The experimental investigations were carried out in a 300 mm square, shell type water cooled fluidized bed combustor shown schematically in Figure 4.1. It was made of sections of 100 and 200 mm height to facilitate variation of bed height. During the present investigations, the bed height was 280 mm excluding the thickness of packings.

The inner and outer walls of the sections were made of 3 mm thick mild steel plate with an inner dimensions of 300 x 300 mm. The cooling water passage in between the inner and the outer walls was 30 mm. The test sections were covered at the bottom and top by a 5 mm thick mild steel plate as shown in Figure 4.2. These end plates were joined to the inner and outer walls by arc welding. A steel pipe of 12 mm diameter and 100 mm long fixed to the outer shell nearer to the bottom plate served as the inlet for cooling water and a similar one fixed nearer to the top plate 180° apart served as the outlet. A 35 mm diameter hole was drilled in the walls of the section with its axis inclined at 45°. A 25 mm diameter and 150 mm long steel pipe was cut to 45° angle at one end and fixed to the above hole. Care was taken to ensure that the inclined
FIGURE 4.1 EXPERIMENTAL SET-UP

1 AIR REGULATOR
2 ORIFICE METER
3 DUST COLLECTOR
4 AIR DIFFUSER
5 AIR DISTRIBUTOR
6 RADIOMETER
7 THERMOCOUPLE
8 FLUXMETER
9 BED SECTIONS
10 OVERFLOW PORT
11 60mm OUTER DIA. STEEL TUBE
12 VIEW PORT
13 FREE BOARD SECTION
14 CHIMNEY
15 COAL INLET
16 WATER JACKET
Figure 4.2 Test Section with Overflow Pipe

A - Inner Wall of Test Section
B - Outer Wall of Test Section
C - Overflow Pipe
D - Static Pressure Probes

All dimensions in mm
edge of the pipe was flush with the inner surface of the test section. The other end of the pipe was connected with another 25 mm diameter pipe and this combination served as the overflow passage for the bed materials.

In the 200 mm height test section, provision was made to accommodate horizontal tubes of different diameters. A 120 mm diameter right through hole was made in the water jacket on opposite sides of the section. Two rings of 120 mm outer diameter and 110 mm inner diameter with inside threads were inserted in the holes and welded as shown in Figure 4.3. Care was taken to ensure that one end of the rings were flush with the inner surface of the test section. Spacer nuts with a centre hole of 60 mm and 110 mm outer diameter were screwed on either side of the coupling, in such a way that they were flush with the inner surface of the test section. Lock nuts with a 60 mm hole at the centre and 90 mm outer diameter were screwed to the inside threaded step in the spacer nut. Asbestos packing was used in between the spacer nut and the lock nut to prevent the leakage of gas from the bed. A cleaning door of 100 mm diameter was provided on one side of this section to facilitate cleaning of the bed materials and charging the materials required for starting the unit.

The test sections were joined together with a 6 mm thick asbestos packing in between them to prevent gas leakage and provide thermal insulation between the test
FIGURE 4.3 TEST SECTION ACCOMMODATING TUBES

ALL DIMENSIONS IN MM

A - INNER WALL OF TEST SECTION
B - OUTER WALL OF TEST SECTION
C - THREADED RING
D - SPACER NUT
E - LOCKNUT
F - ASBESTOS PACKING
G - CLEANING DOOR
W - WATER JACKET

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sections. While assembling, care was taken to ensure that the inner surface of the packing was flush with the combustor wall surface. The asbestos packing, after tightening the jointing bolts was found to have shrunk to 5 mm. The bed height during the investigation was thus 290 mm. The water was supplied to test sections, through a distributor main from a constant level tank.

Air distributor was provided at the bottom of the test section to ensure uniform flow. This was of a perforated plate type with 18 percent of its area open for air flow. It was made of 3 mm thick mild steel plate with holes of 3 mm diameter drilled with a pitch of 6.27 mm. To minimise pressure losses, these holes were countersunk at an angle of 30° and to a depth of 0.75 mm. A schematic diagram of the distributor is shown in Figure 4.4 and its salient design details are given in Appendix G.

Air was supplied to the combustor from a 3 h.p. blower through a 75 mm diameter air pipe and a 460 mm long conical diffuser, made of 2 mm sheet metal. The diffuser diverged from 75 mm diameter at one end where the air pipe was connected to 300 mm square section at the other end where it was fixed to the distributor plate. A 25 mm diameter and 50 mm long pipe was welded to the air pipe where it took a 90° turn before joining the diffuser and provided with a plug. Any bed material that fell through the distributor holes in between experiments was collected
in this portion and removed, with the plug taken off by running the blower. A 3 mm rubber packing was used between the diffuser and the distributor and a 6 mm asbestos packing between the distributor and the bottom test section to prevent air leakage and ensure thermal insulation. The flow of air through the system was regulated by a throttle valve fixed to the air pipe.

