

IMPROVEMENT OF COMPUSTION CHARACTERISICS IN FLUIDIZED BED

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ABSTRACT

The present investigation is directed towards the experimental study of the effect of a new design of the bed temperature on the overall thermal efficiency and heat transfer by conduction, convection and radiation in gaseous fuel-fluidized bed combustion system.

The experiments are performed on a water-cooled fluidized bed model furnace with cylindrical cross-section of 0.25 m diameter and its height is 0.60 m. the fluidizing medium used is sand particles with average diameter 1.5 mm. The bed temperature is varied between 700°C and 1100°C. Measurements of carbon dioxide, carbon monoxide and oxygen concentrations are carried out by using water-cooled sampling probe, and infrared and paramagnetic analyzers.

The results obtained show that the bed temperature, the total heat transfer to the wall and the bed combustion efficiency increase with the decrease of the air-fuel ratio. It is also found that 91% of the total heat transfer is in the fluidizing part of the bed and most of this heat is transferred by convection from hot sand particles to the wall.

Two empirical formulae for the calculation of the wall heat transfer coefficient and the particle convective heat transfer coefficient are proposed. A verification of the proposed empirical formulae is made by comparing the calculated values with the experimental results.

INTRODUCTION

Fluidization is the technique by which beds of particulate solid materials come into contact with upward moving fluids under such conditions, the pressure drop through the bed remains substantially unchanged, whatever the fluid flow rate. This technique has many advantages such as high effective internal thermal conductivity, high rates of heat transfer between the fluidized solids and an immersed surface, high thermal inertia of solid in heat transfer operations and low vapour pressure at very high temperatures.

Bed system usually consists of a vertical tube, a side tube and a grid. The granular material is poured from the side tube while the flow gas is passed through the grid. The bed is said to be fluidized if the fluid flows upwards through the bed and the

drag force will tend the particles to rearrange themselves within the bed to offer less resistance to the fluid flow. The bed expansion continues and a stage will be reached where the drag forces exerted on the particles, will be sufficient to support the weight of the particles. Fluidized bed combustion of fuels is a technique to improve the efficiency of energy utilization, especially for inferior types of fuels. It also reduces the emissivity of the pollutant components from the exhaust gases of solid, liquid and gas fuels.

The present work is concerned with the study of the effect of the bed temperature on the combustion efficiency and the heat transfer by radiation and convection in gaseous fuel fluidized bed combustor.

The fluidized bed is only one of the many types of reactor employed in industry for carrying out gas-solid reactions but it has a number of advantages over its competitors that are worth noting at the outset. Its most important advantages stem from the fact that the solid particles it contains are in continuous motion and are normally very well mixed. The result is that hot spots are rapidly dissipated and the bed operates in an essentially isothermal manner.

The phenomenon of Fluidizations:

A bed of loose particles offers resistance to fluid flow through it. As the velocity of flow increases, the drag force exerted on the particles increases. If the fluid is flowing downward through a bed of particles it will tend to compact it. However, if the fluid flow is upwards through the bed, the drag force will tend to cause the particles to rearrange themselves within the bed to offer less resistance to the fluid flow.

General Feature of Gas-Solid Fluidization:

When a quantity of finely divided solid particles is placed in a cylindrical container fitted with a porous baseplate, the top of the cylinder is open to the atmosphere. If the air is pumped into the cylinder through the base, the air will percolate through the particles and emerge at the surface. Now if the air pressure at the base of the bed is increased gradually the gas velocity and hence the drag force acting on the particles, will also increase until a point is eventually reached at which the drag force is equal to the gravitational force holding the particles within the container. At this point the particles will begin to move apart and the bed will expand upwards as the particles become suspended in the flowing air stream. The particles are then said to be fluidized and in this condition the bed takes on the appearance of a liquid having a flat surface and responding in the same way as a liquid to stirring or pouring. The superficial gas velocity at which this occurs is called the minimum fluidization velocity U_{mf} , and its value depends on the physical properties of the gas and of the solid particles.

TEST RIG

Experimental program, in this work, was carried out on a test rig which was fully constructed and elaborated in the continuous, combustion laboratory, hot laboratory center, Atomic Energy Authority. The design of the test rig and the experimental program are made carefully to meet the main objective of the present work which is the study of heat (in particular) and mass transfer in a model of gaseous

fuel-heat generating fluidized-bed plant. A fuel and detailed description of the model with its five stages is given below.

