retort during the gas production, volume of gas collected, amount of residue, weight of condensate collected and the calorific value of gas are listed in the table 4.2.

B.4.5 ANALYSIS OF GAS

B.4.5.1 Experimental set up

The experimental arrangement for the qualitative analysis of gas by Orsat[3] is as shown in figure 8. It consists of a graduated glass burette 'B' of 100 ml capacity with two capillary outlets on both the sides. The lower capillary outlet is attached to an aspirator bottle 'A' of 500 ml capacity by a flexible rubber tube. The upper capillary outlet is connected to a three way glass stopper 'C'. One of the capillary connections of stopper is connected to Orsat gas pipette filled with absorbent solution 'D' as shown in figure. 8. The Orsat gas pipette contains several thin glass tubes to increase the surface of contact between the absorbent solution and the gas. Other capillary connection of glass stopper is connected to gas holder whenever the gas is sucked into graduated burette for analysis.

B.4.5.2 Procedure

The aspirator bottle is filled with water. It is raised to a level above the point E so that the graduated burette is filled with

water upto mark E expelling the air. Now the three way stopper is connected to gas holder and tne aspirator bottle is lowered below the marking F so that the water level in the burette receeds sucking the gas. The gas holder is disconnected and the water level in the burette is adjusted to mark F. The stopper is closed to gas holder capillary and it is opened to gas pipette containing 50% solution of potassium hydroxide. Keeping the stopper open to pipette tne aspirator bottle is raised so that the gas rushes into solution container in whicn CO_2 is absorbed. The aspirator bottle is raised and lowered cautiously several time so that gas shall come in contact with KOH solution intimately and all the CO_2 present in pyrolysis gas is absorbed efficiently. As soon as all the CO_2 present in pyrolysis gas is absorbed wnich is indicated by no change in water level in graduated burette, KOH solution in both tne bulbs is brought to tne same level, mark G, and tne stopper is closed to tne pipette. Then tne level of aspirator bottle is adjusted so that levels of water in bottle A and B are same, ensuring measurement of gas at atmospheric pressure. From this, amount of CO_2 present in 100 ml of pyrolysis gas as indicated by the rise in water level from mark F to present level in the burette is noted. The procedure is reported by taking fresh 100 ml of pyrolysis gas from each batch to get the concordent readings.

Similar procedure is followed by taking ammoniacal cuprous chloride solution in the Orsat gas pipette whicn absorbs both the carbon dioxide and carbon monoxide present in pyrolysis gas. The difference between the readings with KOH and ammonical cuprous chloride solutions gives the amount of carbon monoxide present in pyrolysis gas. The volume is converted to NTP after accounting for the aqueous tension and the results are tabulated in Table 4.3.

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B.4.6 THERMOGRAMETRIC ANALYSIS

B.4.6.1 Experimental set up

This consists of a Chenomatic balance placed on a wooden chamber. To the bottom of the left pan of the balance, a small hook is soldered. A steel pan of 5 cm diameter with a depth of 4 mm is hung to this hook using a metal wire which passes through the hole made in wooden chamber just below the left pan of balance. The steel pan is hung in such a way that it freely suspends in the hot zone of the furnace placed inside the wooden chamber, as shown in the figure 9. A cromel-alumel thermocouple junction is placed inside the furnace to measure the temperature the terminals of which are connected to a pyrometer of range 0-1220°C with graduation in 20°C.

B.4.6.2 Procedure

The steel pan is hung and its weight is accurately recorded. A representative sample of 6 to 8 g of powdered solid waste is taken in the steel pan and its initial weight is accurately recorded. The furnace is switched on. The initital temperature is noted. As the temperature in the furnace rises, at a span of 20°C increase in temperature, the weight of solid waste with pan is accurately recorded. The rate of increase of temperature is 10°C per 3 minutes. The measure ments are recorded over a temperature range of 27-720°C.

A few representative thermograms in percentage weight loss and weight against temperature in °C are given in figures 10-13.

PART : C

C.4 RESULTS AND DISCUSSIONS

The waste is analysed with a view to give us information regarding the following points.

C.4.1 Pyrolysis

(1) To know the nature of pyrolysis products by carrying out anaerobic distillation. Here oxidation of carbonaceous matter is ristricted and the organic component produces the degradation products which range in volatility. Some quantity of low molecular weight combustible gases, water vapour originating from the dehydration of the charge as well as the breakdown component in the thermal degradation, CO_2 from carbonates resulting from partial combustion, a variety of liquids giving tarry chacolate brown viscous mass are present.

(2) The residue left in the retort which is almost black in colour. Since enough of oxygen is not available non-volatile carbonaceous residue resulting from the thermal degradation is retained along with other nonvolatile materials like sand, clay, grit, glass, metal pieces and otner inert material. Althougn distillation process cannot further yield any combustible carbonaceous gas or liquid it is not totally unavailable and can still be useful constituent for further processing by using alternative utilization techniques.

(3) The pyrolysis process must be assessed by knowing the available gaseous fuel from pyrolysis, the pyrolingeous acid as a source of organic chemicals, mainly polyphenols, and the residue as

building material, material for preparing bricks, and road making and finally the landfill. Of these uses of solid residue, the use for mixing with clay to give good quality mud in low cost housing needs careful exploration. The residue is granular and their holding capacity may be poor, but addition of fibrous material like waste coir may give good strength. Use in road making after carefully sieveing off of glass and metal also needs further study. The pyrolyzed residues c mixed with asphalt in forming top layer in the road making by spread ing it over the road for subsequent spray with molten asphalt may prove advantageous. The pyrolysis products generally do not form plastic clays on waiting and hence the residues are suitable for the above two uses. The landfill is of course a somewhat wasteful proposition and material suitable for other applications should not merely be used for landfill purposes. The advantages which are obvious in the landfill usage are (a) the residues are compact and therefore the filling is also compact and no shrinking of layers is possible, (b) all the organic material has been removed and therefore further degradation by decay is not possible, and (c) the process of landfill by dumping and pounding will give compact filling.

The disadvantages in pyrolysis process are the expenditure on fuel for heating the retort which may in unfavourable conditions not be economical. Even to use part of waste as a source for heat for this purpose is wasteful.

For the study of pyrolysis of Kolhapur Municipal solid waste an experimental set up was prepared which consisted of cast iron retort which can be heated by aetna lamps or an electric muffle

furnace. The temperature of the charge in the retort is measured by a cromel-alumel thermocouple connected to pyrometer. The outlet tube of retort is connected to water cooled condenser which has two outlets one giving condensed liquid by downward flow in a receiver and upward flow of gases. Since moisture and the constitutional water present in all biological residues are distilled off the condensate contains large quantity of water which is decanted off. The heating of the retort is continued upto around 360-400°C, and the resulting water-free pyroligneous component and volume of gases are noted down. This way all the samples were studied. The left over carbon was estimated by anaerobic combustion at a still higher temperature in the free access to air and from it the total fuel value of the waste was worked out. Since pyroligneous acid is valuable component and a source of organic compounds it was not assessed as a fuel. We have not in this project tackled the topic of complete analysis of pyroligneous acid. The results of pyrolysis are given in Table 4.2.

The pyrolysis gas that obtained by pyrolysis of solid waste is analysed by using Orsat method[3] for its CO_2 and CO content. The absorption in alkali solution gave the amount of CO_2 and on repeating the experiments with sample of gas with alkaline cuprous chloride as absorbent the loss observed is due to CO_2 and CO. From this measurement estimatiion of CO is done. Results of all these measurements are given in Table 4.3. The gases collected in gas holders were lead to a gas combustion calorimeter and the calorific value per unit volume (say m^3) of gas were calculated. The design of calorimeter has many advantages. The heat is effectively collected by the copper coil and

quickly transmitted by upwaerd motion of water. This has added advantage that the water in coil is constantly renewed, as it is at lower temperature. Even after heating the temperature is not significantly high thereby minimizing the radiation heat loss. The automatic circulation of water helps precision measurement of the total heat transferred. In this measurement radiation correction is not applied and thus the experimentally estimated calorific value as entered in last column of Table 4.2 are slight underestimates but this should be taken as an inevitable loss factor at any stage of operation.

The analysis of gas produced by pyrolysis of powdered solid waste in presence of limited amount of air which has been trapped in the retort shows that the amount of CO_2 produced is more ranging from 28%-52% by volume of tne total gas produced from a batch. In most of the cases the CO_2 percentage is in the vicinity of 38-40% by volume. This excessive percentage of carbon dioxide gas can be attributed to combustion of carboneous materials in an exothermic reaction at the temperature of pyrolysis conducted. Tne formation of CO would have been favoured if tne pyrolysis is conducted at elevated temperatures and with the air shut off to enhance the reaction between CO_2 and the residual carboneous matter.

The calorific value of pyrolysis gas estimated are ranging from 6200 to 7500 kJ m^{-3} in majority of cases. The amount of heat that is contributed by combustion of CO gas fraction to the total calorific value is nearly 30-45% indicating that tne remaining amount of heat that constitutes the total calorific value of pyrolysis gas is contributed by combustible gases which form 32-50% by volume of total gas.

The amount of residual combustible char present in tne pyrolysis residue ranges from 5.78 to 22.13% by weight of powdered solid waste. This combustible char is mostly low density charcoal and it would have contributed either to organic condensate or to pyrolysis gas that has been produced if the pyrolysis temperature is higher than 350°C.

The organic condensate obtained in the pyrolysis of powdered solid waste forms a substantial fraction of the pyrolytic products. The amount of condensate obtained in the temperature range 0-350°C is from 4.8% to 18.81% by weight of solid waste with 35% of the cases yielding condensate above 10% by weight of solid waste pyrolyzed.

There is no correlation between the amount of gas produced and the compositioin of the solid waste. This may be ascribed to the fact that the composition of unclassified fines which forms 20-60% by weight of solid waste (composition expressed after removal of metals and stones) with respect to its combustible fraction content is not clearly ascertained. In majority of cases, more than 70%, the gas obtained is above 9 L and in the range of 9-12.25L from 200 g of powdered solid waste pyrolyzed. In the remaining cases the amount of gas produced is falling in the range 4.25 to 9 L per 200 g of solid waste.

Also it is not possible to bring any correlation between the amount of gas produced and the temperature of pyrolysis. The variation in pyrolysis temperature among different batches of solid waste is only 90°C.

C.4.2 THERMOGRAVIMETRIC ANALYSIS

The aerobic thermolysis was studied by using a thermal balance consisting of a Chainomatic balance having a facility of weighing below the balance. A stainless steel pan was freely suspended from the arm of the balance into the verticle cylindrical muffle furnace. There was free access to air and therefore all the changes at the corresponding temperature were of the nature of complete combustion. This did not leave any carbonaceous residue and the thermograms can be analyzed in terms of initial loss of volatile matter and moisture upto 110°C followed by a continuous loss of weight due to the organic constituents. At $\curvearrowright$275°C the mass catches fire and burns vigorously with the evolution of smoky fumes. This is a major loss in weight. Due to low temperature firing at 300°C material chars and the charred carbon very slowly reacts with oxygen over a temperature range of 325–540°C. There is no further significant change in weight indicating that entire combustible matter is fully utilized which is obvious from inspection of residue which is slightly reddish white in appearance with a faint brick red tinge. The thermograms of four representative samples are given in figures 10–13, and the observations are entered in tables 4.4 – 4.23.

The thermograms obtained have four distinct segments representing different thermal changes. Depending on the temperature range of different segments the thermograms are classified broadly into four major categories. The variation in transition temperature in different categories is small.

Group A : Batch Nos. 1, 4, 7, 10, 15, 16 and 19.

Group B : Batch Nos. 8, 17 and 18.

Group C : Batch Nos. 2, 11, 13, 14 and 20.

Group D : Batch Nos. 3, 5, 6, 9 and 12.

C.4.2.1 Group A : The thermogram of this group has four segments. The first segment extends upto 260°C. This first segment is divided into two portions of temperature ranges 0–120°C and 120–260°C. The first portion of the segment represents the moisture loss from the powdered waste. The moisture content of the solid waste for this group ranges from 1.738% to 5.402% by weight of powdered sample. The second portion represents the vapourization of volatile matter other than free moisture and is predominent and accounts for 5.15% to 15.93% by weight of solid waste.

The second segment spaning over only 20–40°C between 260–300°C represents the rapid loss of organic components characterised by evolutioin of smoky fumes. The amount of combustible components undergo expulsion in this region is approximately 50% of the total combustible material (10–30% by weight of powdered solid waste).

The third segment is concave downwards and represents the slow combustion of the leftover combustibles over a relatively larger tempe rature range of 300–520°C. The percentage weight loss due to slow combustion under this segment is ranging from 5.75 to 11.64% by weight of solid waste. This segment is marked by very less or absence of smoky fumes.