The combustor test section was covered by free board section of same cross section. Asbestos packings of 6 mm thick was used between them to prevent gas leakage and ensure thermal insulation. To minimise loss of combustible particles by elutriation with the gas stream, this section was made to be 660 mm in height. It was made from a 3 mm thick mild steel plate. A sight tube, fitted with fireglass at one end and inclined at 45° was fixed to this section. It was a steel tube of 25 mm diameter and provided visual observation of the elutriating particles. The free board section was covered on top by a 6 mm thick mild steel plate. A 100 mm diameter steel pipe attached to this plate served as the chimney.

A photographic view of the experimental set up is given in Figure 4.5.

4.2 Screw Feeder

A screw feeder, schematically shown in Figure 4.6 was used to deliver coal to the combustor. A 100 mm diameter
FIGURE 4.5 PHOTOGRAPHIC VIEW OF EXPERIMENTAL SET-UP
FIGURE 4.6 SCREW FEEDER

A - HOPPER  B - REGULATOR  C - FEED SCREW  D - OUTLET  E - HOUSING

ALL DIMENSIONS IN MM
and 900 mm long steel pipe was used as the housing. A slot 50 mm wide and 300 mm long was milled at a distance of 15 mm from one end of the steel pipe for attaching the feed regulator which, in turn, was fixed to the hopper. A right hand, standard pitched, tapered screw mounted in gun metal bush bearing was employed for feeding the fuel. The inflow of coal from the hopper to the housing was controlled by adjusting a plate provided in the feed regulator. The coal was discharged through a spout of 40 mm diameter. A 40 mm diameter metallic tube connected to the spout delivered the fuel to the top of the bed through an opening in the free board section. The feeder was driven by a 230 volts, single phase, 0.5 h.p. geared motor running at 20 rpm. This assembly was mounted at a height of 1m above the distributor plate in a frame.

The salient design details of the screw feeder are furnished in Appendix H.

4.3 Crusher

The crusher used for crushing coal, is shown schematically in Figure 4.7. It mainly consisted of a hopper, crushing chamber, gear wheels and spring loaded bearings. The hopper was made of 2 mm thick sheet metal and could hold 10 kgs of coal. The crushing chamber consisted of two spur gear wheels, 160 mm diameter and 60 mm wide with a module of 3.0. One gear wheel was driven
FIGURE 4.7 COAL CRUSHER

A - CRUSHING CHAMBER  B - DRIVE GEAR  C - DRIVEN GEAR
D - SPRING LOADING ARRANGEMENT  E - COAL HOPPER

FIGURE 4.7 COAL CRUSHER
by an electric motor through a gear reduction unit and the other engaging with it was spring loaded. The size to which the particles were crushed was regulated by varying the compression of the spring. The crushed coal was then sieved to the required size and then burnt in the combustor. The crusher was run at a speed of 100 rpm.

4.4 Instrumentation

4.4.1 Static pressure probe

The static pressure of the fluidizing gas in the bed at various locations along the wall surface was measured by static pressure probes. A schematic diagram of the probe is shown in Figure 4.8. They were made of 60 mm long steel pipe with 6 mm outer diameter and 3 mm inner diameter. They were located along the walls of the test sections at intervals of 25 mm, the first one being located 12.5 mm above the bottom end. A right through hole of 6 mm diameter was drilled in the water jacket of the test section, the probe was inserted and then secured to the walls by brazing. Care was taken to ensure that one end of the probe was flush with the inner wall surface of the combustor. These probes were connected through flexible transparent PVC tubing, to a multilegged manometer using water as the measuring fluid. By removing the PVC tubing, some of these probes were also used as the insertion points for the temperature probe used for measuring the bed temperature.
A - INNER WALL OF TEST SECTION  
B - OUTER WALL OF TEST SECTION  
W - WATER JACKET  
ALL DIMENSIONS IN INCHES

FIGURE 4.8 STATIC PRESSURE PROBE
4.4.2 Bed temperature probe

The temperature of the bed was measured by a 3 mm diameter inconel metal sheathed, chromel-alumel thermocouple with magnesium oxide insulation as shown in Figure 4.9. The thermocouple junction was welded to the protective inconel metal sheath to give faster response.