The general layout of the test rig is shown in figures (1.1) and (1.2). It consists of the following main systems: the air supply and fuel supply equipments and the cooling water system, the fluidized bed system. Each system is equipped with the necessary controlling devices.

The fuel gas and the blown air are premixed before entering onto the bed furnace. The mixture passes through one concave tube to the nozzles plate across the mixing chamber. In the bed furnace, the mixture of fuel gas and air is burnt and sand particles are started to fluidize. The bed and the fluidization itself can be easily observed through two different-level-windows, built in two opposite furnace-walls. The following sub-sections are arranged to give a detailed description of the different components of the test rig.

The fluidized bed system:

The fluidized bed system consists of a furnace (combustion chamber), mixing pipe with mixing chamber, sand collector and chimney.

The furnace, shown in figures (2) and (3), is a cylindrical parallelepiped. Its inner cross-sectional diameter is 254 mm its outer cross-sectional diameter is 274 mm and its height is 600 mm. The furnace is surrounded by cooling water Jacket (c.w.j) of 304.8 mm inner cross-sectional diameter, 324.8 mm outer cross-sectional diameter and 600 mm height. A window is built in one side of the first stage at a height of 237.5 mm from its lower edge (bed plate) as shown in Fig.(3). It has an inner diameter of 50.8 mm and an inclined axis 26.5° to the vertical. The window is used, first of all to start the ignition, secondly, to observe the fluidized bed and finally to feed the furnace with the bed material. The furnace and mixing is supported by a base on the ground by four legs. Insulating material (asbestos) is used to prevent fluid and sand leakage between the base and the furnace.

On one of the furnace sides, six holes are made to fit thermocouples for measuring the bed and free-board temperatures, the six holes are distanced 20 mm, 100 mm, 200 mm, 300 mm, 400 mm, 500 mm, 600 mm from the lower edge of the furnace. Above the perforated plate with 20 mm and below the perforated plate with 40 mm a hole is made to measure the bed pressure through.

A brass circular distributor plate of 457.2 mm and 13 mm thick is incorporated to the furnace. The plate carries a matrix of 65 nozzles having a center-distance of 28mm and each of nozzle diameter of 8 mm. A set of eight slots of 6 mm width and 8mm depth are grooved in the plate and eight copper tubes are mounted in the grooves where plate cooling water flows. Screwed plugs are fitted in the perforated plate; these plugs ensure uniform distribution of the efflux flowing mixture of fuel gas and air, and permit the required pressure to convey sand particles. Each plug has an outer diameter of 10 mm and inner diameter of 5 mm, with three drilled holes (Jets) of 2.89mm with their axes inclination to the center line x-axis of the plug with 60° and in the same direction as shown in Figures (4 and 5).

To ensure particle fluidization, it was found that the jet area should not less than 2% of the total bed section area. In this work, the total number of screwed plugs would ensure a jet (nozzles) area of 2.5% of the bed section area. It was, also,

confirmed after trials that present nozzle dimensions is quite enough for fluidization process.

The plate cooling copper tubes (6 mm outer diameter, 4 mm inner diameter) are used to prevent plate failure due to excessive heating. Overheating could also initial thermal ignition beneath the plate in the mixing chamber.

The mixing pipe in which air stream is mixed with fuel gas before entering the bed furnace has an inner diameter of 152.4 mm and length of 1584.96 mm. It has one groove split pins for supplying the fuel gas. It is connected with one feeding concave tube (convergent-divergent tube: 152.4 mm inner convergent diameter and 254 mm inner divergent diameter); they are constructed to distribute the mixture of fuel gas and air in the mixing chamber and to decrease the height of the mixing chamber.

The purposes of the mixing chamber (wind cylindrical box) are to ensure complete mixing, give uniform mixture velocity and to deliver a suitable pressure necessary to move sand particles more freely. It is connected with the mixing pipe by the concave tube (convergent-divergent tube). The cross-sectional diameter of the minor base of the mixing chamber is 152.4 mm, its cross-sectional diameter of the major base is 254 mm and its height is 400 mm. The mixing chamber is directly connected with the distributor plate, as shown in figure (5).