The fourth segment represents almost inertness of the residue to thermal treatment. The percentage weight loss is 0.8–1.2% by weight

solid waste over the temperature range 520-660°C. This segment is almost horizontal in nature. Above the temperature 660°C the termo-

• grams show bends slightly upward indicating the decomposition of

carbonates present the residue.
in
4

C.4.2.2 Group B : The thermograms are similar to the previous ones except for their transition temperature range. The first segment is spaning over 0-320°C. The moisture content of solid wastes in this group represented by loss of weight between 0-120°C is ranging from 3.7 to 8.34%. The vapourization of volatile matters is indicated by slow reduction in weight of sample over the temperature range 120-320°C. The loss in weight is ranging from 13.62 to 15.11% by weight of powdered solid. But from the amount of organic condensate collected from these batches of solid waste during pyrolysis is less in comparison with amount of volatile matter vapourization indicating that the combustion of the combustible matter starts earlier than 320°C. This is also supported by larger volumes of pyrolysis gas produced during pyrolysis of waste from these batches (11.25-12.25 L) for charge of 200 g.

The combustion of organic matter as indicated by drastic change in the weight of sample with production of smoky fumes, is between 320-340°C. The weight loss is 9.9-11.1% by weight of solid waste. Above 340°C the combustion of organic matter slows down and the weight of waste that is lost at 340-640°C is ranging from 9.13 to 12.61% by weight of solid waste. The combustion nearly ceases at 640°C.

In segment 4, above the temperature 560-640°C the change in the weight is 0.95-1.00% by weight of solid waste.

C.4.2.3 <u>Group C</u> : The moisture content of the solid waste in this group of solid wastes between the temperature 0-120°C is 9.26 to 17.65% by weight of solid waste. The amount of volatile matter as indicated by the loss in weight between 120-220°C is relatively less, ranging from 1.1 to 7.30% by weight of solid waste.

The rapid evaporation of organic content of solid waste is taking place in the narrow temperature range 220-240°C, represented by the nearly verticle line in the thermogram i.e., second segment. The weight loss is 9.9 to 13.52% by weight of solid waste.

The slow combustion of combustible matter is taking place between 240 to 500°C with change in weight ranging from 8.33 to 11.33% by weight of solid waste. The amount of solid waste that has been consumed during rapid combustion is nearly equal to that amount consumed in slow combustion.

The fourth segment represented in the thermogram is nearly horizontal in nature representing the inert compounds which are less prone to thermal treatment. Though temperature change is from 500 to 660°C and above the change in weight is only 1.01 to 1.37% by weight of solid waste.

C.4.2.4 <u>Group D</u> : This group of solid waste is characterised by relatively low moisture content, and volatile and combustible matter. The first segment indicating the moisture content and volatile matter spans upto 280°C with moisture content ranging from 1.26 to 2.65% and volatile matter ranging from 3.59 to 10.00% by weight of solid waste.
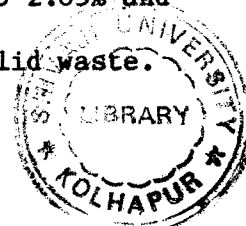
The second segment indicates the rapid combustion of organic matter over a very short temperature change of 20°C from 280°C to 300°C. The weight loss is ranging from 7.56 to 9.48% by weight of solid waste.

The third segment of these thermograms span over a temperature range 300–520°C with a weight loss of 7.18 to 11.16% by weight of solid waste.

The fourth segment of thermograms is spanning over a temperature change of 140° from 520 to 660°C with the weight loss ranging from 0.77 to 3.63% by weight of solid waste.

C.4.3 AMOUNT OF GAS, CHAR AND ORGANIC CONDENSATE THAT CAN BE OBTAINED FROM ENTIRE KOLHAPUR MUNICIPAL AREA

The amount of solid waste produced from each division (according to Map 2) is approximately 6 metric tons per day. Based on this amount of solid waste the amount of pyrolysis gas, char and organic condensate can be calculated.

C.4.3.1 Pyrolysis gas

The amount of pyrolysis gas that can be obtained by the pyrolysis of solid waste collected in any area varies from 127.5 m^3 to 367.5 m^3 per day. The calorific value of the gas is also varying from 5600 kJ-m^3 to 8600 kJ-m^3. The total amount of pyrolysis gas that can be obtained from the solid waste produced in entire Kolhapur Municipal

area per day is 5640 m^3. The heat that can be derived from the burning of this is 405,59,060 kJ–day^{-1}. This is very insignificant compared with the total amount of waste that is produced, representing only 338 kJ kg^{-1} of solid waste.

The amount of stones and metal that were present in total solid waste produced per day in Kolhapur municipal area is around 16 metric tons. Thus the amount of solid waste that can be subjected to pyrolysis is only 104 metric tons per day.

As revealed by the thermogravimetric analysis the inert residue is 78.5 metric tons per day. Thus the amount of solid waste that is prone to thermal pyrolysis system is only 25.5 metric tons per day.

C.4.3..2 Char

The amount of char that can be obtained from each area varies from 193.5 kg to 1327.85 kg per day. The total amount of char that can be obtained from pyrolysis of solid waste produced in entire Kolhapur municiple area amounts to 11.602 metric tons per day. If all this amount, assuming it as completely carbon, is utilized in the production of CO by pyrolysis it would give 21670 m^3 of CO per day with a heating value of 25,50,00,000 kJ. Thus, the char forms the potential source of energy which is untapped.

Thus total energy that can be obtained by char (in the form of CO) and pyrolysis gas is 29,55,59,060 kJ day^{-1}, and a kilogram of solid waste produces 2462.99 kJ of heat apart from the organic condensate that is produced.

C.4.3.3 Organic condensate

The organic condensate that is available from each area varies from 147.9 kg to 1030.8 kg per day. The total amount of organic condensate that can be obtained from entire solid waste produced from Kolhapur municipal area is around 9.655 metric tons per day. This is a chief source of raw materials for many organic compounds like pnenols and cresols.

C.4.3.4 Inert residue

If the pyrolysis is efficient to convert all the carboneous material present in the solid waste into the gas and organic condensate, as revealed by the thermogravimetric analysis, the amount of residue available is enormous.The percentage of residue that is available from different areas varies from 51.475 to 80.797% by weight of solid waste. The amount of residue available from the entire Kolhapur Municipal solid waste is around 78.5 metric tons per day. This residue may prove beneficial as source of metals or as a building material.

Table 4.1 : Screening Analysis of Powdered Solid Waste (Wt.%)

Batch No.	Mesh size				
	Pan-1.0 mm	1.0-1.18 mm	1.18-2.36 mm	2.36-4.75 mm	4.75 mm and above
1	71.0	7.5	11	4	6.5
2	82.0	2.5	9.5	3.5	2.5
3	90.5	2.0	4.0	2.0	1.5
4	85.5	1.0	7.5	2.0	4.0
5	86.0	1.5	7.5	2.5	2.5
6	86.5	1.5	5.5	3.0	3.5
7	88.0	1.0	8.5	1.5	1.0
8	67.0	7.0	15.0	6.0	5.0
9	88.5	1.5	7.0	2.0	1.0
10	90.0	1.5	5.5	1.5	1.5
11	86.5	2.0	6.5	2.5	2.5
12	86.5	3.0	6.0	2.0	2.5
13	81.0	2.5	10.0	4.0	2.5
14	85.5	2.0	7.0	2.5	3.0
15	84.5	1.5	8.5	2.5	3.0
16	90.0	1.0	3.0	2.0	4.0
17	78.0	3.5	10.0	3.5	5.0
18	84.5	2.5	4.0	2.0	2.0
19	73.5	3.0	11.0	5.5	7.0
20	80.5	4.0	7.0	2.5	6.0

Table 4.2 : Data of Pyrolysis of Solid Waste

Batch No.	Maximum Tempera- ture °C	Volume of gas collected L	Amount of Residue g	Amount of Condensate g	Calorific value of Gas $kJ - m^{-3}$
1	350	9.75	138	45	7060.16
2	390	11.50	150	30	6650.88
3	350	7.50	173	16	5627.64
4	350	10.00	149	28	8594.98
5	460	11.25	157	23	7060.16
6	350	6.50	179	19	6446.24
7	400	6.00	164	28	6855.52
8	350	11.25	133	16	6753.18
9	350	5.75	163	20	6241.56
10	350	8.25	160	26	6343.90
11	350	9.00	148	42	6548.54
12	350	10.75	152	28	7878.72
13	350	9.50	115	52	6957.82
14	350	9.50	146	38	6753.18
15	430	12.25	148	36	8083.36
16	400	4.25	168	16	7264.80
17	380	11.25	134	40	7571.74
18	400	12.00	138	40	7776.42
19	400	10.25	143	26	8390.34
20	350	11.50	146	36	7264.80

Table 4.3 : Data of Analysis of Pyrolysis Gas

Batch No.	Maximum Tempera- ture °C	Volume of gas collected L	CO_2 (% vol)	CO (% vol)
1	350	9.75	40	25
2	390	11.50	40	15
3	350	7.50	37	13
4	350	10.00	42	23
5	460	11.25	38	18
6	350	6.50	28	22
7	400	6.00	40	17
8	350	11.25	52	16
9	350	5.75	43	14
10	350	8.25	30	18
11	350	9.00	32	20
12	350	10.75	43	19
13	350	9.50	42	20
14	350	9.50	40	20
15	430	12.25	42	24
16	400	4.25	38	22
17	380	11.25	40	19
18	400	12.00	42	23
19	400	10.25	40	18
20	350	11.50	46	13

Table 4.4 :   TGA data (Batch 1)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	5.7476	0	380	3.2313	43.78
40	5.7418	0.10	400	3.1732	44.79
60	5.7002	0.82	420	3.1367	45.42
80	5.6614	1.49	440	3.0849	46.32
100	5.6025	2.52	460	3.0462	47.00
120	5.5354	3.69	480	3.0004	47.79
140	5.4418	5.32	500	2.9653	48.40
160	5.3430	7.03	520	2.9404	48.84
180	5.1184	10.94	540	2.9330	48.97
200	4.9236	14.33	560	2.9271	49.07
220	4.7358	17.60	580	2.9240	49.12
240	4.6807	18.56	600	2.9178	49.23
260	4.6200	19.61	620	2.9151	49.28
280	3.5249	38.67	640	2.9043	49.46
300	3.4647	39.71	660	2.8916	49.69
320	3.4111	40.65	680	2.8747	49.98
340	3.3573	41.58	700	2.8479	50.45
360	3.2909	42.74	720	2.8364	50.65

Table 4.5 : TGA data (Batch 2)

Temperature °C	Weight of sample g	Percent weight loss	Temperature °C	Weight of sample g	Percent weight loss
27	5.2813	0	380	3.6431	31.01
40	5.2806	0.01	400	3.6151	31.54
60	5.2168	1.22	420	3.5948	31.93
80	4.4904	5.50	440	3.5566	32.65
100	4.7865	9.36	460	3.5416	32.94
120	4.7716	9.65	480	3.5280	33.19
140	4.7636	9.80	500	3.5167	33.41
160	4.7472	10.11	520	3.5141	33.46
180	4.7358	10.32	540	3.5063	33.60
200	4.6964	11.07	560	3.4972	33.78
220	4.6805	11.37	580	3.4873	33.96
240	4.0261	23.76	600	3.4835	34.04
260	3.9204	25.76	620	3.4697	34.30
280	3.8770	26.59	640	3.4663	34.36
300	3.8172	27.72	660	3.4555	34.57
320	3.7804	28.42	680	3.4230	35.18
340	3.7241	29.48	700	3.3876	35.85
360	3.6844	30.23	720	3.3752	36.09

Table 4.6 : TGA data (Batch 3)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	5.2586	0	380	4.4497	15.38
40	5.2586	0	400	4.4008	16.31
60	5.2573	0.02	420	4.3687	16.92
80	5.2469	0.22	440	4.3533	17.21
100	5.2313	0.51	460	4.3302	17.65
120	5.1827	1.44	480	4.2743	18.71
140	5.1438	2.18	500	4.2316	19.52
160	5.1125	2.77	520	4.1917	20.28
180	5.0727	3.53	540	4.1842	20.43
200	5.0261	4.42	560	4.1677	20.74
220	5.0055	4.81	580	4.1578	20.93
240	5.9968	4.97	600	4.1485	21.11
260	4.9891	5.12	620	4.1401	21.26
280	4.9669	5.54	640	4.1264	21.53
300	4.5693	13.10	660	4.1056	21.92
320	4.5267	13.91	680	3.9090	25.66
340	4.5065	14.30	700	3.8987	25.86
360	4.4736	14.92	720	3.8831	26.15

Table 4.7 : TGA data (Batch 4)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	7.2600	0	380	5.3852	25.82
40	7.2417	0.25	400	5.3418	26.42
60	7.2207	0.54	420	5.2781	27.29
80	7.1519	1.48	440	5.2085	28.25
100	7.0469	2.93	460	5.1431	29.15
120	6.8678	5.40	480	5.0788	30.04
140	6.8268	5.96	500	5.0545	30.37
160	6.6907	7.84	520	5.0440	30.52
180	6.5896	9.23	540	5.0339	30.66
200	6.5286	10.07	560	5.0279	30.74
220	6.4981	10.49	580	5.0205	30.84
240	6.4793	10.75	600	5.0170	30.89
260	6.3851	12.05	620	5.0014	31.11
280	6.0564	16.57	640	4.9888	31.28
300	5.7283	21.09	660	4.9755	31.46
320	5.6451	22.24	680	4.9528	31.77
340	5.5635	23.36	700	4.9314	32.07
360	5.4717	34.63	720	4,9170	32.27

