HEAT TRANSFER INVESTIGATIONS IN A SLURRY BUBBLE COLUMN: QUARTERLY REPORT FOR THE PERIOD JULY-SEPTEMBER 1987

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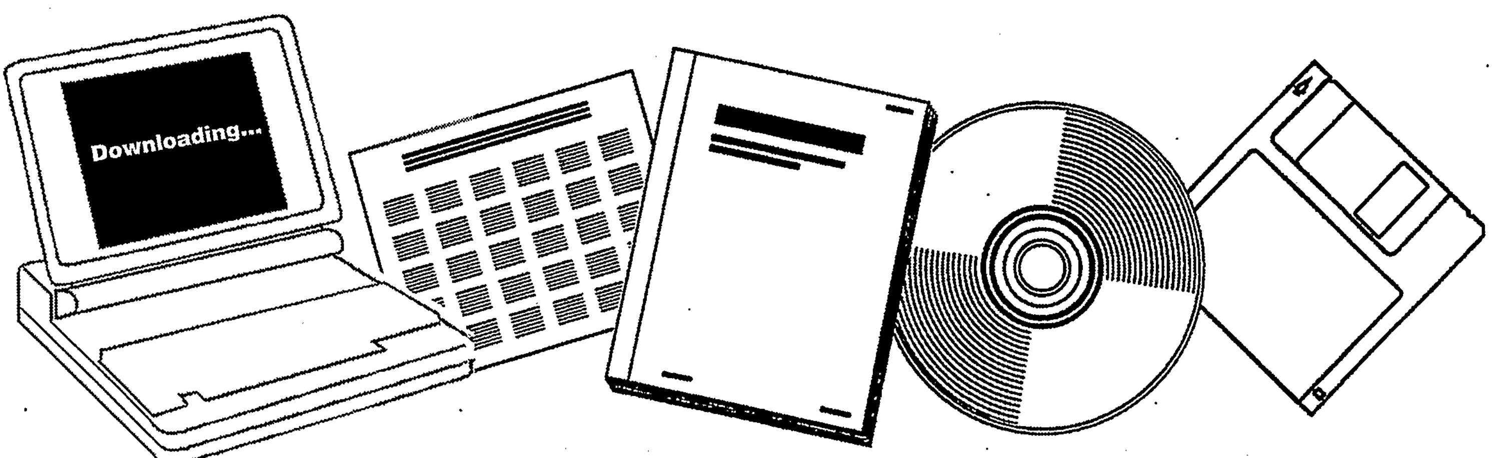

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HEAT TRANSFER INVESTIGATIONS IN A SLURRY BUBBLE COLUMN

Quarterly Report for the Period July-September 1987

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OBJECTIVES

To investigate the heat transfer characteristics in two slurry bubble columns (10.8 and 30.5 cm) as a function of system and operating parameters.

SUMMARY

Fabrication and installation of the 10.8 cm internal diameter Plexiglas slurry bubble column as well as of the associated gas and slurry flow loops is completed. The heat transfer probes together with its power supply system, and temperature measurement circuit have been constructed and are functional. Details of this facility and the results of some of the preliminary test runs completed to-date are described in this report. Substantial design and partial fabrication of the 30.5 cm diameter pyrex glass slurry bubble column is completed, and many components required to complete the remaining parts of the system are under order. Review and collection of the literature dealing with the hydrodynamics and heat transfer in two-and three-phase slurry bubble columns has been initiated.

DESCRIPTION OF TECHNICAL PROGRESS

TASK 2

The schematic of the 10.8 cm diameter Plexiglas slurry bubble column with its associated measurement and supply loops is shown in Figure 1. Many design details and technical descriptions of various components are given in the quarterly report for the period September-November, 1986, and will not be repeated here. Only the details of the new measuring circuits developed during this quarter and not reported earlier will be described. In addition, several experimental runs conducted with water (tap and distilled) and with and without heat transfer probe bundle to understand the hydrodynamic behavior will be described. Preliminary testing of the heat transfer probe to assess the power requirements, and to establish the adequacy of the electrical measuring circuit are briefly reported in the following.

The air distributor plate for the calming section of the bubble column and having five bubble caps fabricated from hexagonal cap steel screws showed signs of rusting on use with air-water system. These were, therefore, replaced with newly fabricated stainless steel bubble caps, and have been functioning quite satisfactorily since then. The dimensions of these bubble caps are exactly the same as those of the earlier ones. Five thermocouple probes employing copper-constantan wires have been designed, fabricated and installed along the height of the column to establish the bulk column temperature required for the computation of the heat transfer coefficient. The design of such a probe is shown in Figure 2. The thermocouple is made from 28 AWG copper and constantan wires with glass braid insulation. The two wires are made bare and welded together to form a junction which is then imbedded in a well on the front face of a specially designed Teflon plug by using copper cement as shown in the figure. The plug is force fitted in a stainless steel tube of 6mm outer diameter, 1mm wall thickness and 15cm long. The thermocouple wires are threaded through the plug and the tube and are locked in position by a PVC shrink tube and epoxy cement at the other end of the stainless steel tube. The thermocouple probes at five vertical positions along the column wall can be inserted to various radial depths and locked in position by the swagelok connector arrangement as shown in Figure 2.

In these experiments the heat exchanger configuration is simulated by a bundle of five heat transfer probes, each 1.9 cm in outer diameter and 188cm long. Each of these probes are made from Plexiglas tubes and have a 30.48cm long brass section inside which is housed a calrod heater. At either ends of the brass section are Teflon sleeves to minimize end heat loss. The five probes of the bundle are arranged in a square configuration. The central probe is placed along the column axis while the remaining four probes are placed around it in square arrangement. The distance between the axes of the central and outer probes is 4.6 cm. For temperature measurement copper-constantan thermocouples are bonded to the brass surface in milled grooves with technical quality copper cement. Three thermocouples are positioned on the outer probes each separated by a 120° interval and located at 5.08, 15.24 and 25.4 cm from the end of the brass section. The central probe has five thermocouples and these are placed 72° apart at 5.08, 10.16, 15.24, 20.32 and 25.4 cm from the end of the brass section. To prevent vibration and movement of this probe bundle inside the column four spacer rods have been provided, each passing through three tubes and providing a snug fit in the column. The probe bundle is suspended in the column by a support plate sitting on three support rods. Each probe is attached to the support plate though a support ring.

Seventeen thermocouples from these five heaters designated hereafter as A, B, C, D and E are connected to terminal strips located on a wooden board. Five thermocouples used for measuring the bulk column temperature as mentioned above are also brought to this board through a thermocouple selector switch as shown in Figure 3. The output of all these twenty-two thermocouples is fed to a Hewlett Packard data acquisition/control unit model number 3497A with option No. 001, digital voltmeter with I source (DVM); and No.020, thermocouple compensation. The DVM assembly is a systems quality, 5 1/2 digit, 1 microvolt sensitive DC voltmeter which can measure voltages up to 119.9999 volts. The DVM assembly is fully guarded and uses an integrating A/D conversion technique which provides excellent common and normal mode noise reduction. The DVM includes a programmable three-level current source. The option 020 assembly adds a special isothermal connector block for Thermocouple compensation to eliminate unwanted measurement errors when measuring thermocouple voltages. This unit in conjunction with software compensation can convert the measured voltages to the corresponding temperatures and for this interface HP9122D disc drive is necessary. The latter has two flexible disc drives and allows the computer which is a HP 310 controller either to read data stored on the disc or to write data on the disc with the help of HP 4620A United States - English keyboard. Finally the processed data are displayed on a HP35731A monochrome video, may be recorded on a HP2225A Think Jet printer. A HP7440A eight-pen graphics plotter for A4/A-Size media with HP-1B interface option has been ordered to process the data. A block diagram of all these units which constitute our data recording and processing workstation is displayed in Figure 3.

To energize the five heaters provided in the heat transfer probes with known and constant electrical power a system of master-slave series connection of the outputs of three power supplies, as shown in Figure 4, is developed. Any of the five heaters can be connected to a HP6274A D.C. power source comprising of a master and two slaves, each providing 0-60V and 0-15A with a power regulation of 0.01 percent. This arrangement of auto-series operation is characterized by one-knob control in the master and the amplitude of the slaves output voltage is equal to (or proportional) to that of the master. As shown in Figure 4, a voltmeter and an ammeter enables to establish accurately the power fed to a heater.