The exhaust gases pass through the second, third and four stages of the cooling system, and the exhaust collector into the chimney. For the exhaust collector, the cross-sectional diameter of the lower base is 254 mm while the cross-sectional diameter of the upper base is 203.2 mm and its height is 200 mm. The inner diameter of the chimney is 203.2 mm and its length is 400 mm. The sand collector is welded to the furnace as shown in Fig.(1.2). It is used to collect and onto the sand to the bed plat of the furnace. The cross-sectional diameter of the inner base is 50.8 mm while of the outer base is 60.8 mm and its length is 300 mm with their axes inclination to the center vertical line axis of the furnace with 26.56° .

The air supply system:

The air is supplied to the furnace by a radial blower which is driven by an A.C. electric motor (15 H.P., 2900 R.P.M.) through a double V-belt. The blower delivers the blown air which passes through the air pipe line, the mixing pipe, the mixing chamber (wind cylindrical box) to the packed bed of sand particles. Air must enough to ensure fluidization and to overcome any possibility of flash-back into the wind cylindrical box), if the fluidizing velocity drops below 0.2 m/s. By-bass valve is used to control the air flow before entering the furnace.

The fuel supply system:

The fuel is a mixture of propane (C_3H_8) and butance (C_4H_{10}) of approximate volumetric percentage of 10/90, respectively. The fuel gas has a calorific value of 45.56 MJ/kg and density of 2.4 kg/m^3 at ($P= 1.033 \text{ kp/cm}^2$ and $T= 288^\circ\text{K}$); at the volumetric percentage of 48/52, respectively. The fuel gas has a calorific value of 46.8944 MJ/kg and a density of 2.25 kg/m^3 at ($P= 1.013 \text{ bar}$ and $T= 273^\circ\text{K}$).

It is supplied by two gas bottles each of 50 kg one of them is connected in parallel with the main supply for starting load. The fuel gas is collected in a main manifold through coupling hose then passes through rubber hoses to the mixing pipe.

The fuel mass flow rate is controlled by a ½" ball valve, while the flow rate is measured by a flow-meter of the rotameter type. The two bottles are immersed in a tank which is filled by warm water to stabilize the pressure of fuel gas inside them.

The cooling water system:

The cooling water is supplied to the bed furnace by one feeder from the main water line. The arrangement of cooling water system is shown in Fig.(1.1). The water inlet is controlled by one valve, the feeder while the water outlet is controlled by a valve. A thermometer is fixed to the outlet pipe to measure the cooling water outlet temperature. The mass flow rate of the cooling water is measuring by collecting the circulated water in a calibrated tank.

The first stage:

The cooling water is supplied to the cooling water Jacket around the furnace from the main water line. It is supplied by a pump (0.75 kw, 1450 R.P.M., 1.00 m³/hr at 55 m) which driven by an A.C. electric motor (1.1 kw, 1440 R.P.M.). Pressure gage (0.5 kp/cm²) is connected in parallel to the delivery pipe. The water inlet is controlled by a ¾" ball valve. The first stage of the cooling system is a cooling water jacket as shown in figure (5).

A two horizontal staggered tube (inside and outside diameters are 25 mm, 35 mm, respectively), which the cooled water is passed through one of them and the hot water is passed through other of them.

A cooling water Jacket is built around the outer tube of the second stage the dimensions of this Jacket is 25 mm inner diameter and 35 mm outer diameter. The cooling water is supplied to the bed furnace by one feeder from the main water line. A window is built in a side in the face of the bed furnace. Six holes are made to fit thermocouples for measuring the gases temperatures among the rows. A ¾" bass valve is fitted to water inlet.

Water is metered by one mercury manometers. Orifice plates and piping assemblies are designed and constructed according to the standards. One thermometers are fixed to the outlet collectors and Jacket to measure the cooling water outlet temperature.

The second stage:

The second stage of cooling system as the same of the first stage. Cooling water from the inlet pipe passé through the shell is a cylindrical parallel shape. The mixing shell has inner cross-sectional diameter of 274 mm, outer cross-sectional diameter of 304.8 mm and height of 600 mm. A cooling water system as the same in the first stage. Two thermometers are fixed to the inlet and outlet pipes to measure the cooling and heating water inlet and outlet temperatures of the water Jackets and water drainage, for calculating the enthalpy loss of water in hoses while a thermometer is fixed to the outlet pipe to measure the overall water outlet temperature.