Table 4.8 : TGA data (Batch 5)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	10.1766	0	380	7.9520	21.86
40	10.1745	0.02	400	7.8557	22.80
60	10.1682	0.08	420	7.7659	23.68
80	10.0776	0.97	440	7.6919	24.41
100	10.0182	1.55	460	7.6158	25.16
120	9.9971	1.76	480	7.5358	25.94
140	9.9333	2.39	500	7.4632	26.66
160	9.7956	3.74	520	7.4109	27.17
180	9.6317	5.35	540	7.3734	27.54
200	9.5042	6.60	560	7.3435	27.83
220	9.3690	7.93	580	7.3190	28.08
240	9.3212	8.40	600	7.2814	28.44
260	9.2766	8.84	620	7.2420	28.83
280	9.1310	10.27	640	7.2123	29.12
300	8.5808	15.68	660	7.1559	29.68
320	8.1659	19.75	680	7.0960	30.27
340	8.1020	20.38	700	7.0718	30.50
360	8.0122	21.26	720	7.0354	30.86

Table 4.9 : TGA data (Batch 6)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	7.9998	0	380	6.8561	14.29
40	7.9989	0.01	400	6.8133	14.83
60	7.9980	0.02	420	6.7925	15.09
80	7.9842	0.19	440	6.7604	15.49
100	7.9632	0.45	460	6.6858	16.42
120	7.8986	1.26	480	6.6302	17.20
140	7.8468	1.91	500	6.5760	17.79
160	7.8051	2.43	520	6.5673	17.90
180	7.7520	3.09	540	6.5433	18.18
200	7.6898	3.87	560	6.5321	18.34
220	7.6624	4.21	580	6.5161	18.54
240	7.6508	4.36	600	6.5085	18.64
260	7.6405	4.49	620	6.4900	18.87
280	7.6109	4.86	640	6.4637	19.20
300	7.0807	11.48	660	6.2003	22.49
320	6.9970	12.53	680	6.1866	22.66
340	6.9532	13.08	700	6.1759	22.80
360	6.9213	13.48	720	6.1670	22.91

Table 4.10 : TGA data (Batch 7)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	8.4125	0	380	6.5608	22.01
40	8.4020	0.12	400	6.5015	22.71
60	8.3829	0.35	420	6.4488	23.34
80	8.3666	0.54	440	6.4361	23.49
100	8.2623	1.78	460	6.3795	24.16
120	8.1892	2.65	480	6.3157	24.92
140	8.0568	4.22	500	6.2364	25.86
160	7.9232	5.81	520	6.2040	26.25
180	7.6625	8.91	540	6.1872	26.45
200	7.5724	9.98	560	6.1587	26.79
220	7.5422	10.34	580	6.1401	27.01
240	7.4695	11.20	600	6.1289	27.14
260	7.4313	11.66	620	6.1124	27.34
280	6.9836	16.98	640	6.0919	27.58
300	6.8964	18.02	660	6.0740	27.79
320	6.8233	18.89	680	6.0649	27.90
340	6.7144	20.18	700	6.0453	28.13
360	6.6345	21.13	720	6.0334	28.28

Table 4.11 : TGA data (Batch 8)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	8.8030	0	380	6.0921	30.79
40	8.7685	0.39	400	6.0066	31.76
60	8.7398	0.71	420	5.9037	32.93
80	8.7174	0.97	440	5.7749	34.39
100	8.5835	2.49	460	5.6858	35.41
120	8.4779	3.69	480	5.5782	36.63
140	8.4373	4.15	500	5.4869	37.67
160	8.4037	4.53	520	5.3684	39.01
180	8.3214	5.47	540	5.3627	39.08
200	8.2341	6.46	560	5.3555	39.16
220	8.0449	8.61	580	5.3445	39.28
240	7.9057	10.19	600	5.3319	39.43
260	7.7475	11.99	620	5.3171	39.59
280	7.5315	14.44	640	5.3060	39.72
300	7.2399	17.75	660	5.2742	40.08
320	7.1476	18.80	680	5.2465	40.40
340	6.3135	28.28	700	5.2238	40.65
360	6.1671	29.94	720	5.2100	40.81

Table 4.12 : TGA data (Batch 9)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	6.9986	0	380	5.7744	17.49
40	6.9977	0.01	400	5.7099	18.41
60	6.9961	0.03	420	5.6742	18.92
80	6.9762	0.32	440	5.6468	19.31
100	6.9547	9.62	460	5.6180	19.72
120	6.8897	1.55	480	5.5903	20.12
140	6.8270	2.45	500	5.5347	20.91
160	6.7799	3.12	520	5.4311	22.39
180	6.7132	4.07	540	5.3982	22.86
200	6.6537	4.92	560	5.3803	23.12
220	6.6010	5.68	580	5.3493	23.56
240	6.5709	6.11	600	5.3106	24.11
260	6.5184	6.86	620	5.2553	24.90
280	6.5071	7.02	640	5.2410	25.11
300	5.9472	15.02	660	5.2038	25.64
320	5.8801	15.98	680	5.1764	26.03
340	5.8500	16.41	700	5.0456	27.90
360	5.8132	16.93	720	4.9840	28.78

Table 4.13: TGA data (Batch 10)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	9.0631	0	380	7.1269	21.36
40	9.0556	0.08	400	7.1051	21.60
60	9.0411	0.24	420	7.0661	22.03
80	9.0247	0.42	440	7.0345	22.38
100	8.9220	1.55	460	6.9634	23.16
120	8.8390	2.47	480	6.8947	23.92
140	8.6934	4.07	500	6.8157	24.79
160	8.5994	5.11	520	6.7824	25.16
180	8.3328	8.05	540	6.7570	25.44
200	8.2347	9.14	560	6.7413	25.61
220	8.1438	10.14	580	6.7269	25.77
240	8.0796	10.85	600	6.7181	25.87
260	8.0466	11.21	620	6.7086	25.97
280	7.6035	16.10	640	6.6983	26.09
300	7.4531	17.76	660	6.6831	26.26
320	7.3426	18.43	680	6.6737	26.36
340	7.3240	19.18	700	6.6599	26.51
360	7.2470	20.03	720	6.6484	26.64

Table 4.14 : TGA data (Batch 11)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	6.9874	0	380	3.9113	44.02
40	6.9621	0.36	400	3.8361	45.10
60	6.8846	1.47	420	3.7721	46.01
80	6.7755	3.03	440	3.7196	46.76
100	6.1752	11.62	460	3.7080	46.93
120	5.8303	16.56	480	3.6951	47.11
140	5.6923	18.53	500	3.6813	47.31
160	5.5867	20.04	520	3.6711	47.46
180	5.5101	21.14	540	3.6623	47.58
200	5.4353	22.21	560	3.6547	47.69
220	5.3568	23.33	580	3.6528	47.72
240	4.4873	35.78	600	3.6407	47.89
260	4.3978	37.06	620	3.6336	47.99
280	4.2889	38.62	640	3.6243	48.13
300	4.2262	34.51	660	3.6108	48.32
320	4.1329	40.85	680	3.5674	48.94
340	4.0875	41.50	700	3.5459	49.25
360	3.9820	43.01	720	3.4858	50.11

Table 4.15 : TGA data (Batch 12)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	6.5401	0	380	4.8826	25.34
40	6.5227	0.26	400	4.8146	26.38
60	6.4955	0.68	420	4.7597	27.22
80	6.4712	1.05	440	4.7003	28.13
100	6.4210	1.82	460	4.6500	28.90
120	6.3662	2.66	480	4.5875	29.86
140	6.2880	3.85	500	4.5397	30.58
160	6.2092	5.06	520	4.4761	31.56
180	6.1076	6.61	540	4.4425	32.07
200	6.0046	8.18	560	4.4333	32.21
220	5.9392	9.19	580	4.4280	32.29
240	5.8731	10.19	600	4.4251	32.34
260	5.7812	11.60	620	4.4178	32.45
280	5.7116	12.66	640	4.4126	32.53
300	5.4533	16.62	660	4.3919	32.85
320	5.1727	20.91	680	4.3824	32.99
340	5.0167	23.29	700	4.3593	33.35
360	4.9253	24.69	720	4.3236	33.89

Table 4.16 : TGA data (Batch 13)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	5.2224	0	380	2.8704	45.04
40	5.2014	0.40	400	2.8095	46.20
60	5.1397	1.58	420	2.7879	46.62
80	5.0582	3.14	440	2.7766	46.83
100	4.5633	12.62	460	2.7661	47.03
120	4.3001	17.66	480	2.7564	47.22
140	4.2335	18.93	500	2.7466	47.41
160	4.1546	20.45	520	2.7375	47.58
180	4.1234	21.04	540	2.7314	47.70
200	4.0681	22.10	560	2.7263	47.79
220	3.9979	23.45	580	2.7203	47.91
240	3.2957	36.89	600	2.7116	48.08
260	3.2289	38.17	620	2.7030	48.24
280	3.1527	39.63	640	2.6882	48.53
300	3.1058	40.53	660	2.6444	49.36
320	3.0309	41.96	680	2.6296	49.65
340	2.9969	42.61	700	2.5452	51.26
360	2.9181	44.12	720	2.5251	51.65

Table 4.17 : TGA data (Batch 14)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	7.6842	0	380	4.6872	39.00
40	7.6656	0.24	400	4.6116	39.98
60	7.5907	1.22	420	4.6007	40.13
80	7.4614	2.90	440	4.5333	41.01
100	6.9299	9.82	460	4.4733	41.78
120	6.5635	14.58	480	4.4581	41.98
140	6.4213	16.43	500	4.4430	42.18
160	6.3704	17.10	520	4.4326	42.31
180	6.3001	18.01	540	4.4137	42.56
200	6.2139	19.13	560	4.4034	42.70
220	6.1300	20.23	580	4.3952	42.80
240	6.0025	21.88	600	4.3712	43.11
260	5.2417	31.78	620	4.3619	43.24
280	5.1471	33.02	640	4.3424	43.49
300	5.0277	34.57	660	4.3330	43.61
320	4.9476	35.61	680	4.3196	43.78
340	4.8439	36.96	700	4.3083	43.93
360	4.7724	37.89	720	4.2961	44.09

Table 4.18 : TGA data (Batch 15)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	6.2537	0	380	4.4196	29.33
40	6.2486	0.08	400	4.3775	30.00
60	6.2332	0.33	420	4.3426	30.56
80	6.2056	0.77	440	4.2819	31.53
100	6.1503	1.65	460	4.2390	32.22
120	6.0888	2.64	480	4.1916	32.97
140	5.9669	4.58	500	4.1651	33.40
160	5.7688	7.75	520	4.1477	33.67
180	5.6593	9.50	540	4.1394	33.81
200	5.5602	11.10	560	4.1266	34.01
220	5.4478	12.88	580	4.1145	34.21
240	5.4040	13.59	600	4.1068	34.33
260	5.3539	14.39	620	4.0969	34.49
280	5.0293	19.58	640	4.0871	34.65
300	4.6386	25.03	660	4.0700	34.92
320	4.5556	27.15	680	4.0408	35.38
340	4.4995	28.05	700	4.0014	36.01
360	4.4653	28.59	720	3.9528	36.79

Table 4.19 : TGA data (Batch 16)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	8.0477	0	380	6.8060	15.43
40	7.9887	0.73	400	6.7456	16.07
60	7.9572	1.12	420	6.6969	16.78
80	7.9298	1.46	440	6.6459	17.42
100	7.8615	2.31	460	6.5968	18.03
120	7.8186	2.85	480	6.5458	18.66
140	7.7403	3.82	500	6.5159	19.03
160	7.6436	5.02	520	6.4942	19.30
180	7.5476	6.21	540	6.4835	19.44
200	7.4969	6.84	560	6.4701	19.60
220	7.4529	7.39	580	6.4569	19.77
240	7.4231	7.76	600	6.4472	19.88
260	7.4043	7.99	620	6.4353	20.04
280	7.2950	9.35	640	6.4200	20.22
300	6.9554	13.57	660	6.3970	20.51
320	6.9179	14.04	680	6.3559	21.02
340	6.8741	14.58	700	6.2976	21.75
360	6.8435	14.96	720	6.2178	22.74

Table 4.20 : TGA data (Batch 17)

Temperature °C	Weight of sample g	Percent weignt loss	Temperature °C	Weight of sample g	Percent weignt loss
27	7.5214	0	380	4.8426	35.62
40	7.4867	0.46	400	4.7518	36.82
60	7.4604	0.81	420	4.7226	37.21
80	7.3636	2.10	440	4.6871	37.68
100	6.9959	6.98	460	4.6613	38.03
120	6.9023	8.23	480	4.5946	38.91
140	6.8246	9.26	500	4.5130	39.99
160	6.7787	9.87	520	4.4357	41.02
180	6.7502	10.25	540	4.3716	41.88
200	6.6655	11.38	560	4.3164	42.61
220	6.5637	12.73	580	4.2786	43.11
240	6.4447	14.31	600	4.2364	43.67
260	6.1500	18.23	620	4.2111	44.01
280	5.9847	20.43	640	4.1793	44.43
300	5.9347	21.09	660	4.1529	44.78
320	5.8711	21.94	680	4.1356	45.01
340	5.0410	32.98	700	4.1079	45.38
360	4.9592	34.06	720	4.0908	45.61