A series of experiments was performed in this column with air-water system without the probe bundle. As shown in Figure 5, the heights of the initial settled tap water column (H_S) was chosen as 60, 70, 80, 91, 95 and 99 cm and in each case the expanded water column height (H_e) was noted as the air velocity bubbling through the column was increased from zero to about 0.35 m/s. These data were manipulated to compute the average air holdup, $\bar{\epsilon}_g$, from the following relation:

$$\bar{\epsilon}_g = (H_e - H_S)/H_e$$

with the results reported in Figure 6. As shown in Figure 1, pressure measuring ports are provided at fixed interval along the column. By measuring the pressure drop, ΔP, across a section of known height of the column, H, the local air holdup, ϵ_g, can be computed from the following relation:

$$\epsilon_g = 1 - \frac{\Delta P}{H\left(\rho_w - \rho_a\right)}$$

Here ρ_w and ρ_a are the densities of water and air respectively. In Figure 7, are shown these ϵ_g values as a function of air velocity at various heights of the water column. The latter values are indicated as ordinates on the right.

A series of similar runs were conducted with distilled water and the results are reported in Figures 8, 9 and 10. As expected these results are quite similar to those shown in Figures 5, 6 and 7. Next similar experiments were performed with the five heat transfer probe bundle occupying approximately 15 percent of the column volume, and these results are displayed in Figures 11, 12 and 13. Qualitatively these results are similar to those obtained with water and without any internals, to the extent the curves exhibit similar nonmonotonic variation with increasing air velocity. On the quantitative basis it appears that air holdup values change with the presence of baffles. A quantitative interpretation of these results and their comparison with similar investigations conducted in the past by other workers is in progress and will be presented in the future reports.

Very preliminary experiments have been conducted to assess the appropriateness of the heat transfer probes and the measuring equipment described above. The system is found to be adequate to determine heat transfer coefficient between the immersed heater surface and the air-water system for varying air velocities. The experiments are being planned to determine heat transfer coefficients at different locations in the column and these results will be reported in the near future.

TASK 3

Work has progressed on the design and fabrication of the 30.5 cm diameter slurry bubbly column. The schematic of the planned installation is shown in Figure 14. The four glass sections of total height 300 cm (15), the four stainless steel inserts each 7.5 cm high (14), and the bottom conical section (10) constituting the main column are assembled together on a specially designed metal structure. The top end diverger section (16) is designed but is yet to be fabricated. The air supply system consisting of a two-stage air compressor (1), refrigerator drier (2), filter (3), pressure regulator valve (4), rotameters (5), air pressure gage (6), gate valves (7), and one-way valve (8) is at the advanced stage of completion. The pressure measurement loop comprising of four purgemeters (18), four liquid manometers (19), pressure sensors (20), selector switch (21), pressure monitor (22), on-off valves (23), and four trap bottles (17) is in the stage of planning and various components and materials are being ordered. The temperature measurement circuit (24-30) is identical to the one being used with the 10.8 cm diameter bubble column and has been described earlier in this report.

The design details of the bubble cap and perforated plate air distributors are shown in Figure 15. The bubble cap distributor (9) is 203.2 mm diameter stainless steel plate having sixty-one bubble caps arranged in concentric circles as shown in Figure 16 with an equilateral triangular pitch of 28.6 mm. This plate is held in a cylindrical section (10) 44.4 mm high and terminating into the support and air inlet pipe (1) of 12 mm internal diameter. The pipe is introduced into the bottom conical section (8) of the column and is made air and liquid tight by attaching it to a specially designed stainless steel liquid drain adapter (3) through a Teflon coated nut (2). The adapter (3) also provides a similar air and liquid tight seal to conical glass section by a flange joint (6) using gasket (5) and a soft insert (7). The adapter also has a liquid drain (4) for removing any liquid that might drain into this section through the distributor plate from the main column. The air distributor square plate (11) is made from a stainless steel plate of 4 mm thickness and 420 mm to a side and has 0.8 mm orifices in a square arrangement of 9.5 mm pitch as shown in Figure 17. A stainless steel 200 x 200 wire cloth is mounted over this perforated plate to avoid solids weeping from the column into the distributor section. Six locating pins (14) are provided in the distributor plate (11) to ensure its correct positioning in the conical section (8). The perforated plate is held in the right position by three spacer studs (13).

A specially designed clamp system is fabricated to attach the flange at the second metal insert (14) to the support structure. This arrangement absorbs the load of the bottom column section, glass conical section (10), bubble cap distributor plate (11), perforated plate distributor (12) shown in Figure 14, and the liquid drain adapter (3) alongwith its accessories as shown in Figure 15, at the second metal insert from where the entire bottom column assembly is hanging. Similarly, the rest of the upper column section rests and is supported from specially designed damping system attached at the second and third metal inserts from the bottom of the column. The top end of the column is provided with a diverging section as shown in Figure 18. The stainless steel plate (1) of 420 mm in diameter and 4mm thickness is provided as a cover at the top end of the column. It has fifty seven holes of 25.4 mm diameter arranged in a square configuration with a pitch of 35 mm. The conical diverging section has a neck 50mm tall and a slant height of 150 mm. All these designed components are being fabricated and assembled. The required materials have been ordered and some of these have been received.

Some preliminary work has been initiated for producing particles for initial measurements with slurries of different concentrations and of particles of different sizes and properties. Table 1 lists the materials prepared to-date.

TASK 4

Review of the available literature has been started and a thorough collection of research articles published on the subject in general is progressing satisfactorily. It is planned to develop an authoritative assessment of the art to interpret our data and advance theory by introducing new ideas wherever necessary and as revealed by the comparison of our data with the theory.

Table 1. Details of materials prepared for slurry bubble column.

Sieve Size µm		Material	
	Iron shot (lb)	Magnetite powder (lb)	Copper shot (lb)
600-425	6.0		
425-300	12.0		
300-212	3.5		
212-150	1.5		241.0
150-125		5.0	1.0
125-106		11.5	0.25
106-75		10.0	0.13
75-0		15.5	

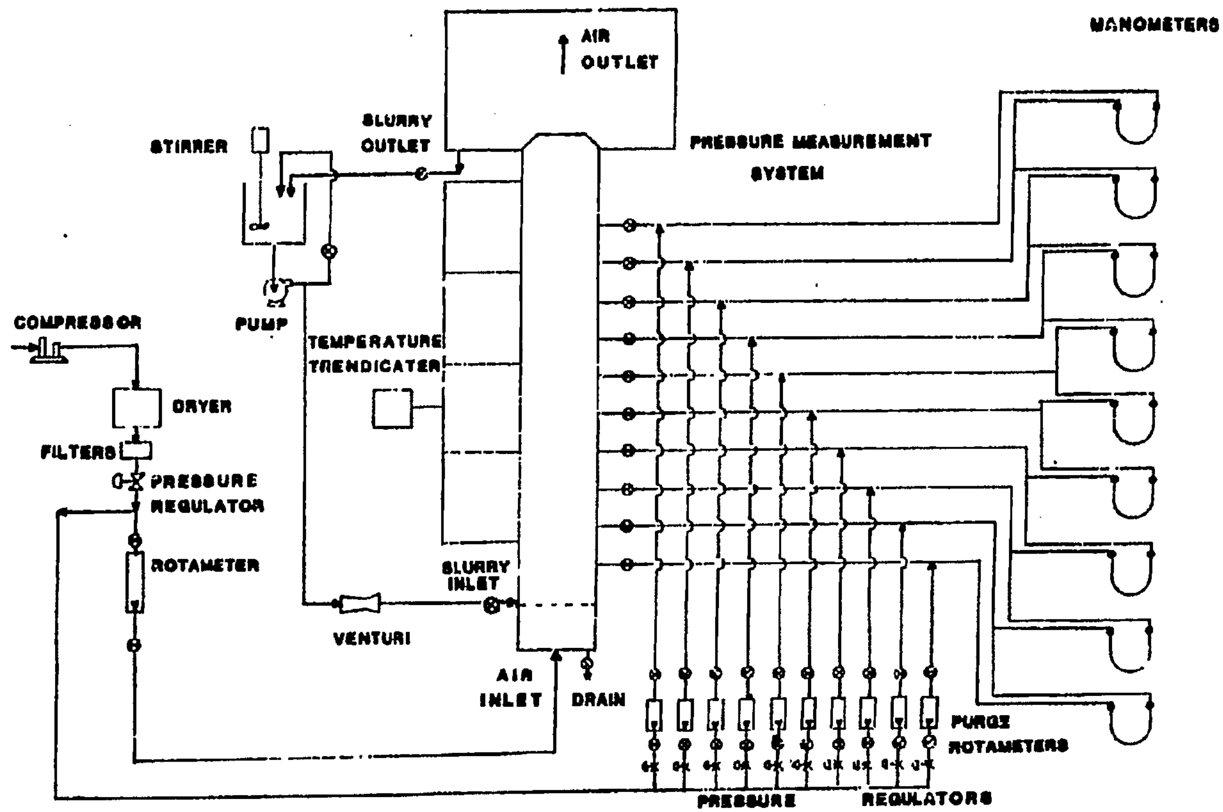

Figure 1. Schematic of the slurry bubble column showing the air supply loop, temperature and pressure measuring circuits.