4.4.3 Fluxmeter

The total heat flux to the surface of the tube was measured by a fluxmeter shown schematically in Figure 4.10. A steel plug, 10 mm diameter and 15 mm long was used as the sensing element. Its edges were chamfered to 45° for a distance of 1 mm. To minimise the effect of roughness that might be caused to the combustor surface of the plug due to erosion by the bed particles during experiments, it was given a rough finish at that surface. The temperature at the ends of the plug were measured by chromel-alumel thermocouples. The thermocouple wires used had two layers of asbestos and glasswool insulation. The 22 gauge thermocouple wires were separated at the ends and made bare for a length of 3 mm to facilitate making the bead. At the combustor end of the plug a 2 mm diameter hole was drilled and countersunk at 45° to a depth of 2 mm. A thermocouple to measure the temperature of this surface was inserted into this hole such that its bead was flush with it and then brazed. A 1.5 mm diameter and 1.5 mm deep hole was drilled at the other surface of the plug such that its axis
FIGURE 4.9  BED TEMPERATURE PROBE

A - INCONEL METAL SHEATH
B - CHROMEL-ALUMEL THERMOCOUPLE
C - ASBESTOS INSULATION
1. STEEL SENSING PLUG
2. COLLAR FOR MOUNTING
3. 60mm O.D. STEEL TUBE
4. BRASS CASING
5. WATER LINE
6. DIFFERENTIAL THERMOCOUPLE

FIGURE 4.10 FLUXMETER
was 5 mm away from that of the hole. The bead of the other thermocouple was inserted into this hole and then carefully brazed. The sensing plug was then housed in a brass casing and then the intervening space was filled with araldite at the edges of the plug. The remainder of the space was left as an air gap to minimise the heat losses from the plug. The two thermocouple wires were taken out through a hole at the bottom of the casing and the gap filled with araldite to prevent water leakage. The water from the thermostat pump was circulated in the space at the lower portion of the casing. The inner surface of the sensing plug was thus cooled by water at constant temperature, while the other surface was exposed to incident heat flux. The resulting difference in temperature of the two surfaces was measured by the differential e.m.f. produced by the two thermocouples fixed to these surfaces. The fluxmeter was mounted to the tube by means of a brass collar.

4.4.4 Radiometer

The radiative heatflux to the tube surface was measured by a radiometer shown schematically in Figure 4.11. A thermistor as shown in Figure 4.12 was used as the sensing element. A quartz plate of 30 x 7 x 2 mm thick was used to filter the incident conductive heat flux. The thermistor was located in a chamber of 30 mm length, 5 mm width and 4 mm deep in the radiometer casing. The lower side of the thermistor chamber was circulated with
FIGURE 4.11 RADIOMETER

1. QUARTZ PLATE
2. THERMISTOR
3. THERMISTOR LEAD POINTS
4. WATER BATH
5. WATER INLET
6. WATER OUTLET
7. 60mm O.D. STEEL TUBE
**FIGURE 4.12 THERMISTOR**

**ALL DIMENSIONS IN MM**

MAXIMUM TEMPERATURE RATING = 200°C
RESISTANCE AT 25°C = 22000 OHMS
MATERIAL CONSTANT : K ± 10% = 4000
TIME CONSTANT AT 25°C = 6 SEC.
TYPE : BAX 22 K
MANUFACTURER : SEMICONDUCTORS LTD. INDIA

<table>
<thead>
<tr>
<th>TEMPERATURE °C</th>
<th>RESISTANCE OHMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>75000</td>
</tr>
<tr>
<td>50</td>
<td>7750</td>
</tr>
<tr>
<td>100</td>
<td>1500</td>
</tr>
<tr>
<td>200</td>
<td>152</td>
</tr>
</tbody>
</table>

**FIGURE 4.12 THERMISTOR**
water at constant temperature. The thermistor leads were taken out through holes in the bottom wall of the chamber and then through the cover plate of water bath. Proper care was taken to fill the gap in the chamber and cover plate holes with araldite to prevent water leakage. Two 4 mm diameter copper tubes were brazed to the cover plate to serve as water inlet and outlet. The cover plate was fixed to the water bath by screws. A coller plate was used to mount the radiometer with the test tube. In the coller plate, a step groove of 30 x 7 x 2 mm depth with an opening of 26 x 5 mm at the centre was milled to accommodate the quartz plate and to allow the radiant flux to pass through. The quartz plate was secured in its place by a holder plate of 0.5 mm thick with an opening of 26 x 5 mm.