Table 4.21 : TGA data (Batch 18)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	8.4562	0	380	5.4529	35.52
40	8.4181	0.45	400	5.3516	36.71
60	8,3866	0.82	420	5.3011	37.31
80	8.2780	2.11	440	5.2603	37.79
100	7.8663	6.97	460	5.2313	38.14
120	7.7509	8.34	480	5.1585	38.99
140	7.6635	9.37	500	5.0727	40.01
160	7.6137	9.96	520	4.9786	41.13
180	7.5808	10.35	540	4.9067	41.97
200	7.4847	11.49	560	4.8356	42.82
220	7.3787	12.74	580	4.7959	43.28
240	7.2457	14.31	600	4.7460	43.87
260	6.9144	18.23	620	4.7250	44.12
280	6.7452	20.23	640	4.6922	44.51
300	6.6704	21.12	660	4.6663	44.82
320	6.5989	21.96	680	4.6403	45.13
340	5.7591	31.89	700	4.6091	45.49
360	5.6332	33.38	720	4.5899	45.72

Table 4.22 : TGA data (Batch 19)

Tempe- rature °C	Weight of sample g	Percent weight loss	Tempe- rature °C	Weight of sample g	Percent weight loss
27	7.2078	0	380	5.0929	29.34
40	7.1917	0.22	400	5.0023	30.59
60	7.1765	0.43	420	4.9388	31.48
80	7.1502	0.80	440	4.8681	32.46
100	7.1203	1.21	460	4.8186	33.14
120	7.0825	1.74	480	4.7523	34.06
140	6.9731	3.25	500	4.7311	34.36
160	6.8737	4.63	520	4.7215	34.49
180	6.7923	5.76	540	4.7136	34.60
200	6.6516	7.72	560	4.7065	34.70
220	6.5440	9.21	580	4.6953	34.86
240	6.3671	11.66	600	4.6879	34.96
260	6.1703	14.39	620	4.6741	35.15
280	5.8514	18.82	640	4.6640	35.29
300	5.5606	22.85	660	4.6511	35.47
320	5.3770	25.40	680	4.6231	35.86
340	5.2763	26.79	700	4.5716	36.57
360	5.1979	27.88	720	4.5298	37.15

Table 4.23 : TGA data (Batch 20)

Tempe-rature °C	Weight of sample g	Percent weight loss	Tempe-rature °C	Weight of sample g	Percent weight loss
27	8.0124	0	380	5.5080	31.25
40	8.0091	0.04	400	5.4686	31.75
60	7.8934	1.48	420	5.4406	32.09
80	7.5388	5.91	440	5.3914	32.71
100	7.2012	10.12	460	5.3649	33.04
120	7.1322	10.98	480	5.3431	33.31
140	7.1282	11.03	500	5.2919	33.95
160	7.0979	11.41	520	5.2833	34.06
180	7.0697	11.76	540	5.2680	34.25
200	7.0516	11.99	560	5.2572	34.38
220	7.0441	12.08	580	5.2392	34.61
240	5.9601	25.61	600	5.2287	34.74
260	5.8481	27.01	620	5.2092	34.98
280	5.7831	27.82	640	5.1984	35.12
300	5.7655	28.04	660	5.1854	35.28
320	5.7084	28.75	680	5.1347	35.91
340	5.6340	28.68	700	5.0741	36.67
360	5.5742	30.43	720	5.0627	36.81