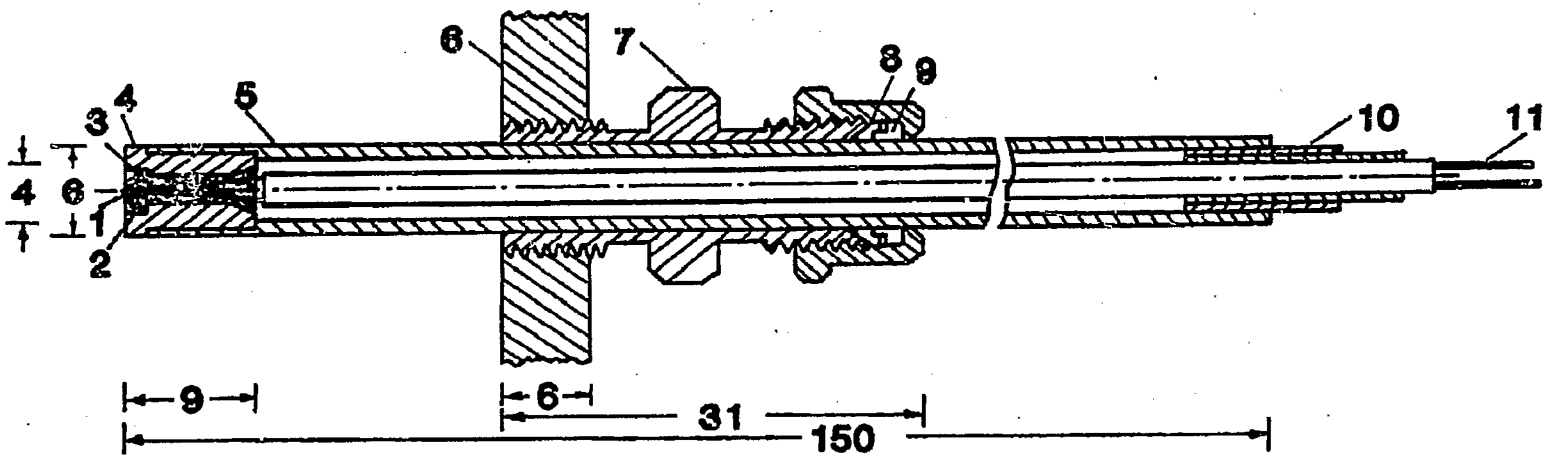

Figure 2. Design details of the thermocouple probe. (1) copper-constantan thermocouple, (2) thermocouple well, (3) copper cement, (4) Teflon plug, (5) stainless steel tube, (6) column wall, (7) swegelok connector, (8) front ferrule, (9) back ferrule, (10 shrink tube, and (11) thermocouple leads. All dimensions are in mm.

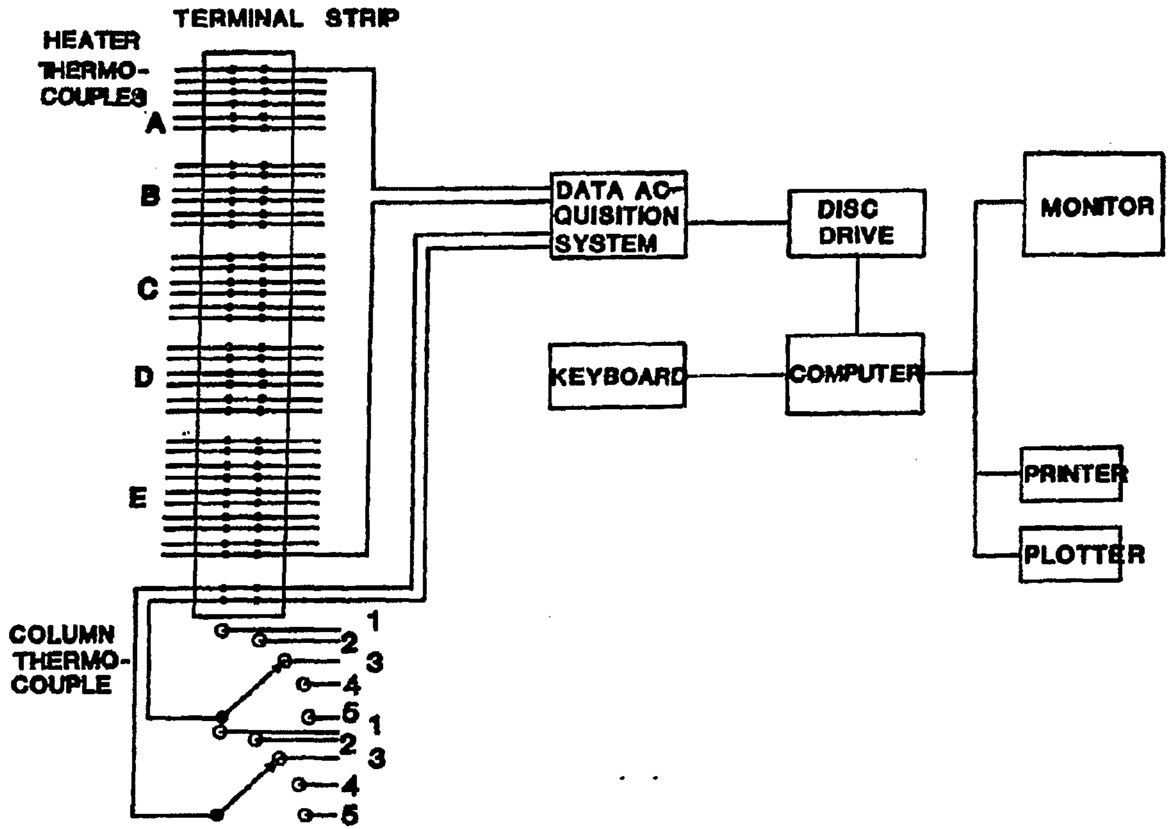

Figure 3. Detailed schematic of the temperature measuring system.

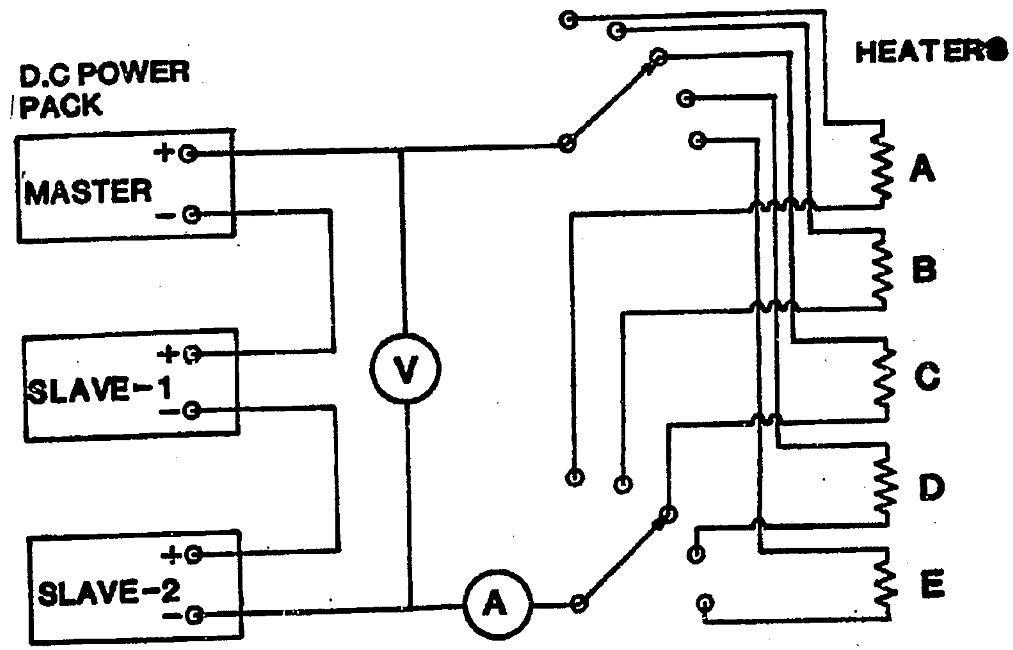

Figure 4. Schematic of the D.C. power supply system for the heat transfer probes.