Distributor plate:

The distributor plate shown in figure (5), is cooled through eight tubes of 6 mm diameter mounted in grooves shaped on the plate at 6 mm width and 8 mm depth. The tubes are 700 mm length each. Water is supplied to a pipe of 1 ½" in diameter in which 8 holes of 6 mm diameter are drilled and 6 mm tubes are attached. Water flows through the pipe to the welded tubes to rubber hoses that are connected to the cooling water of the distributor plate. The outlet water of eight tubes is collected by the exit pipe 1½" to measure the overall water temperature. A thermometer is mounted in the end of the outlet collector to measure the overall water temperature. The orifice meter device is connected in series to the delivery pipe to meter the mass flow rate of water.

RESULTS AND DISCUSSION

The analysis of the experimental result obtained in then present investigation, includes the study of the effect air to fuel ratio and bed temperature on:

- i) The exhaust temperature of the system.
- ii) The overall efficiency of the system.
- iii) The total heat transfer.
- iv) The gases concentration.

Also a comparison is made between the experimental values of maximum wall heat transfer coefficient and conductive-convective heat transfer coefficient for large particles fluidized bed with that obtained from the previous investigations.

Effect of the Air-Fuel Ratio:

The air-fuel mass ratio is varied from 16.58 to 39.752 by changing the fuel mass flow rate, while the air mass flow rate is kept constant. The following sections explain the effect of the air-fuel ratio on the bed temperature and the gases concentration.

The Bed Temperature:

It is found that decreasing the air-fuel ratio increases the bed temperature (830°C – 1132°C). the excessive increase of the air-fuel ratio will result in lowering the bed temperature due to the excess air (50.71% - 134.22%). The bulk of the bed is isothermal because of the rapid circulation of particles and increasing ratio of the heat capacities of the particles and gas [1]. The fluidized bed is an energy storage device [2] which is employed as a regenerator again [3]. The temperature gradient is existent only at the bed furnace walls and the entrance zone over the distributor plat [1]. Thermal equilibrium is quickly established between the gases and the particles because of the very large area exposed by the small particles.

The Gases Concentration:

The concentration of the exhaust gases in the bed is dependent on the temperature gradient and the air-fuel ratio. Increasing the air-fuel ratio increases the average oxygen concentration and decreases the temperature gradient and it decreases the average carbon dioxide concentration. The variation of the concentration of oxygen and carbon dioxide of the exhaust gases with changes in air-fuel ratio is shown. It is found that the lower values of carbon dioxide correspond to the higher

values of air-fuel ratio. Carbon monoxide is not formed due to the complete combustion of the fuel at all runs [1, 5, 6]. Since the rate of chemical reaction is dependent on the temperature of the fluidizing medium will heat to efficient and complete combustion of the mixture.

The Heat Transfer to the Fluidizing Medium Wall:

The radiative heat transfer depends on the bed temperature of the bed furnace inner surface, the degree of blackness of the fluidized bed and the effective emissivity of bed. The degree of blackness of the bed increases with the increase of bed temperature which increases the bubble fraction. The effective emissivity of particulate media increase with (increase of bed temperature. The radiative heat transfer due to both bubble and emulsion phases is calculated. The radiative heat transfer increases directly with the increase of bed temperature (Fig.6). High temperatures above 1000°C result in rapid increase in the radiative heat transfer component. At temperatures above 945°C (Fig.6), the radiative heat due to bubble phase is higher than that in emulsion phase because the bubble voidage increases as a result of the bed temperature.

Effect of the Bed Temperature:

The overall system efficiency:

The value of the overall efficiency is dependent on the fluidizing velocity and the fluidized bed temperature. The overall efficiency is increased with the increase of bed temperature which in turn is dependent on the air-fuel ratio [4]. Also, the overall system efficiencies are in the range of 89.998% $< \xi_{sys} < 98.513$ at excess air values of $164.61 < I < 76.40$, where I is the excess air factor. The dependence of the overall system efficiency on the bed temperature and air-fuel ratio, where the overall system efficiency increased with the decrease of air-fuel ratio is displayed in Figs.(7) and (8).

The total heat transfer:

The major value of the heat liberated is absorbed by the cooling water and is carried away by the exhaust gases. The distribution of the majority of heat transfer, the heat absorbed by the cooling water and the heat carried out by the exhaust gases (Fig. 10). The quantities of the heat absorbed by the cooling water in the stages and in the distributor plate are shown in Fig.(9).