Guide rod

Pulleys

Water

Inner drum

Outer drum

Bend tubes

Tap

GAS HOLDER

Fig. 1

Thermo well

Retort

Lid

Fig. 2

RETORT

Water outlet

Gas inlet

Cork

Bottle

Fig. 3

GAS HOLDER

Fig. 4

Drive rod

Sq. threaded screw

Top plate frame

Nut for screw

Sliding frame

Plunger

Briquette case

Base plate frame

BRIQUETTE PRESS

Fig. 5

Thermometer

Lid

Stirrer

Spiral tapered coil

BHASKARE'S CALORIMETER
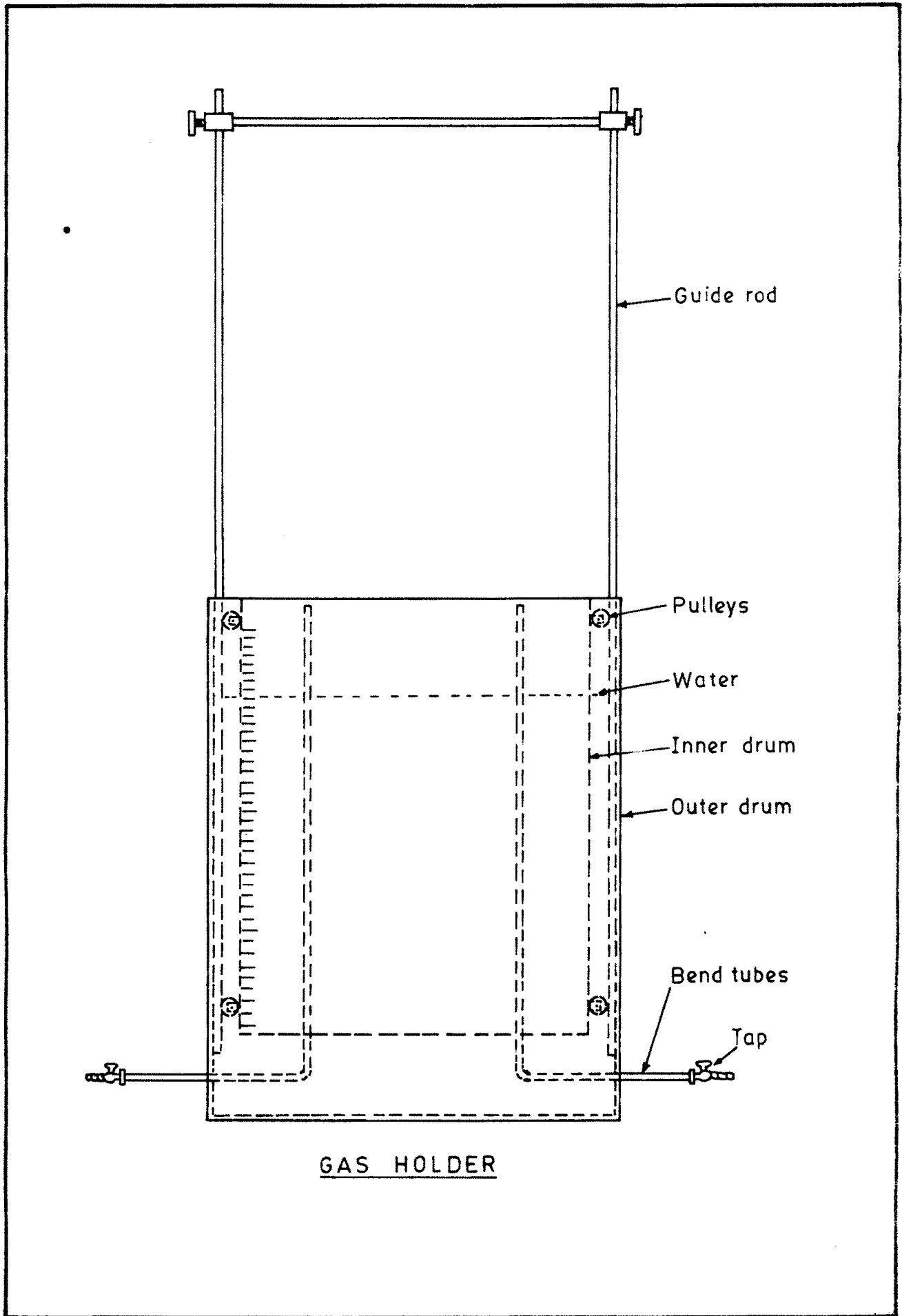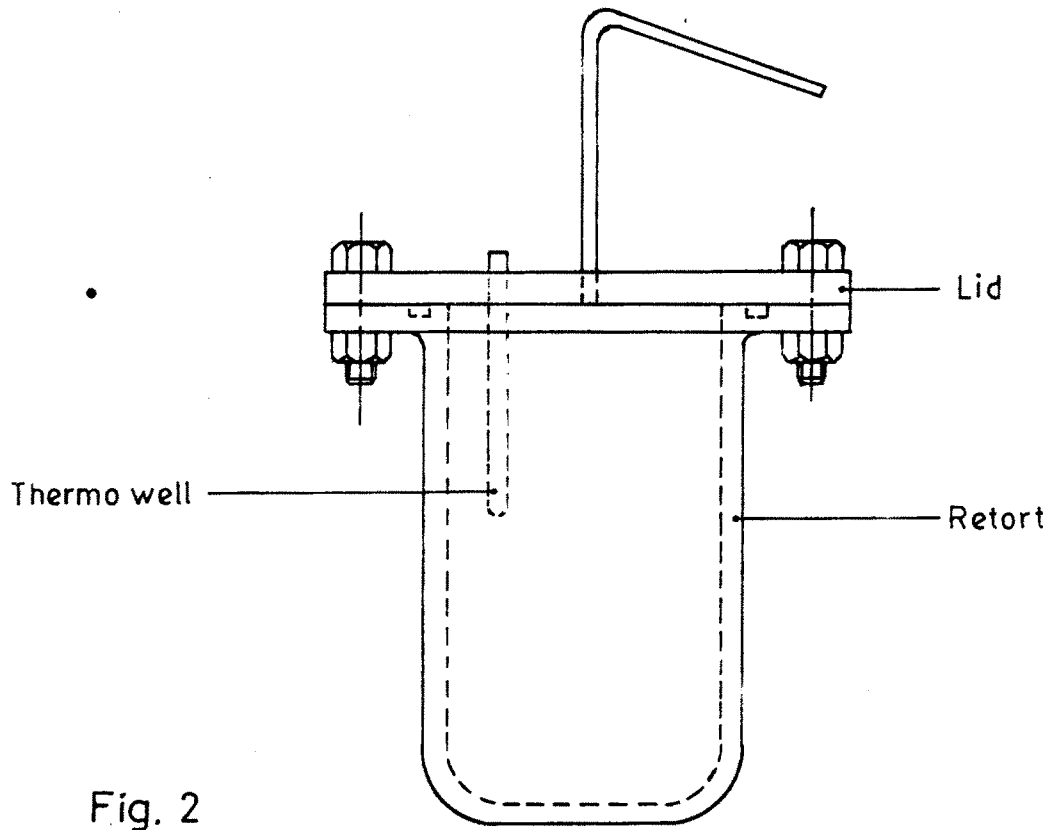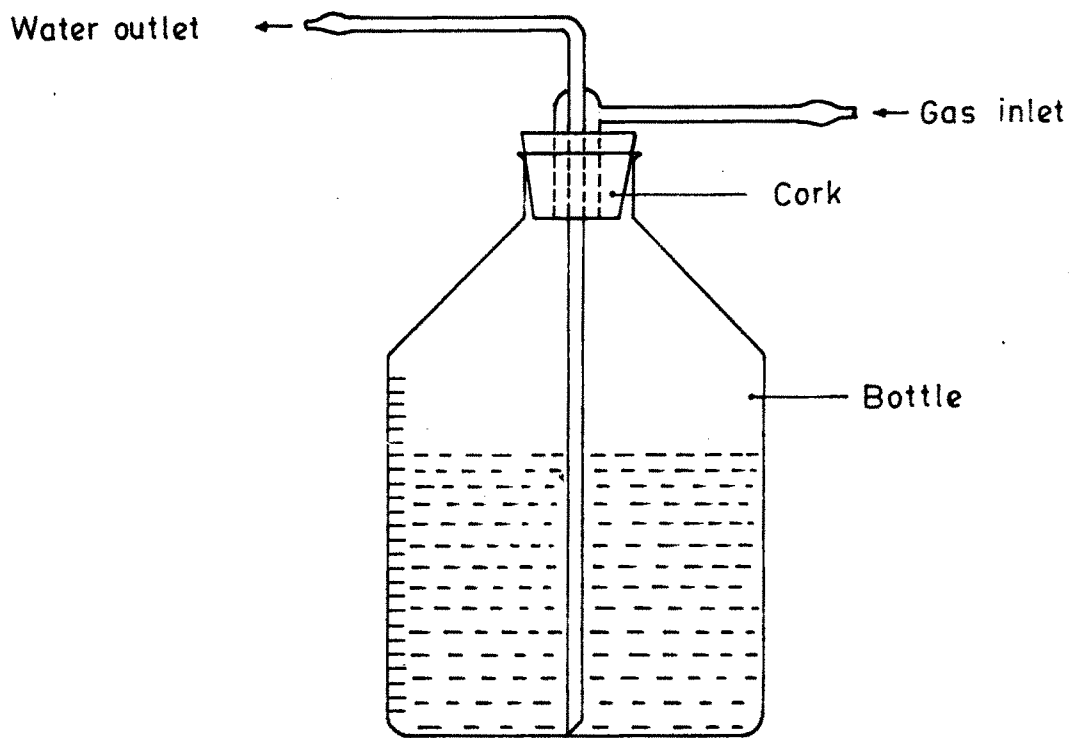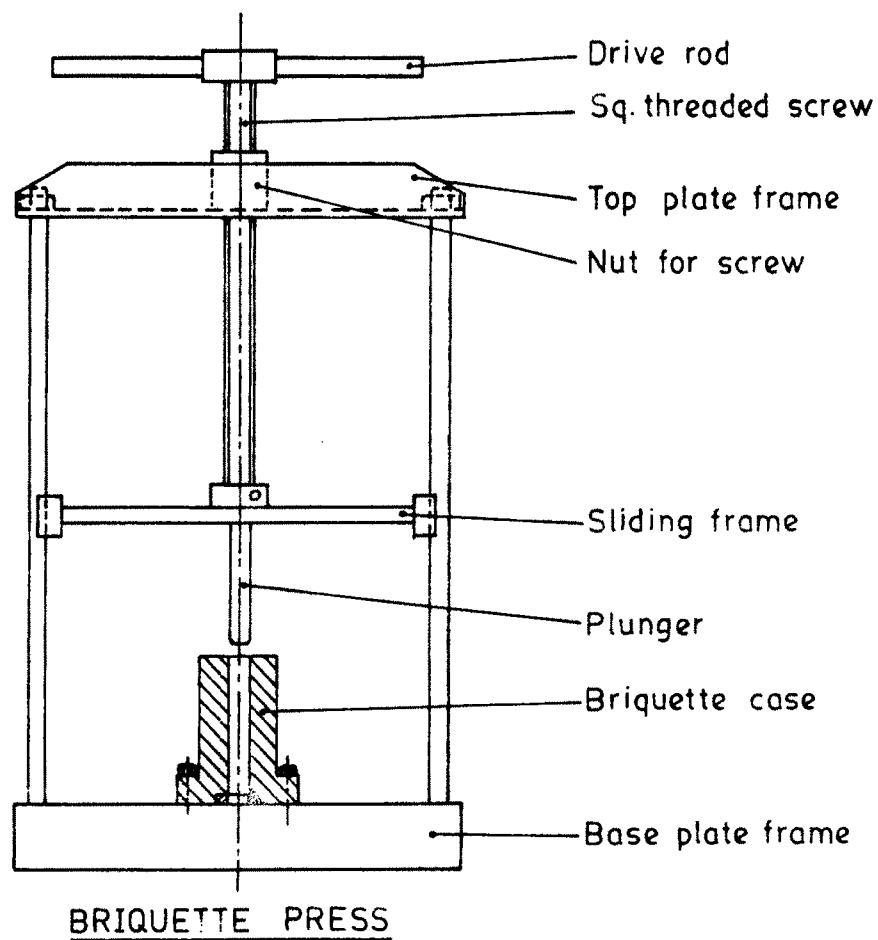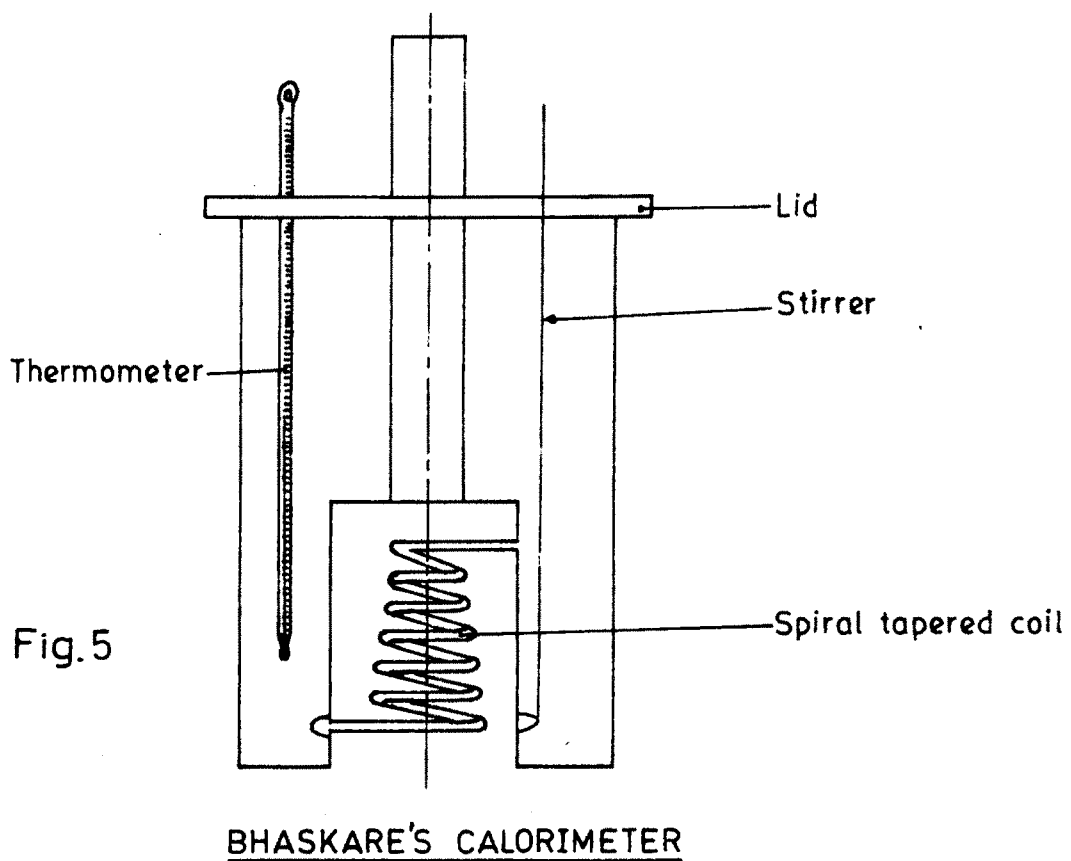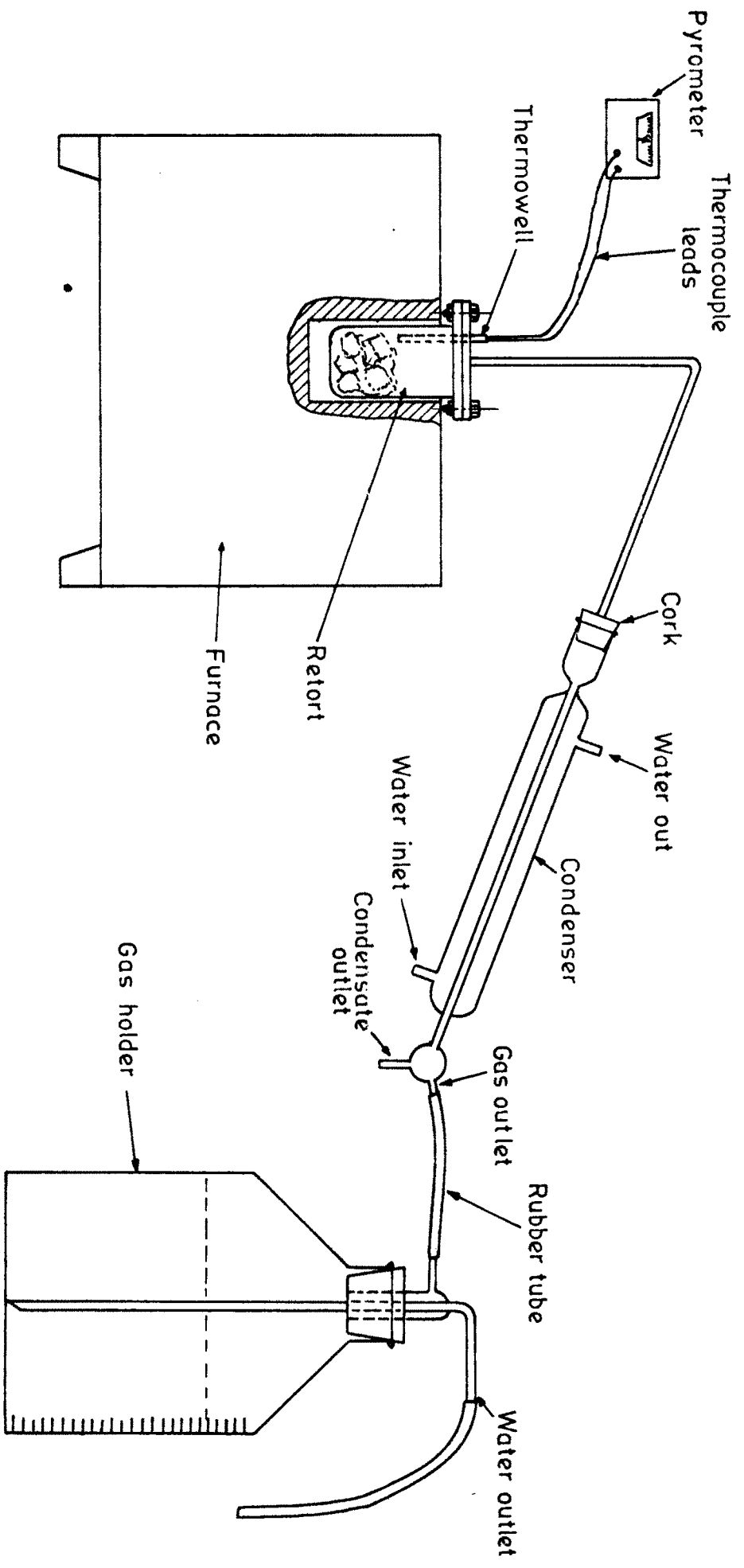
Fig.6   SET UP FOR GAS PRODUCTION

Thermometer → **Stirrer**

Tap water in →

Water

Bhaskare's calorimeter

Burner

Gas holder
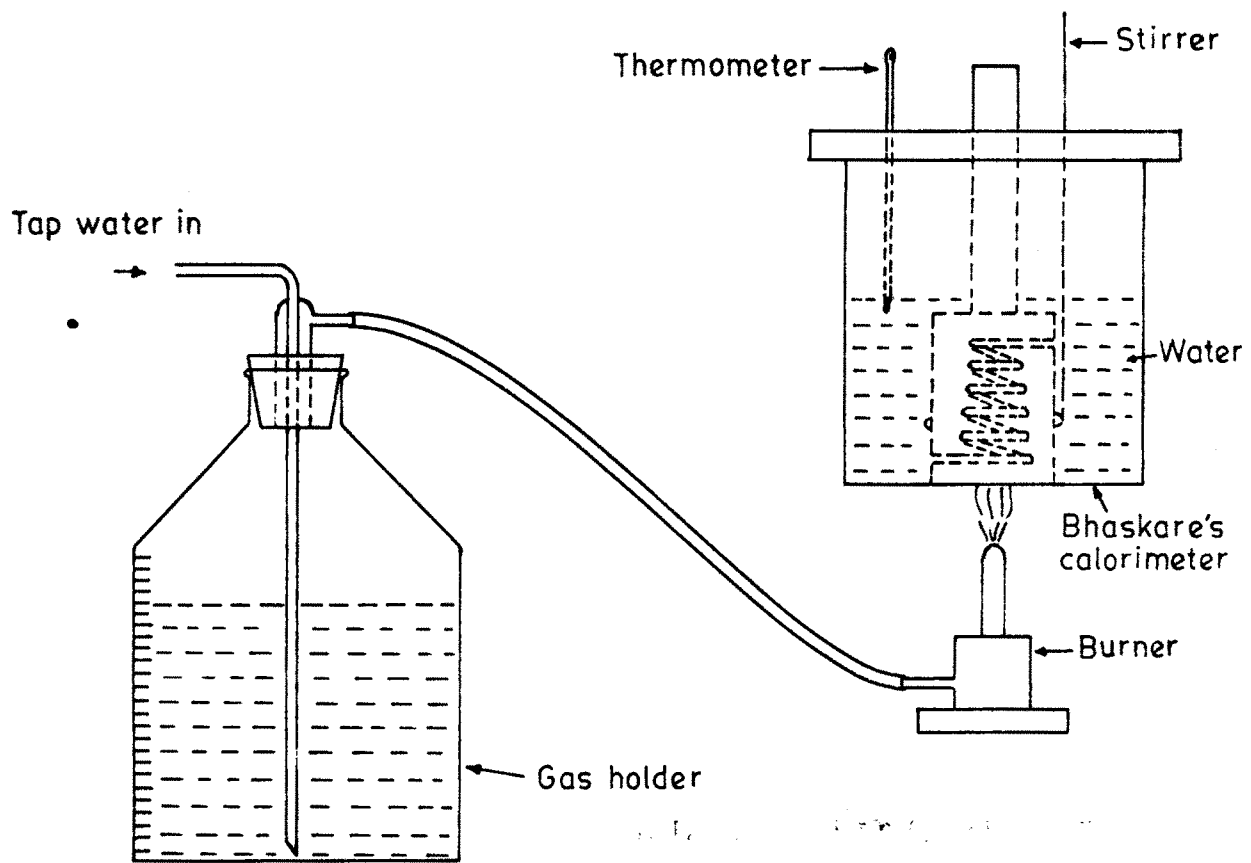
Fig.7 SET UP FOR DETERMINATION
OF CALORIFIC VALUE