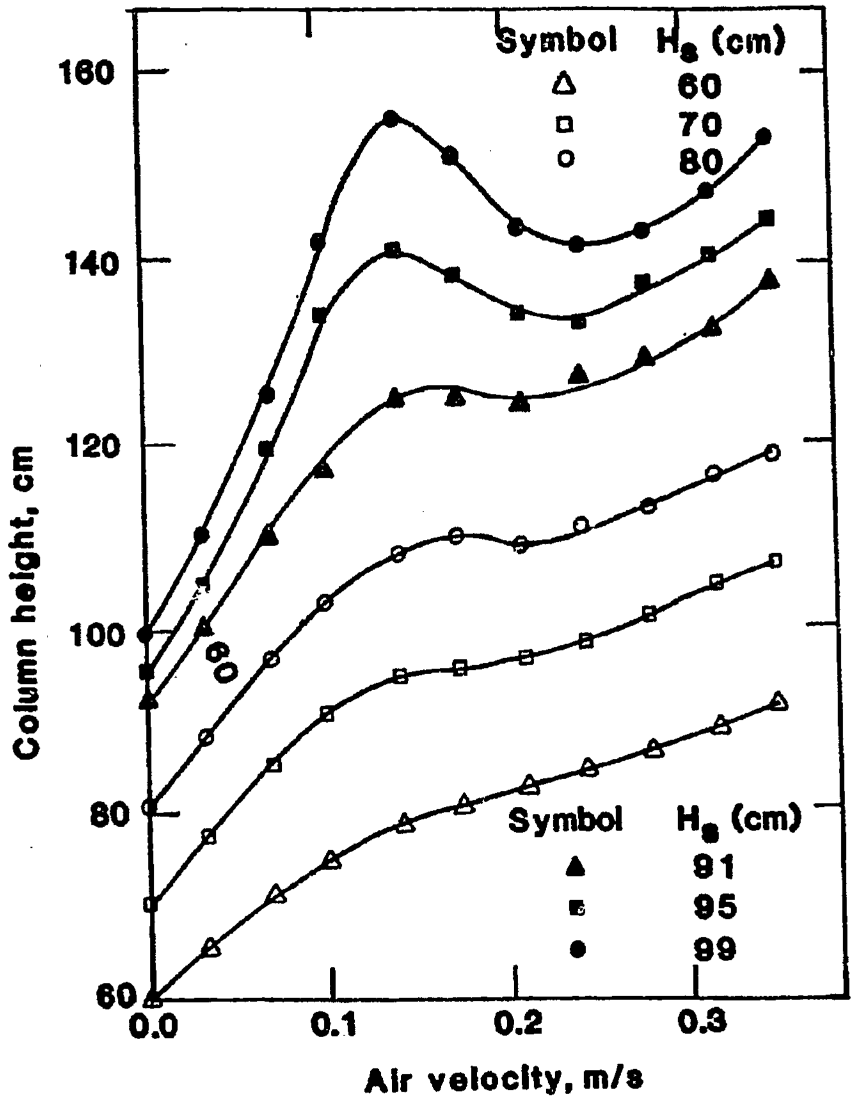

Figure 5. Variation of the column height with the air velocity for different settled heights of the tap water column.

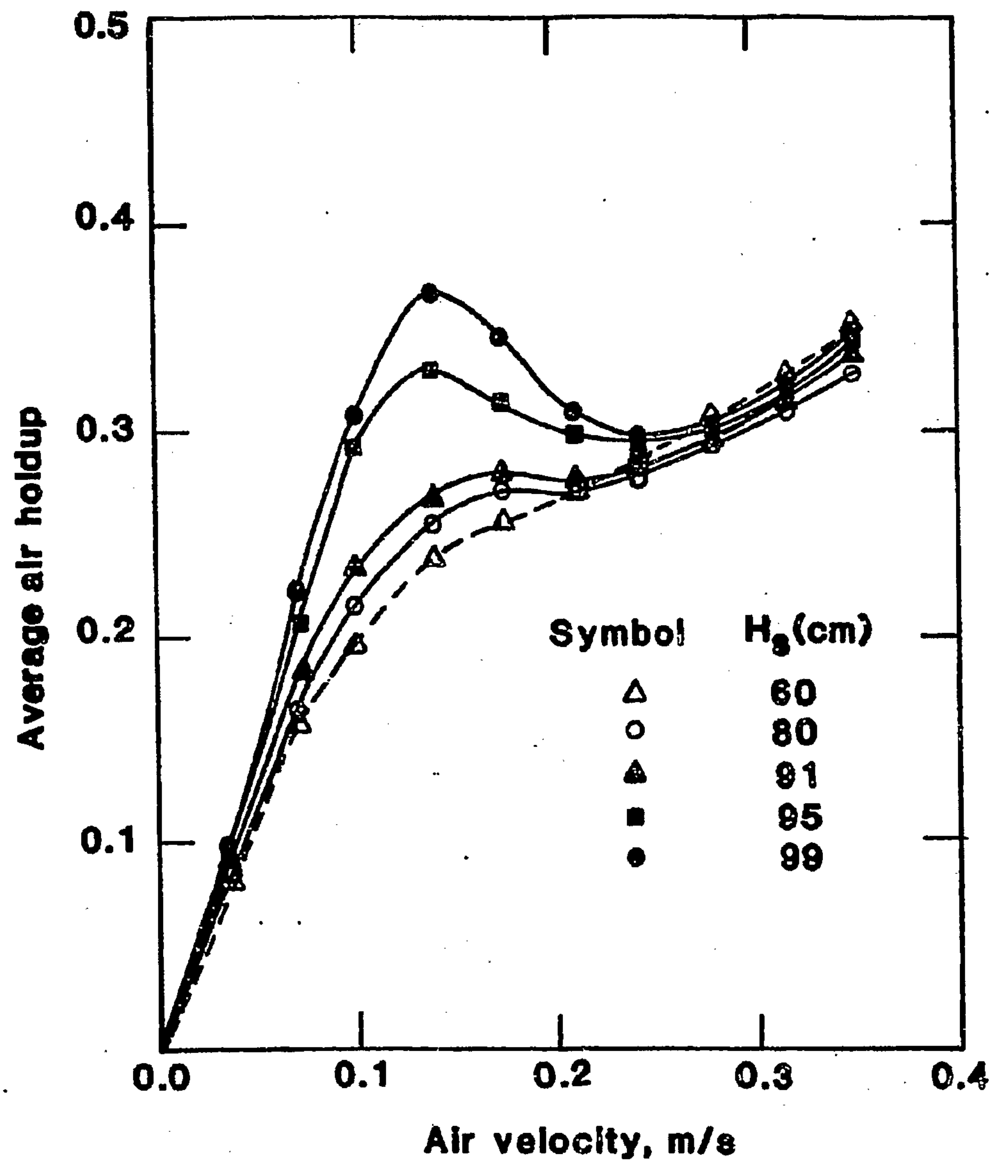

Figure 6. Variation of the average air holdup as a function of the air velocity for different settled heights of the tap water column.