SUMMARY AND CONCLUSION

SUMMARY:

The present investigation is directed towards the experimental study of the effect of bed temperature on the overall model efficiency and heat transfer by different modes in gaseous fuel-fluidized bed heat generator. The calculation of the heat transfer by conduction, convection and radiation, together or individually in the stages of the combustor is developed.

The main parameter considered in this work is the air-fuel ratio which has a direct effect on the bed temperature.

Measurements of carbon dioxide and oxygen concentrations are carried out by using water-cooled sampling probe and Bacharach Fyrite gas analyzers. The fuel mass

flow rate is measured by a-rotameter. The bed temperature measurements are carried out at a distance above the distributor plate by using a bare-wire thermocouple. The temperature measurements of exhaust gases in different sections are carried out by using thermocouples. The cooling water temperatures are measured by thermometers. The inlets and the outlet of the system of cooling water are fitted by orifice flowmeters. The bed pressure drop is measured by using two static probes and a micro-manometer.

The total heat transfer to each part of the system is calculated from the enthalpy rise of the cooling water. The obtained results, different empirical formulae describing the heat transfer within the model, show better agreement with the experimental data in a way one might say that the present work is more expressing the heat transfer in the model than the previous investigations.

CONCLUSIONS:

In the light of what has been mentioned the present work, the following conclusions are drawn:

1. The air-fuel ratio has obvious impact on bed temperature and hence on total heat transfer and overall efficiency as well. It is found that decreasing the air-fuel ratio from 48.791 to 35.812 increases the overall system efficiency from 80.175% to 93.891% and dimensionless that absorbed by cooling water, increases from 54.12% to 63.51%.
2. In the range of operating bed temperature (870°C – 1210°C), the presence of fired fluidized bed causes an increase in the rate at which heat can be transferred to its surroundings by the luminous radiative component. It is found that the luminous radiation increases from 6.989% to 12.889% of the total liberated heat. The heat transfer by conduction-convection and by convection alone dominates the heat transfer by radiation and varies between 29.881% and 33.01% of the total liberated heat.
3. In the fluidizing medium part, the plot of heat transfer coefficient against bed temperature proved that the coefficient undergoes a maximum value at a certain bed temperature above which the coefficient decreases again. The phenomena has been interpreted in the text.
4. The experiments showed that the residence time increases, while the thermal time decreases with the increase of bed temperature. This is true up to a certain bed temperature, above which, the thermal time increase again.