Three way stopper

C

Graduated tubes

E

Gas burette

D
G

B

Absorbent solution

A

F   0

Water

Aspirator bottle
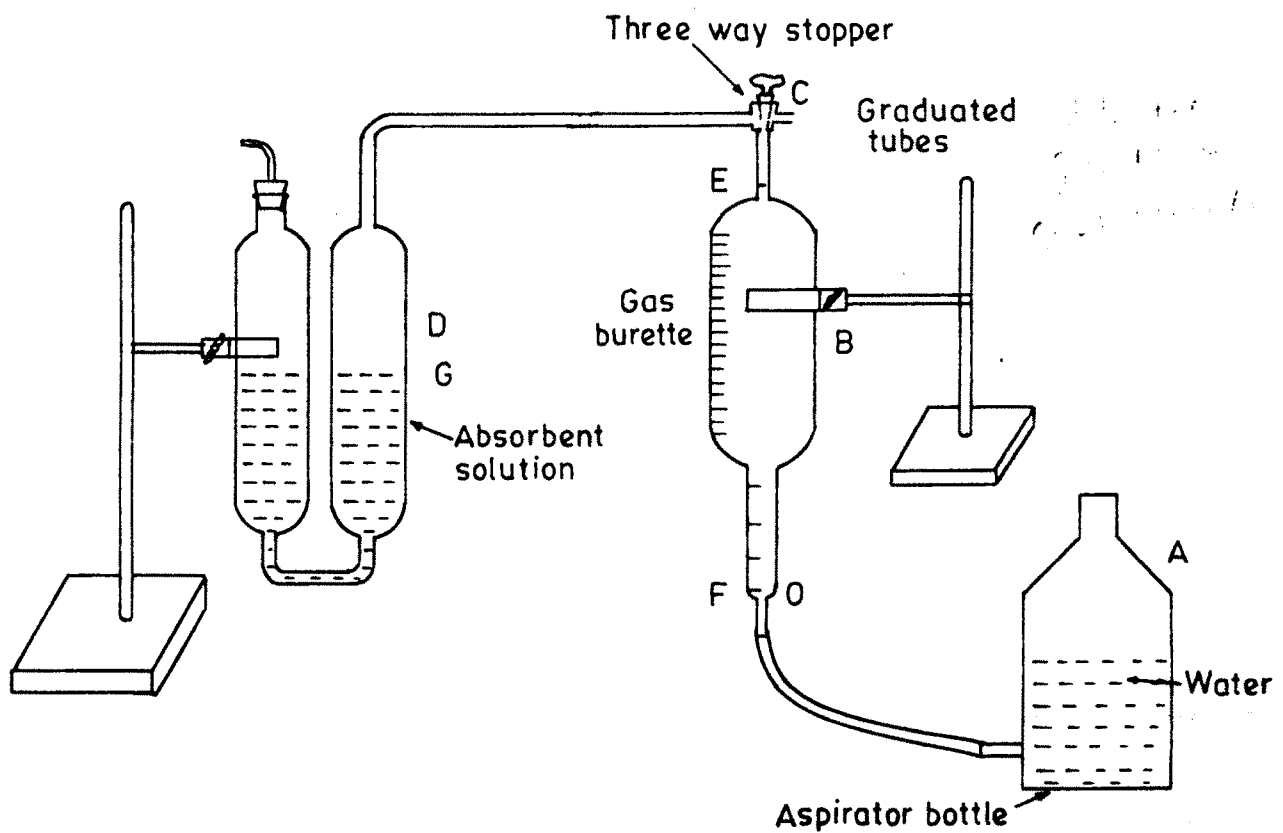
Fig.8 EXPERIMENTAL SET UP FOR GAS ANALYSIS.