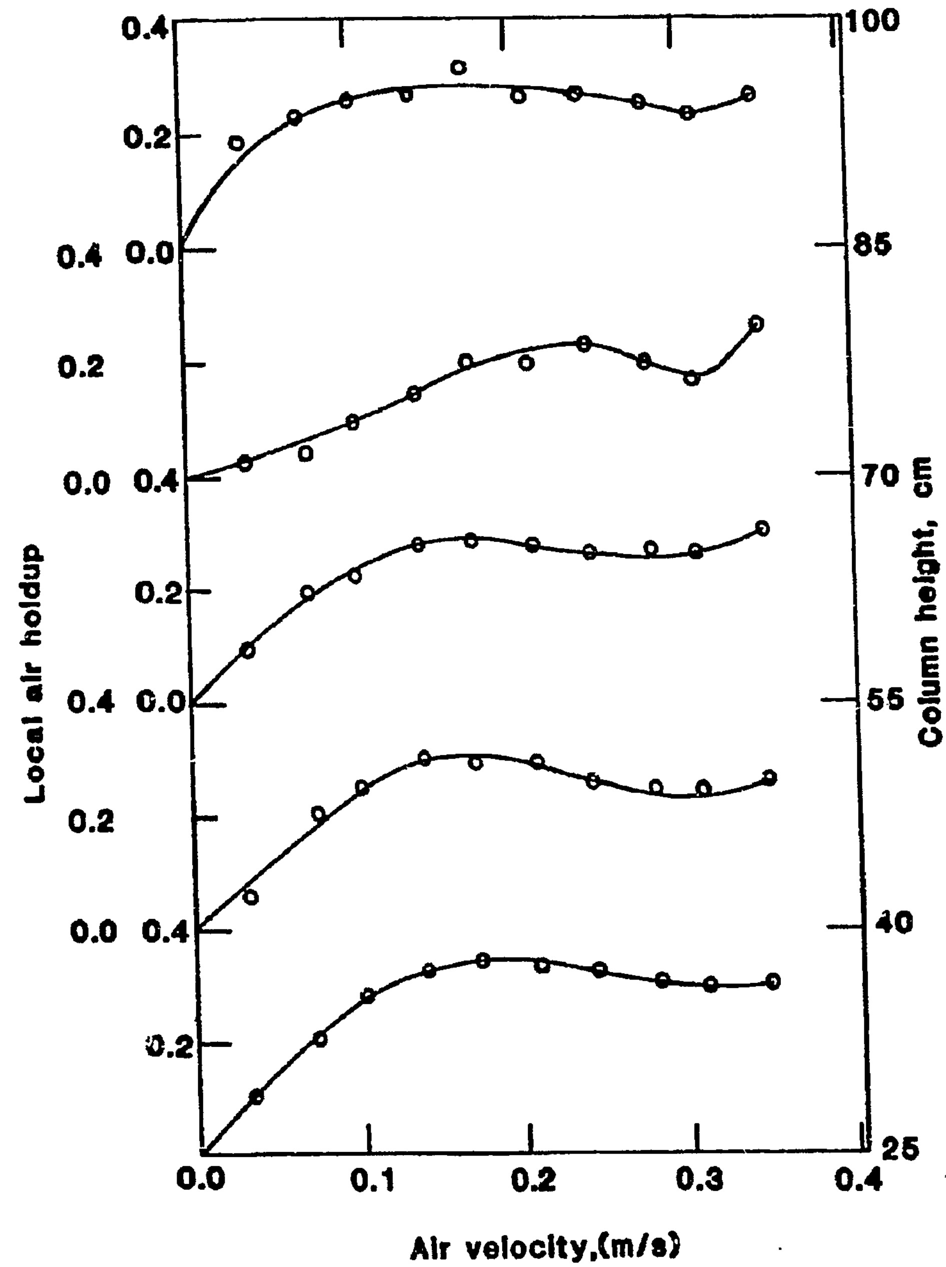

Figure 7. Variation of the local air holdup as a function of the air velocity at different column heights of the tap water column.

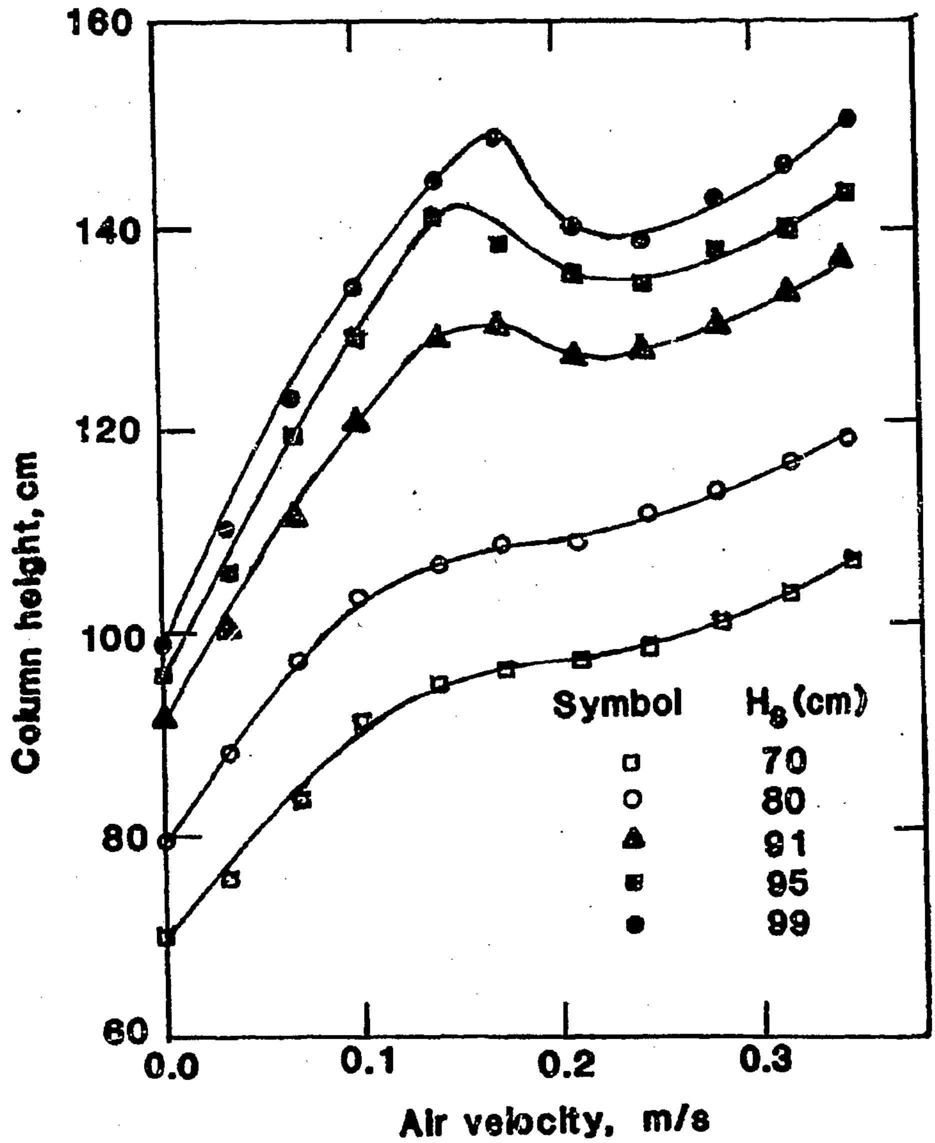

Figure 8. Variation of the column height with the air velocity for different settled heights of the distilled water column.