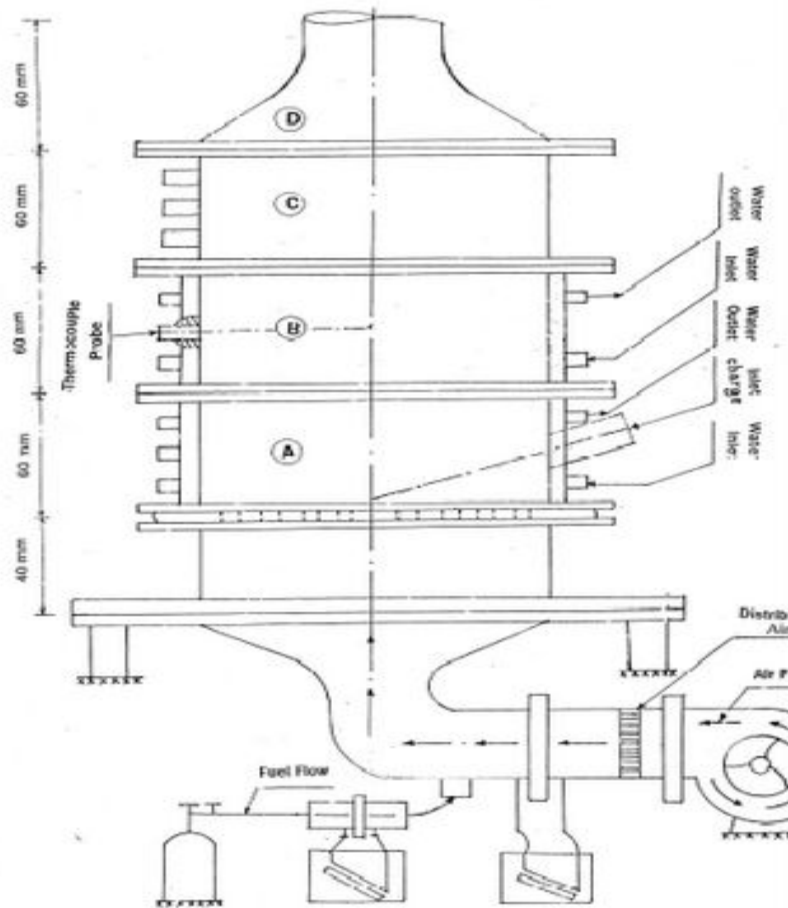


Fig.(1.1): Test Rig Layout

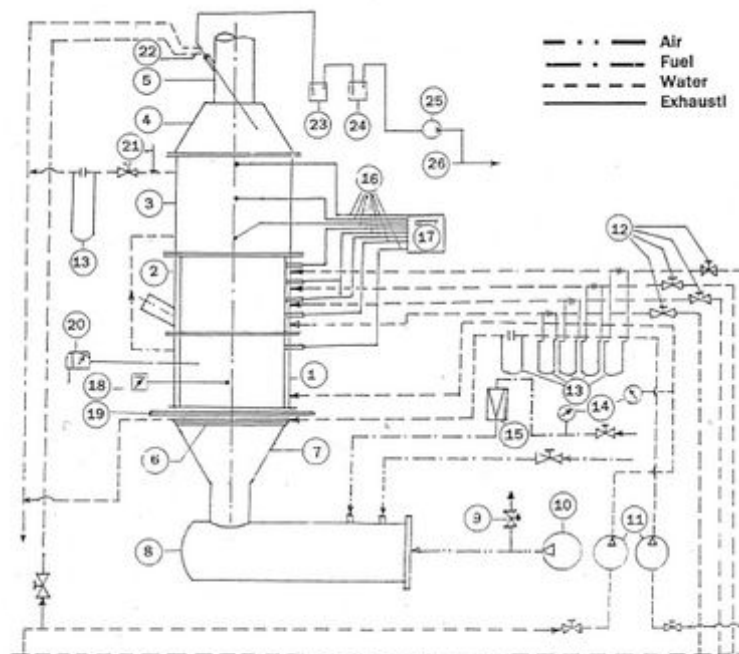


Fig.(1.2): The Test Rig Arrangement

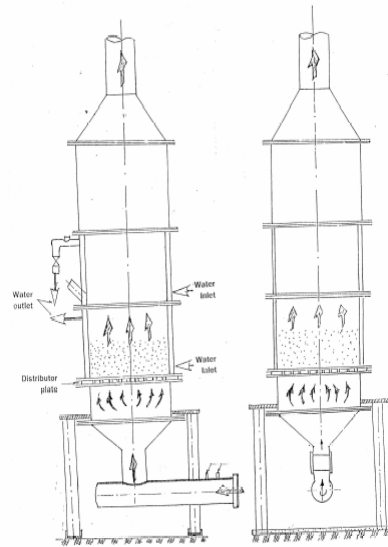


Fig.(3): Flow Diagram of

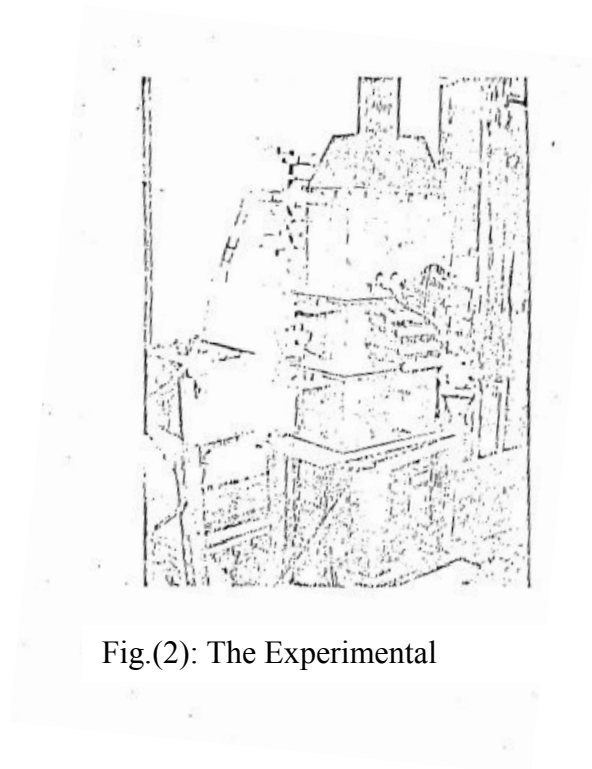


Fig.(2): The Experimental

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