Weight pan

To Pyrometer

Thermocouple

Metal wire

Sample pan

Furnace

Wooden box
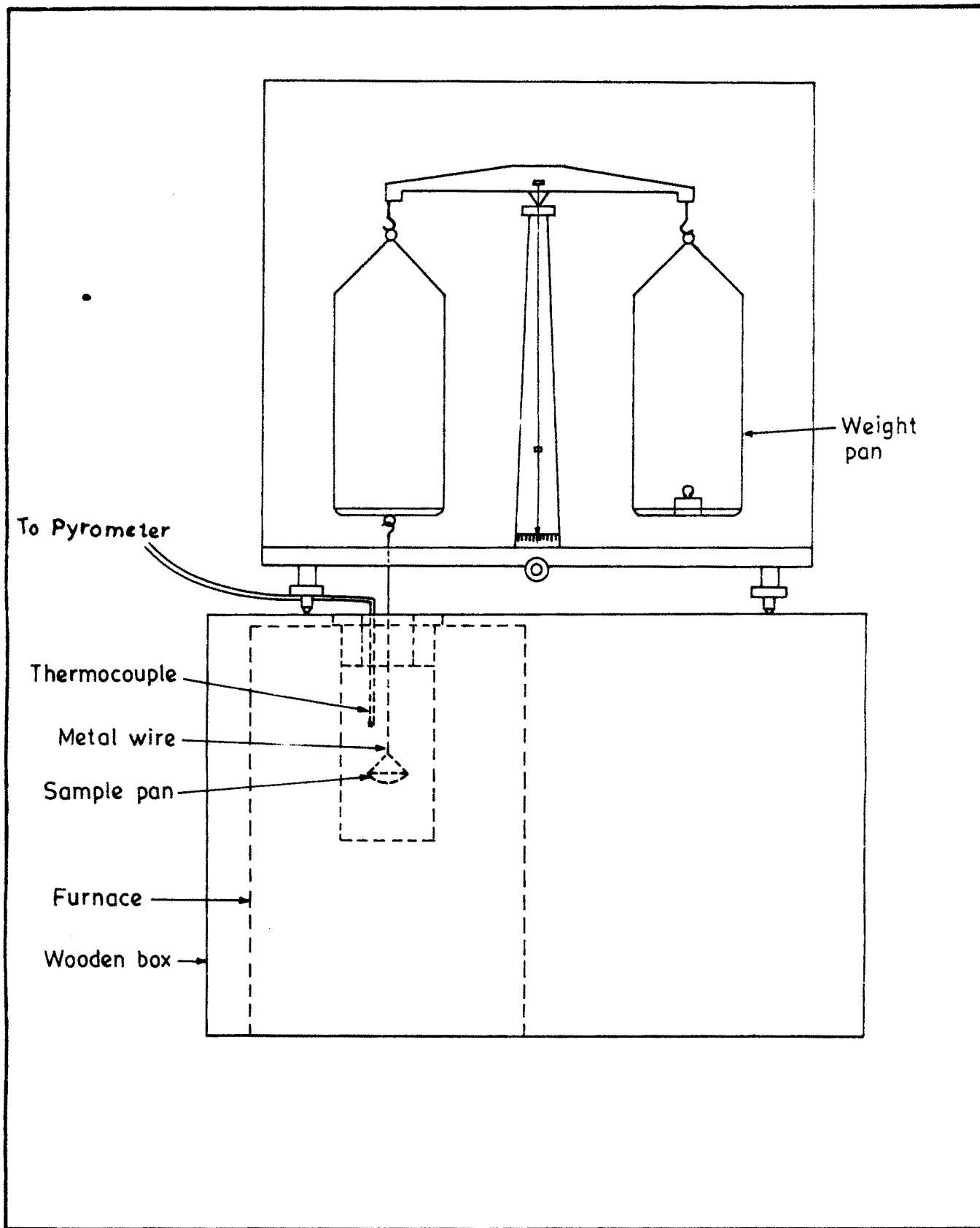
TGA Unit

Fig. 9

THERMOGRAM OF SOLIDWASTE

GROUP-A
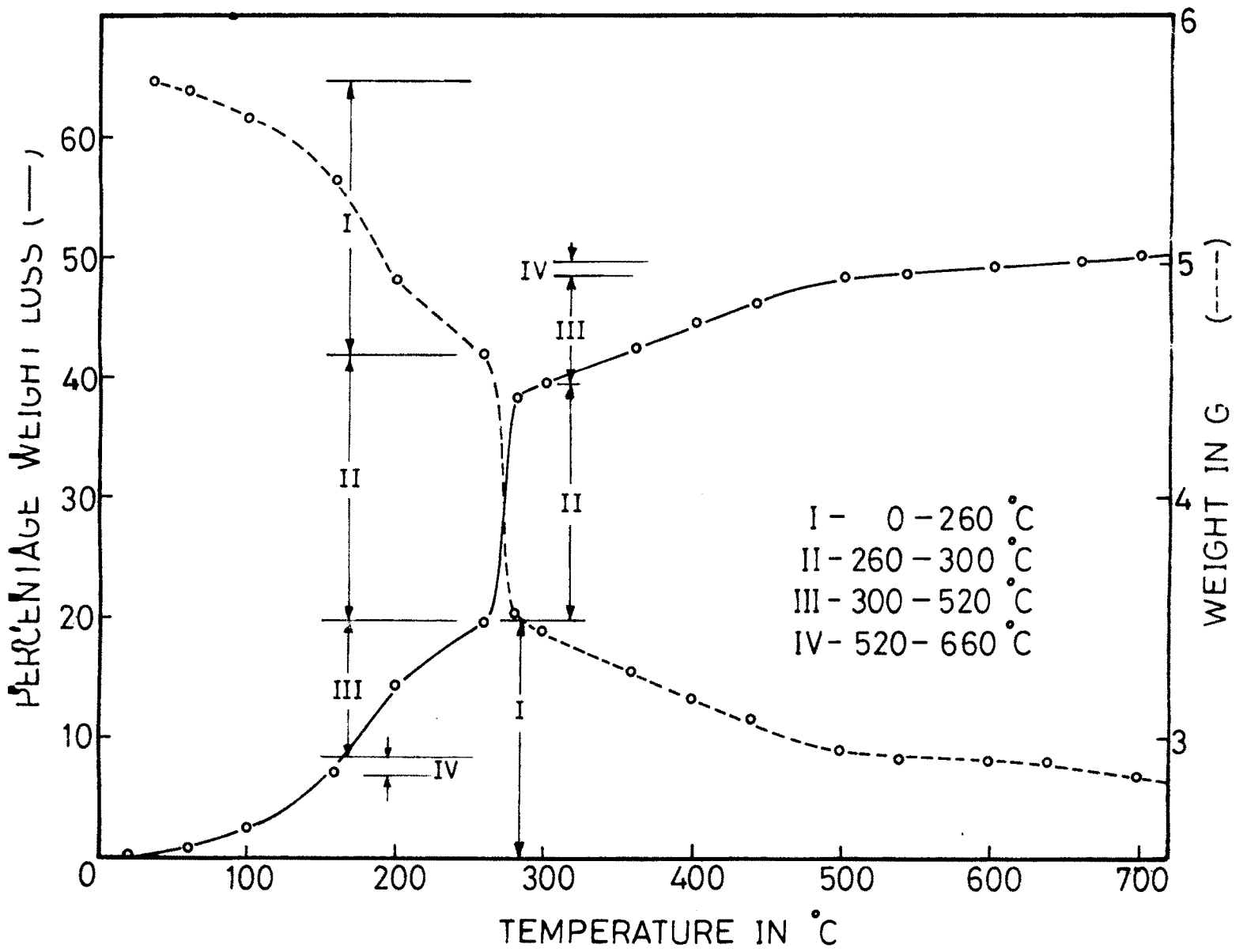
Fig. 10

THERMOGRAM OF SOLID WASTE

GROUP - B

I -   0 - 320 °C
II-   320 - 340 °C
III- 340 - 520 °C
IV- 520 - 640 °C
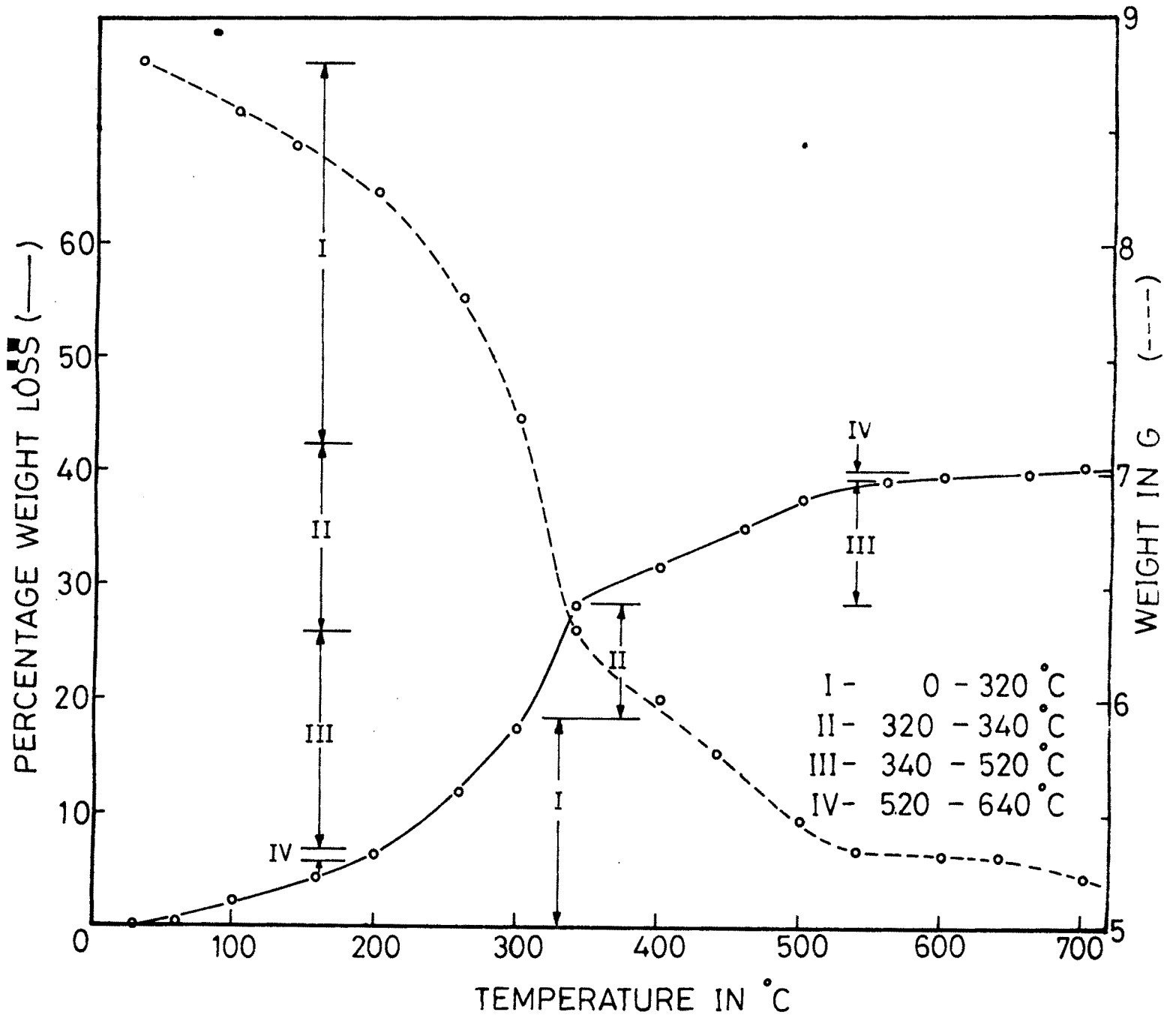
Fig. 11

THERMOGRAM OF SOLIDWASTE

GROUP–C

I –   0 – 220 °C
II – 220 – 240 °C
III – 240 – 500 °C
IV – 500 – 660 °C

TEMPERATURE IN °C

PERCENTAGE WEIGHT LOSS (——)

WEIGHT IN G (- - - -)
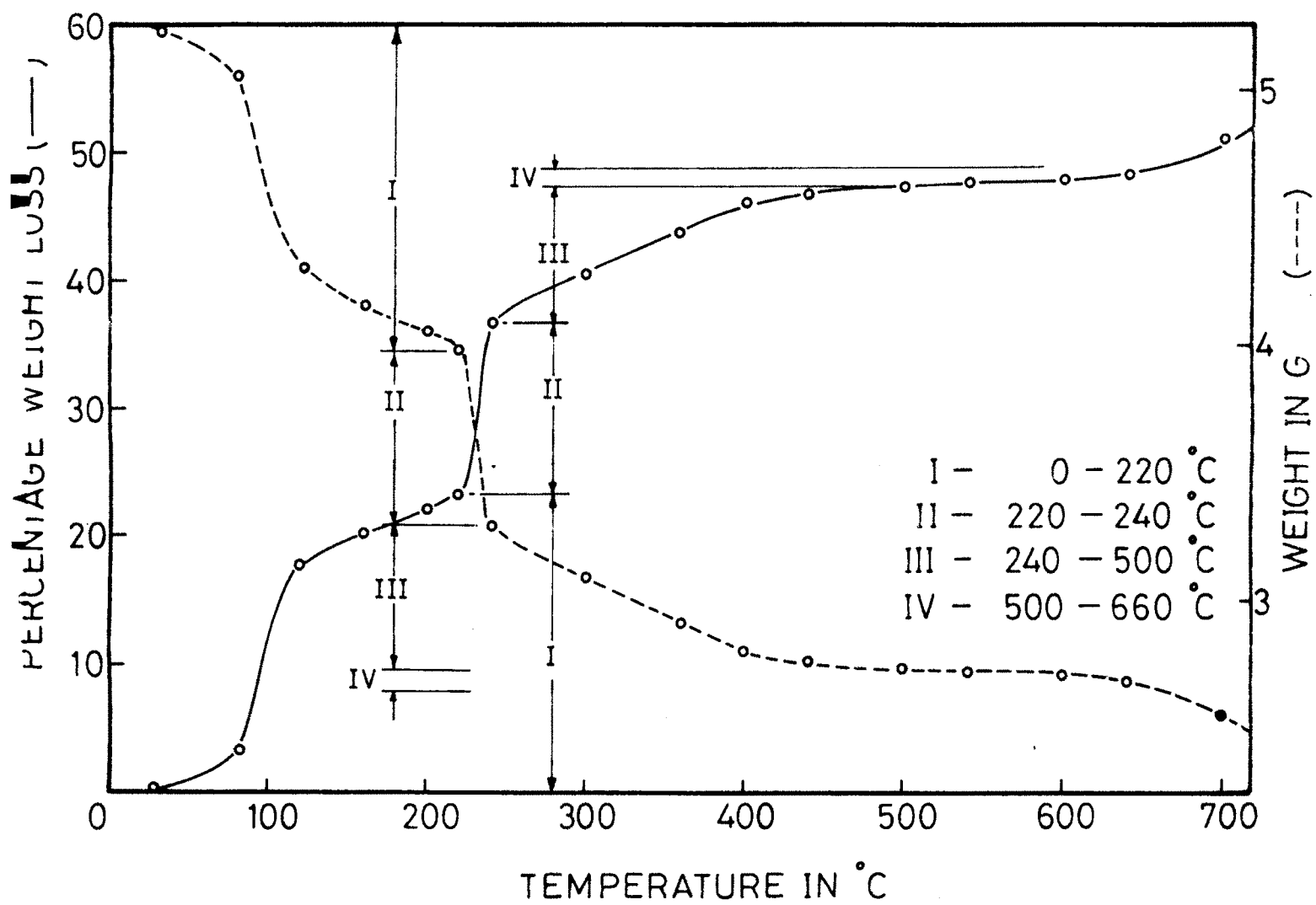
Fig. 12

THERMOGRAM OF SOLIDWASTE

GROUP — D

I —   0 – 280 °C
II —   280 – 300 °C
III —   300 – 520 °C
IV —   520 – 660 °C
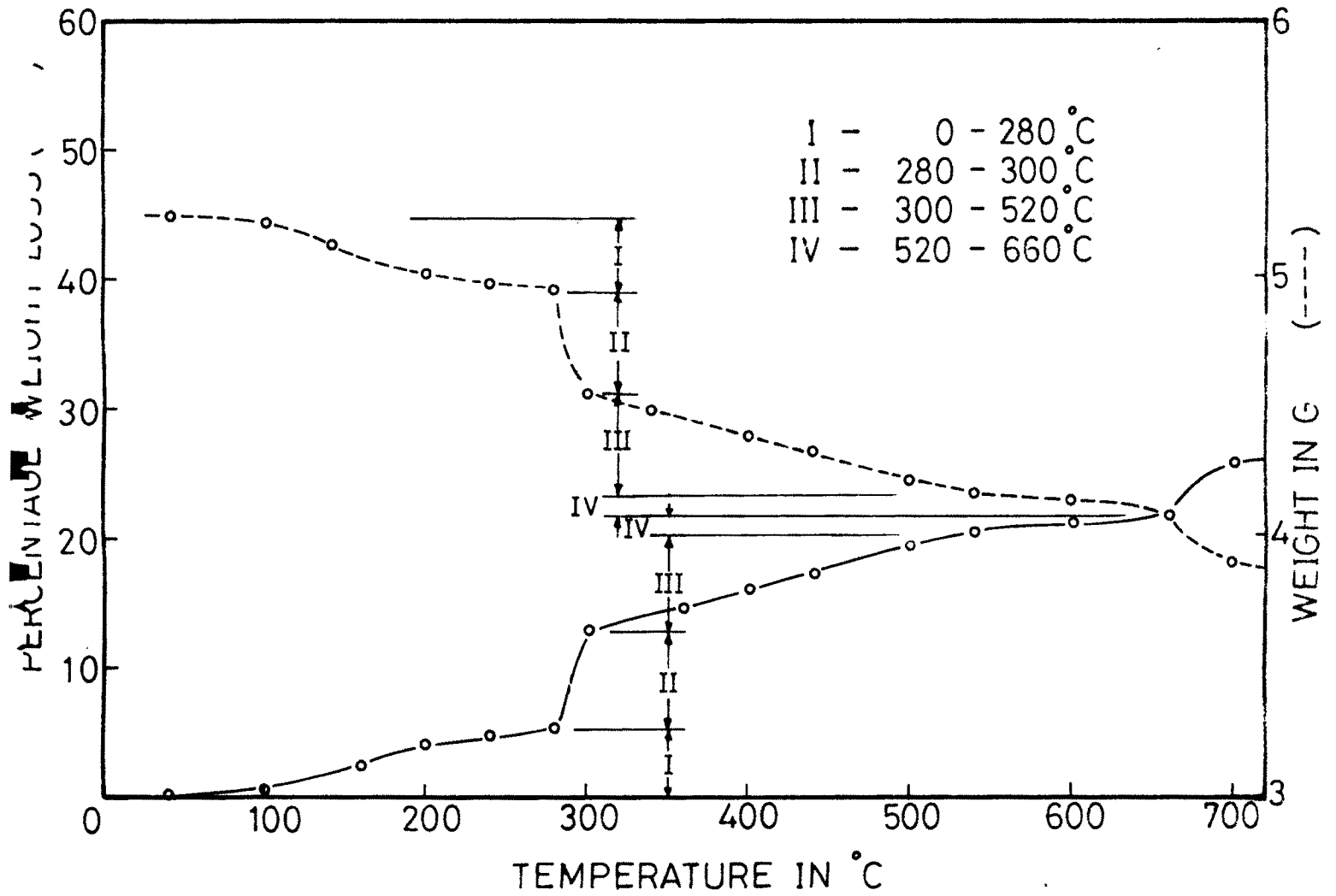
Fig.13