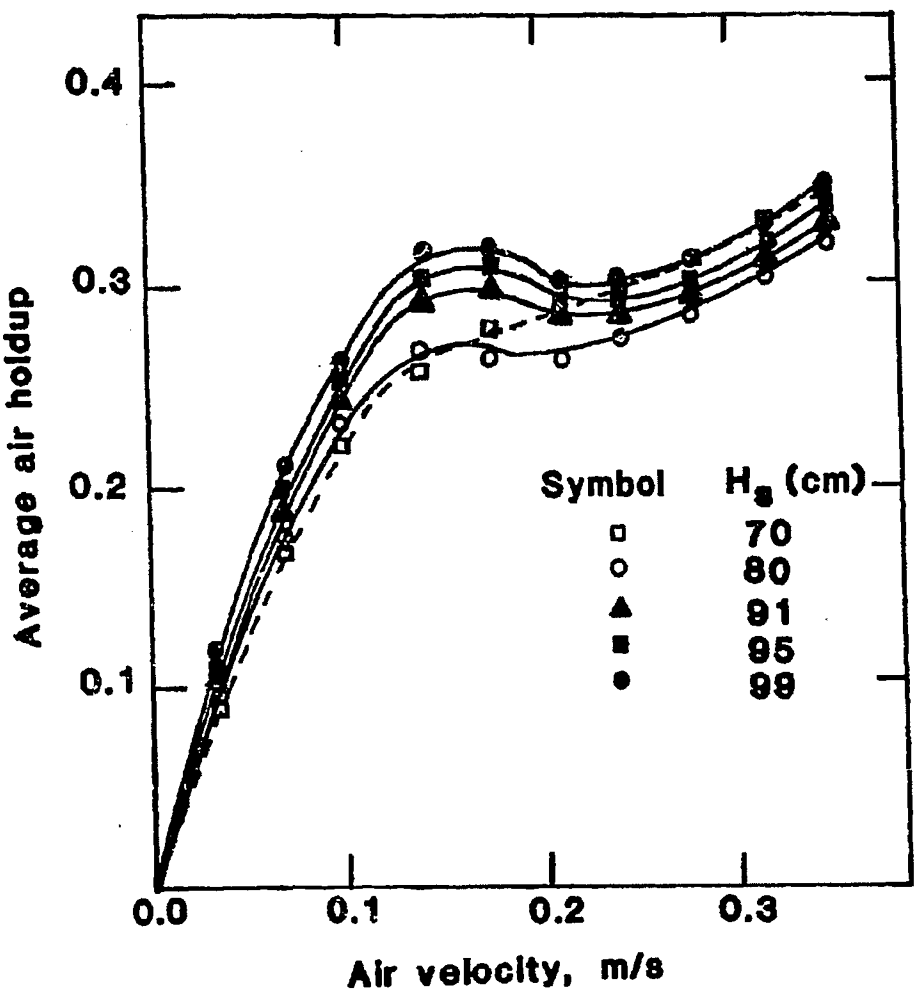

Figure 9. Variation of the average air holdup as a function of the air velocity for different settled heights of the distilled water column.

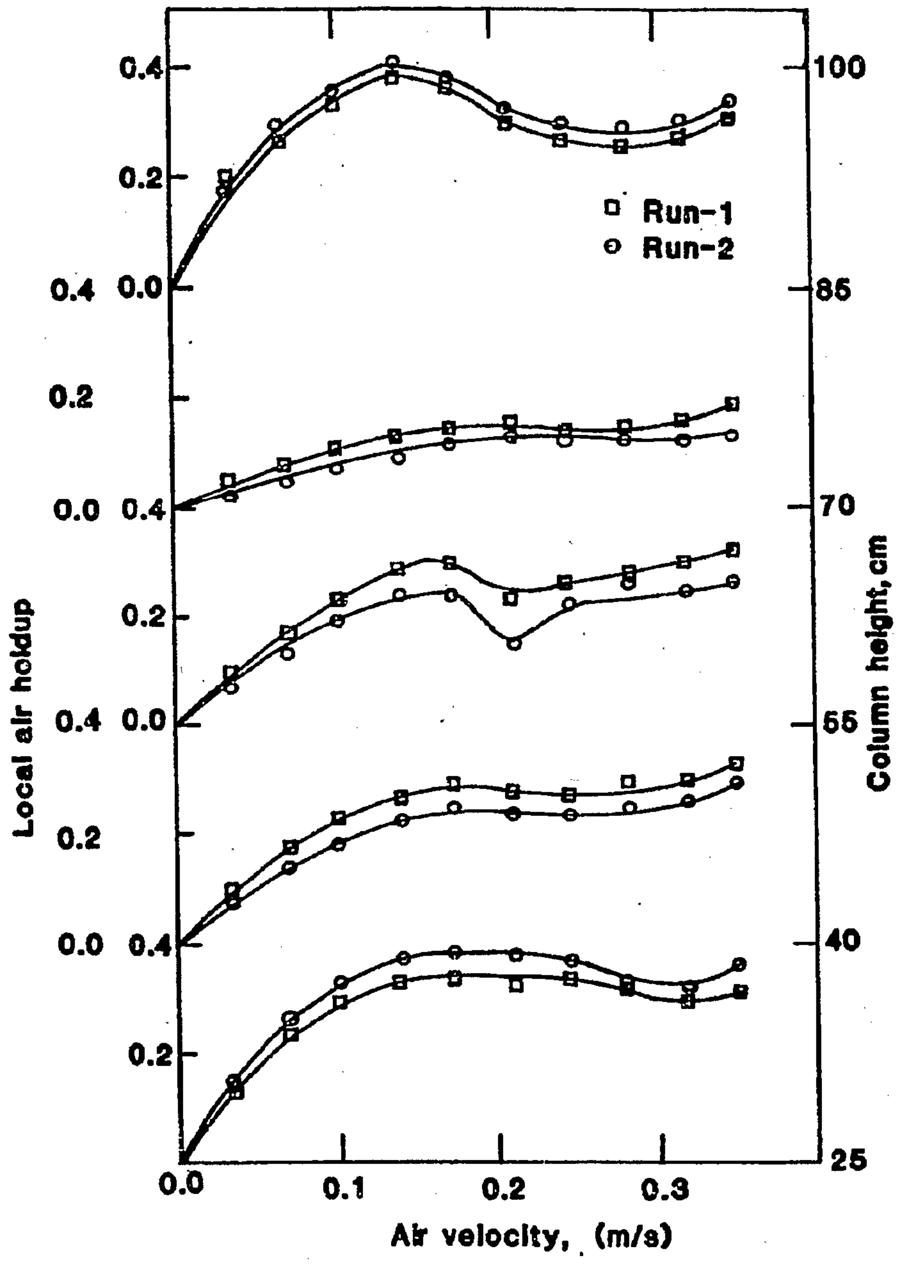

Figure 10. Variation of the local air holdup as a function of the air velocity at different heights of the distilled water column.