4.4.5 Hohlraum

The fluxmeter and radiometer were calibrated by hohlraums shown schematically in Figure 4.13 and 4.14 respectively. It was a rectangular box, made of mildsteel plate of 6 mm thickness to a size of 100 x 100 x 250 mm. A circular opening of 16 mm was provided at one end of the hohlraum used for the calibration of the fluxmeter. In the other hohlraum used for the calibration of the radiometer, a rectangular slot of 35 x 5 mm was provided to allow radiant heat to pass through. Before welding together to make the box, the radiating surfaces of the plates were made rough by cutting 90° angles in a shaper. Twelve
FIGURE 4-13: HOHLRAUM FOR THE CALIBRATION OF FLUXMETER

A - MILD STEEL BOX
B - HEATING ELEMENT
C - THERMO-COUPLE
D - ASBESTOS INSULATION
ALL DIMENSIONS IN MM

1. 1
A - MILD STEEL BOX  B - HEATING ELEMENT  C - ASBESTOS INSULATION

ALL DIMENSIONS IN MM

FIGURE 4.14  HOHLRAUM FOR THE CALIBRATION OF RADIOMETER
inconel metal sheathed, asbestos insulated chromel-alumel thermocouples, two on each surface were used to measure the temperature of the inner surface of the hohlraum. 3 mm diameter holes were drilled along the centre line of the plates at 1/4 points. These holes were countersunk at an angle of 45° to a depth of 1.5 mm on the rough surface. The thermocouples were inserted from the unmachined surface and then brazed carefully at the rough surface. After the plates were welded together to form the box, 18 gauge nichrome wire covered by porcelain beads of 5 mm outer diameter, 1.5 mm inner diameter and 6 mm long was wound over the hohlraum. An 8 mm diameter asbestos rope was wound over the heaters in two layers to provide thermal insulation. This was then covered with 10 mm thick asbestos powder on all the sides. The heating elements were supplied electrical power from four dimmerstats connected to a 230 volts, 50 cycles, A.C. mains supply. The heater on the two ends and sides were connected to four separate dimmerstats of 10 amps capacity supplying energy to the heating elements in parallel.

4.4.6 Instrumented tube

The radiometer and fluxmeter were mounted flush with the outer surface of the steel tube on either side 25 mm away from the centre of the tube. A rectangular slot of 45 x 9 mm was made in the outer surface of the tube. Around the slot a 3 mm wide step was milled for a
depth of 2.5 mm to seat the collar plate, connecting the radiometer with the tube.

A 16 mm diameter hole was drilled in the tube surface, to accommodate the fluxmeter. Around the hole, a step of 3 mm width was milled for a depth of 2.5 mm, to seat the collar, which connects the fluxmeter and the tube.

The radiometer and the fluxmeter were inserted from either end of the steel tube and mounted in their positions. The water at a constant temperature of 40°C was circulated to the meters from a thermostat pump, through copper tubes. The copper tubes circulating water and the leads of the sensing elements were taken out through rubber packings between the flanges on either ends of the tube.

The surface temperature of the steel tube was measured by a 22 gauge chromel-alumel thermocouple, having two layers of asbestos and glasswool insulation. A 2 mm diameter hole was drilled on the surface of the tube and countersunk to 45° for a depth of 1 mm, at 180° away from the centre line of the radiometer and fluxmeter. The thermocouple was inserted from outside and fixed flush with the outer surface of the tube. The thermocouple wires were also taken out through a hole in the rubber flange at one end of the tube. The schematic diagram of the instrumented tube is shown in Figure 4.15. Water was passed through the instrumented tube taking care to ensure that the tube was full of water.
A — RUBBER FLANGE  C — CONSTANT TEMPERATURE WATER CIRCULATING TUBES
F — FLUXMETER  R — RADIOMETER  T — THERMOCOUPLE
FL — FLUXMETER LEAD WIRES  RL — RADIOMETER LEAD WIRES

FIGURE 4.15 INSTRUMENTED TUBE
The tubes with outer diameters of 50, 42, and 32 mm were instrumented similarly with fluxmeter, radiometer and thermocouple. These tubes were fitted with sleeves of 60 mm outer diameter, so that they fitted into the holes in the lock nut and spacer nut in the 200 mm test section. The inner end of the sleeve was flush with the inner surface of the combustor.

4.4.7 Indexing arrangement

An indexing arrangement was used to index the instrumented tube in steps of 30° along the circumference. Markings were cut for a width of 0.5 mm and to a depth of 1 mm in the periphery of a 50 mm pipe coupling in a milling machine by indexing the coupling in steps of 30°. A reference marking was also cut for a width of 0.5 mm and to a depth of 1 mm in a 50 mm pipe as shown in Figure 4.16. The markings in the coupling were made to coincide with the reference marking by rotating the instrumented tube by a handle. The indexing arrangement was connected to the instrumented tube by a flange.
A - MARKINGS IN THE COUPLING  
B - REFERENCE MARKING IN THE PIPE  
F - PIPE FLANGE H-HANDLE  

FIGURE 4.16 INDEXING ARRANGEMENT