(——) PERCENTAGE WEIGHT LOSS
(----) T G A CURVE
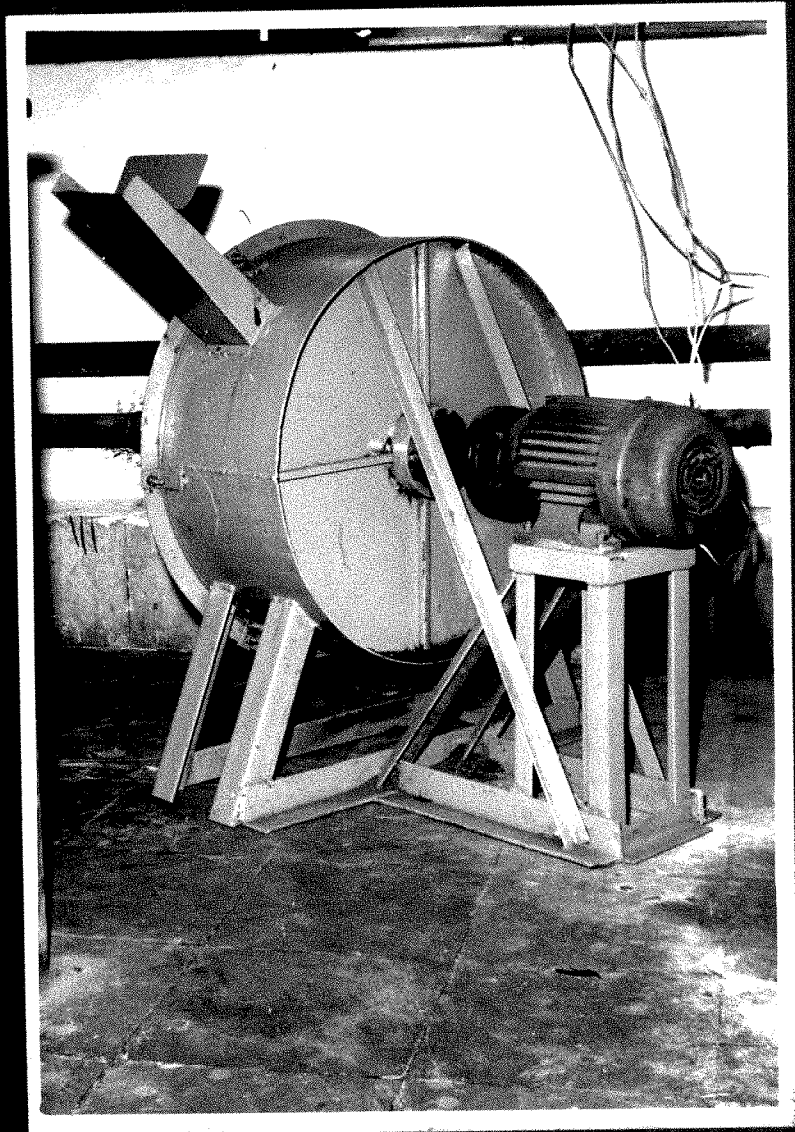
PHOTO.1: DISINTEGRATOR
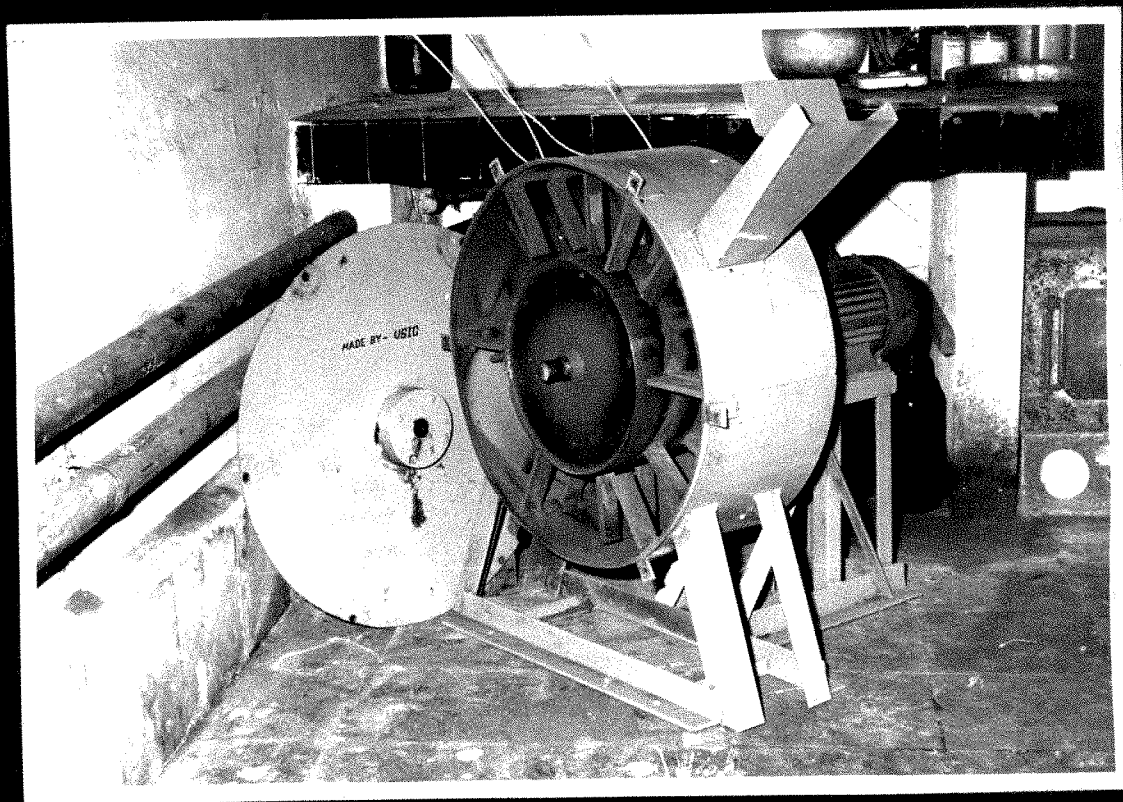
PHOTO. 2: <u>DISINTEGRATOR</u>
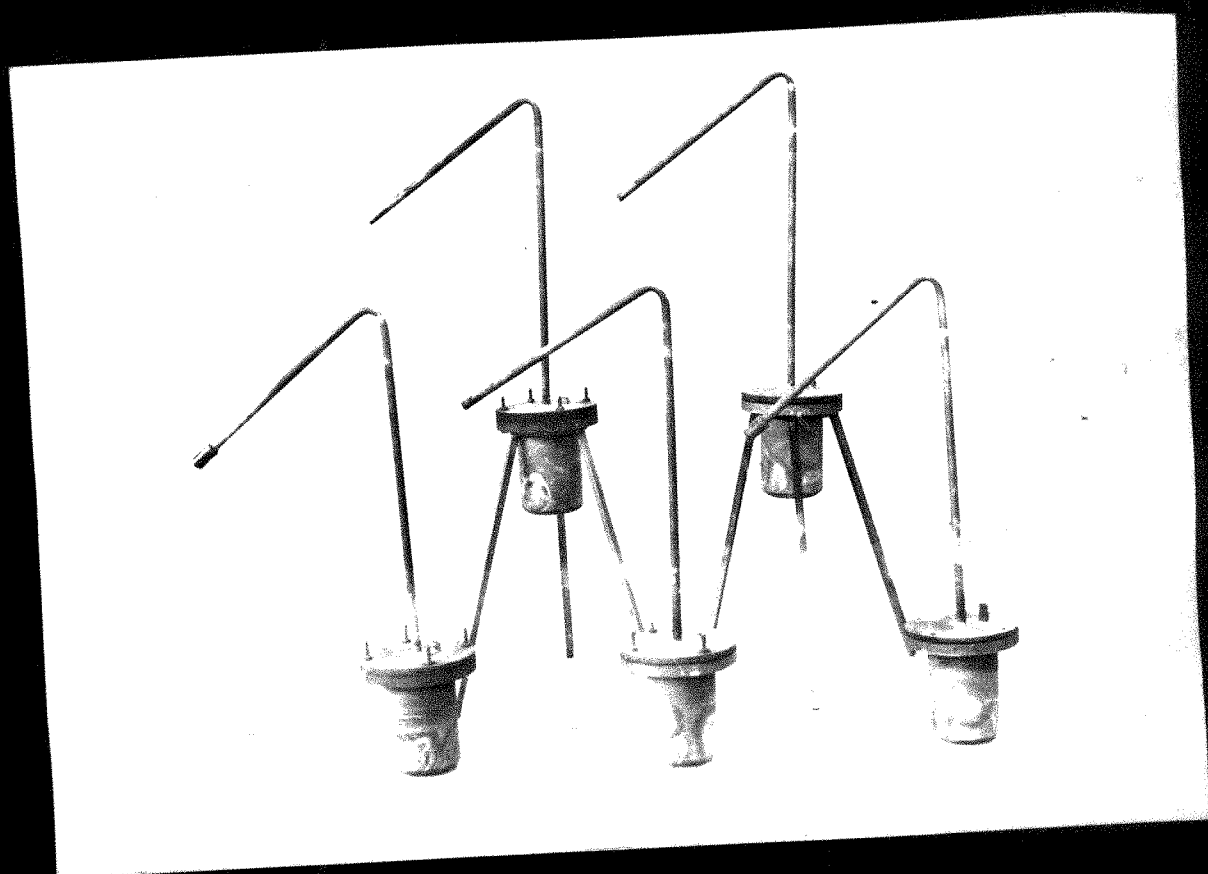(<u>INTERIOR VIEW</u>)
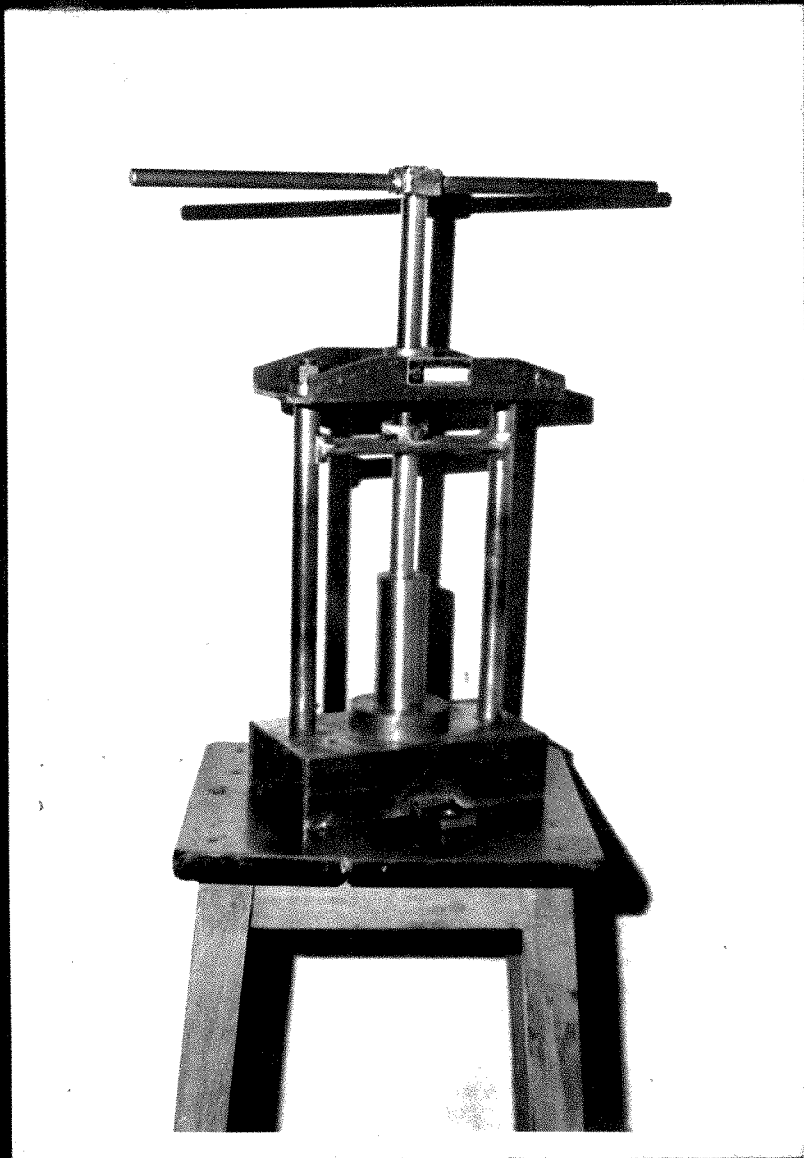
PHOTO.3: BRIQUETTE PRESS
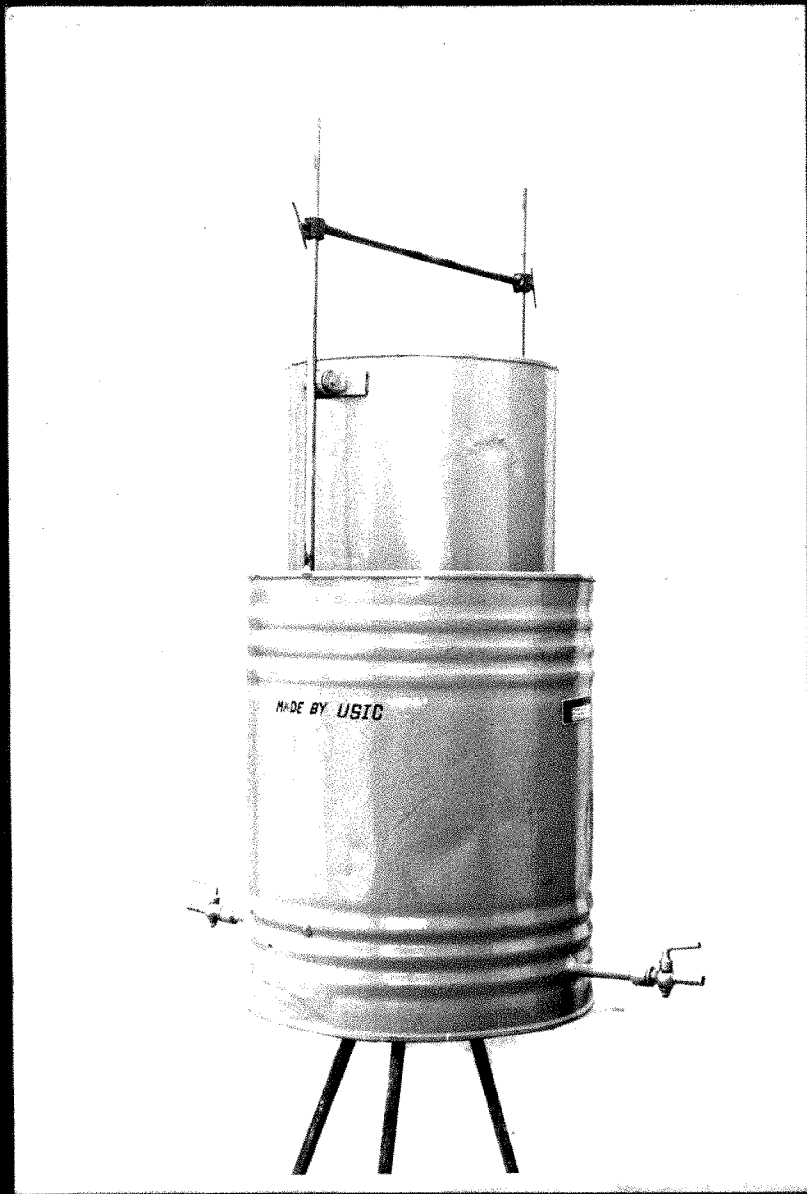
PHOTO. 4 : RETORTS

PHOTO.5 GAS HOLDER

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