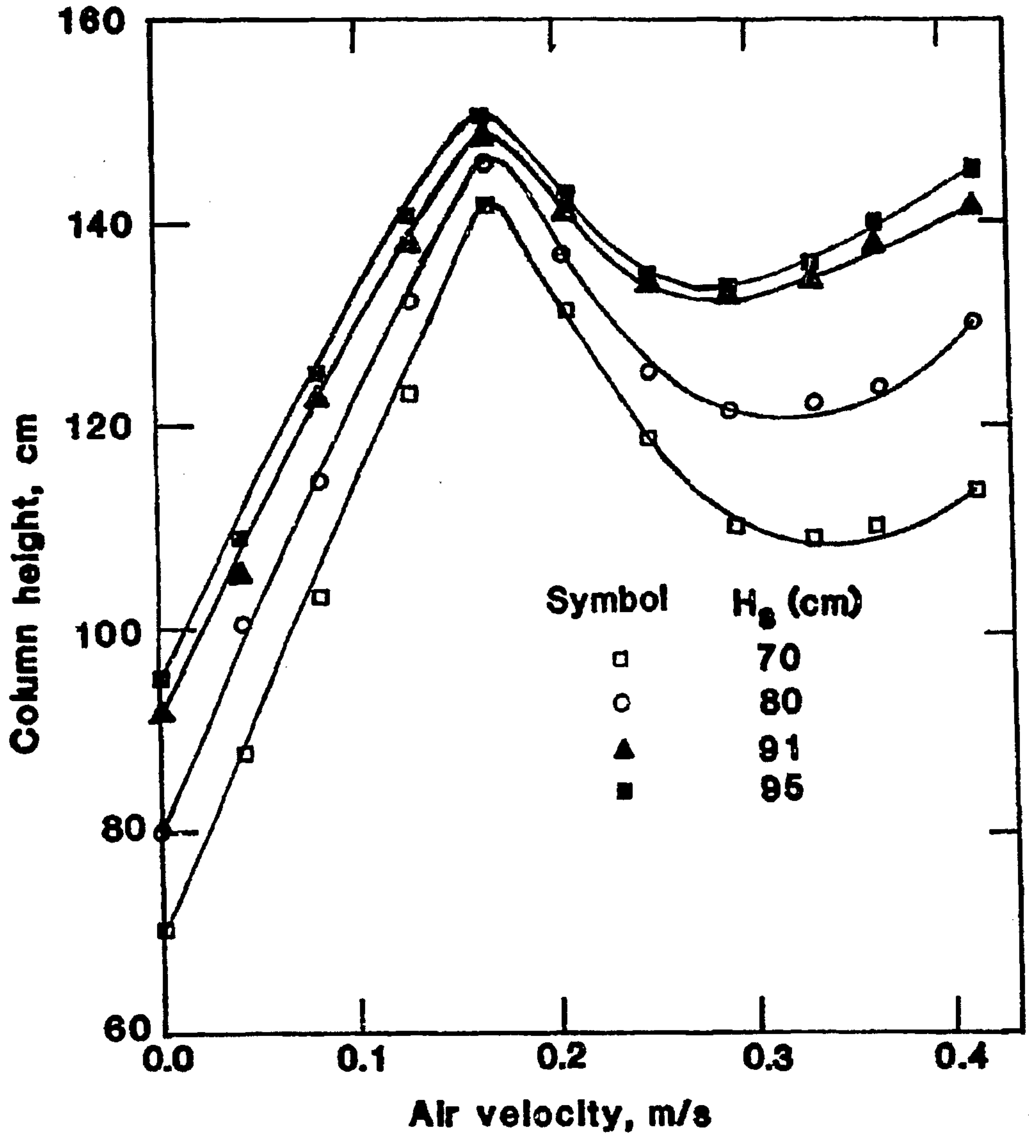

Figure 11. Variation of the column height with the air velocity for different settled heights of the distilled water column with a bundle of five vertical tubes.

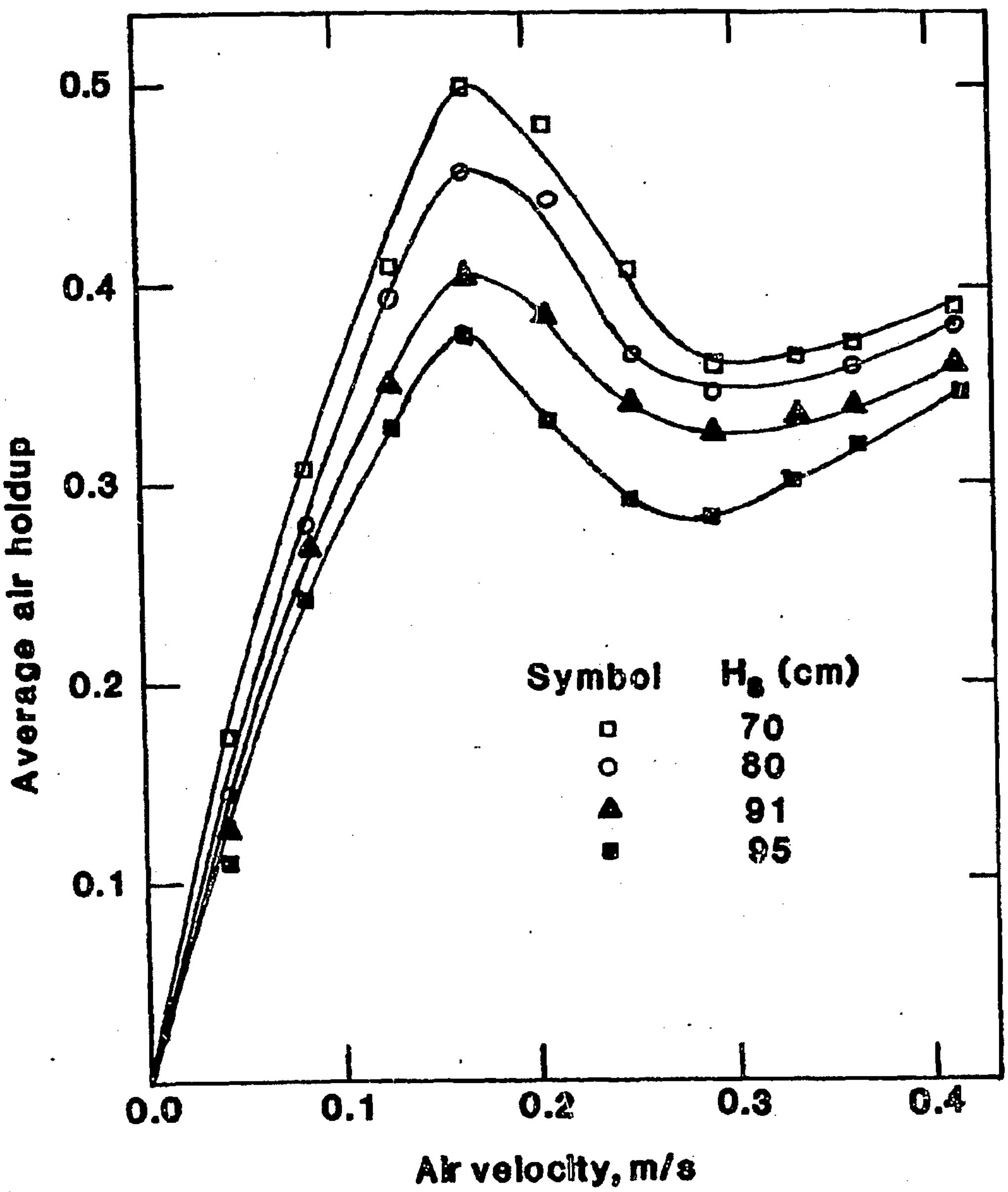

Figure 12. Variation of the average air holdup as a function of the air velocity for different settled heights of the distilled water column with a bundle of five vertical tubes.

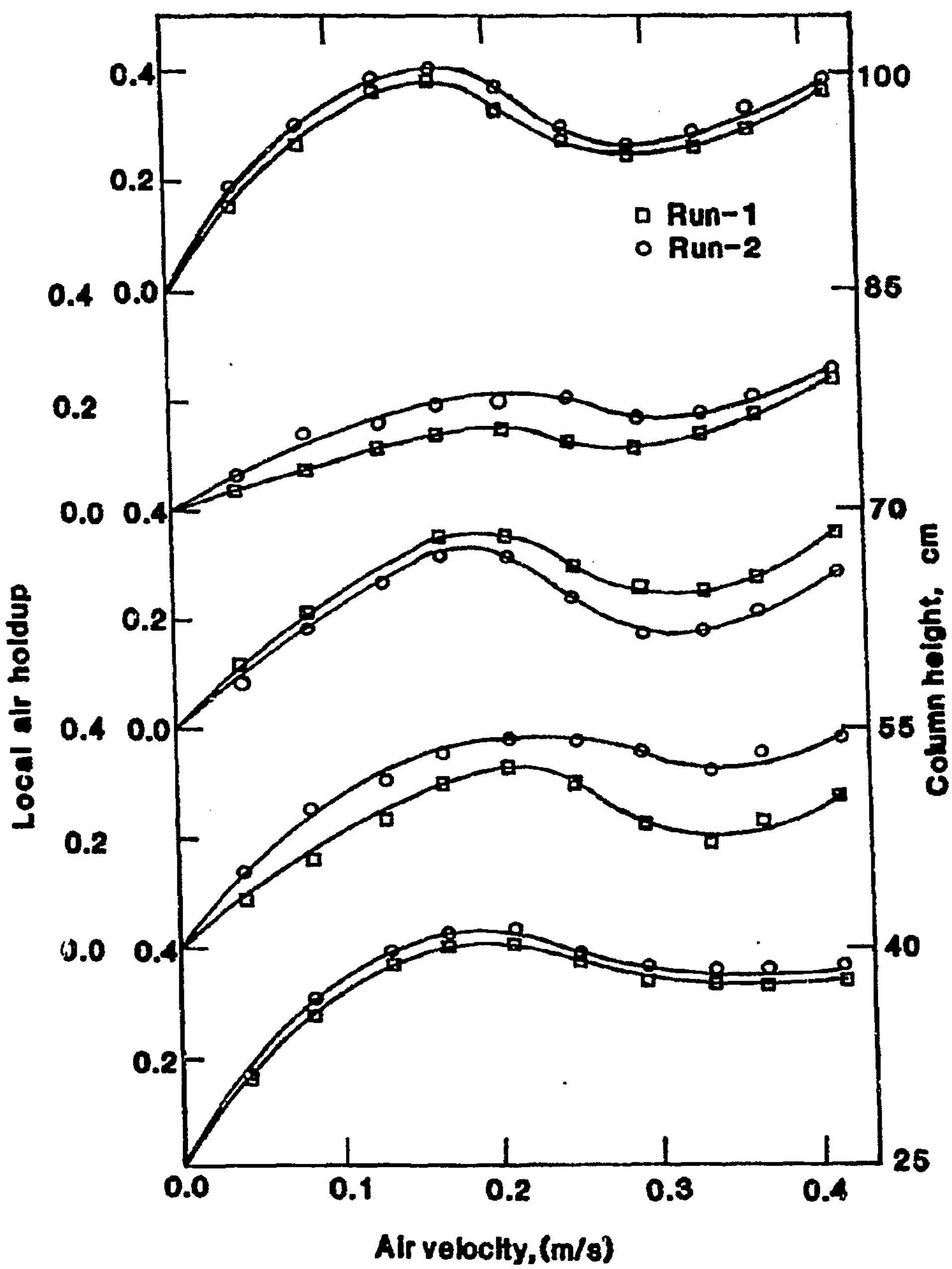

Figure 13. Variation of the local air holdup as a function of the air velocity at different heights of the distilled water column with a bundle of five vertical tubes.

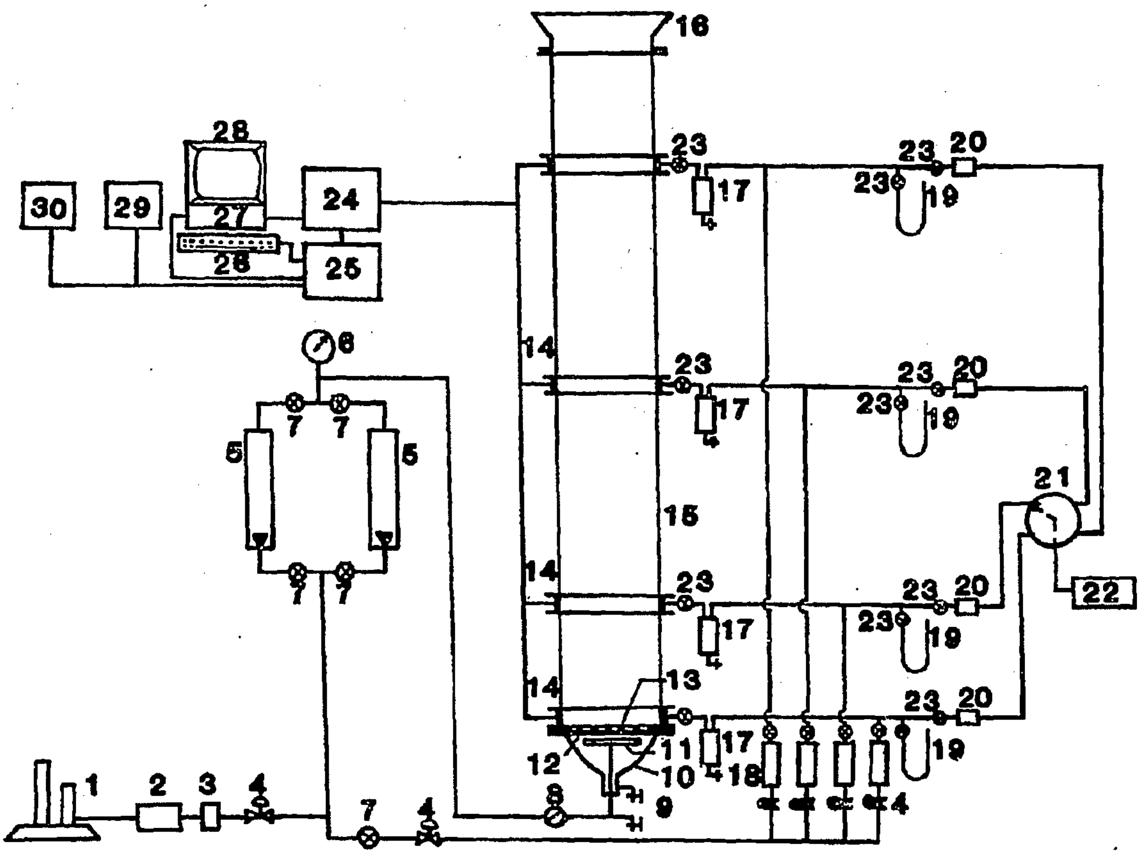

Figure 14. Schematic of the 30.5 cm diameter slurry bubble column along with air supply loop, temperature and pressure measuring circuits. (1) air compressor, (2) refrigerator drier, (3) oilscer filter, (4) pressure regulator valve, (5) rotameters, (6) pressure gage, (7) gate valves, (8) one-way valve, (9) liquid drain, (10) conical section, (11) bubble-cap distributor plate, (12) perforated plate distributor, (13) stainless steel wire cloth, (14) metal inserts, (15) glass column, (16) diverger section, (17) trap bottles, (18) purgemeters, (19) manometers, (20) pressure sensors, (21) selector switch, (22) pressure monitor, (23) on-off valve, (24) data acquisition system, (25) computer, (26) Key-board, (27) disc drive, (28) monitor, (29) printer, and (30) plotter.

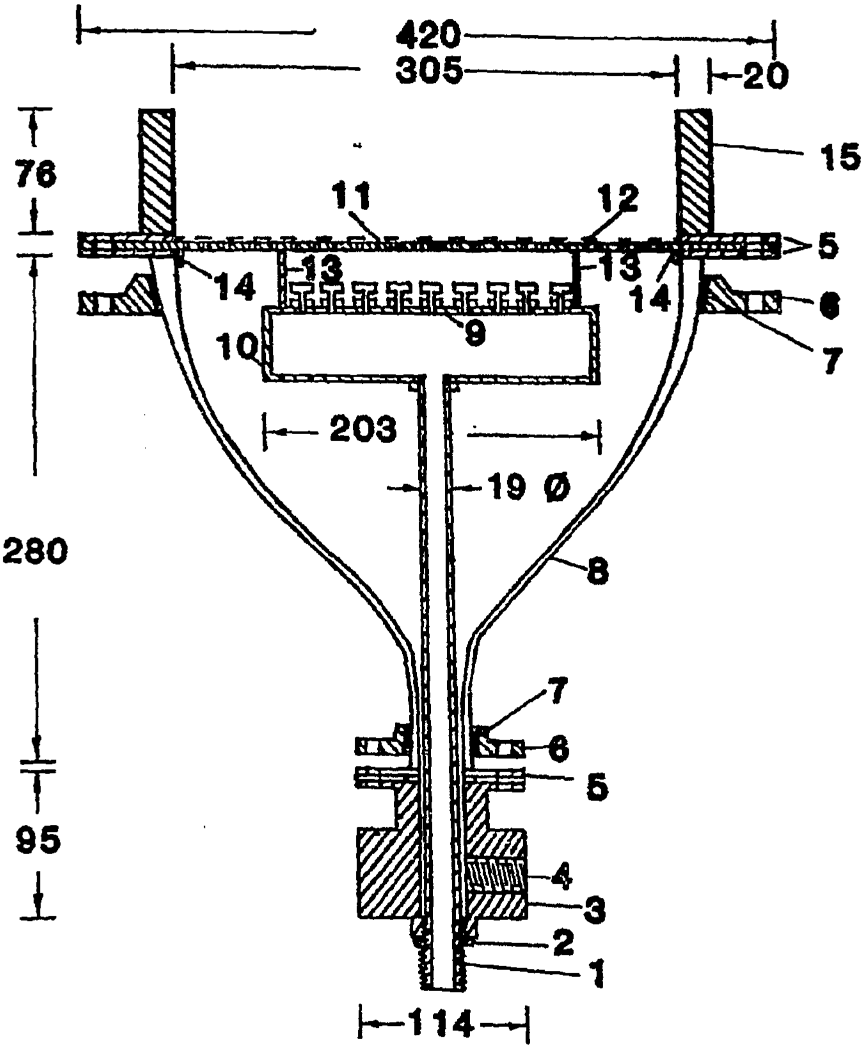

Figure 15. Design details of the bottom end assembly of the 30.5 cm diameter slurry bubble column. (1) gas inlet pipe, (2) Teflon coated nut, (3) liquid drain adapter, (4) liquid drain, (5) gaskets, (6) flanges, (7) soft inserts, (8) conical glass section, (9) bubble cap distributor plate, (10) cylindrical holder, (11) perforated plate distributor, (12) stainless steel wire cloth, (13) spacer studs, (14) locating pins, and (15) metal insert. All dimensions are in mm.

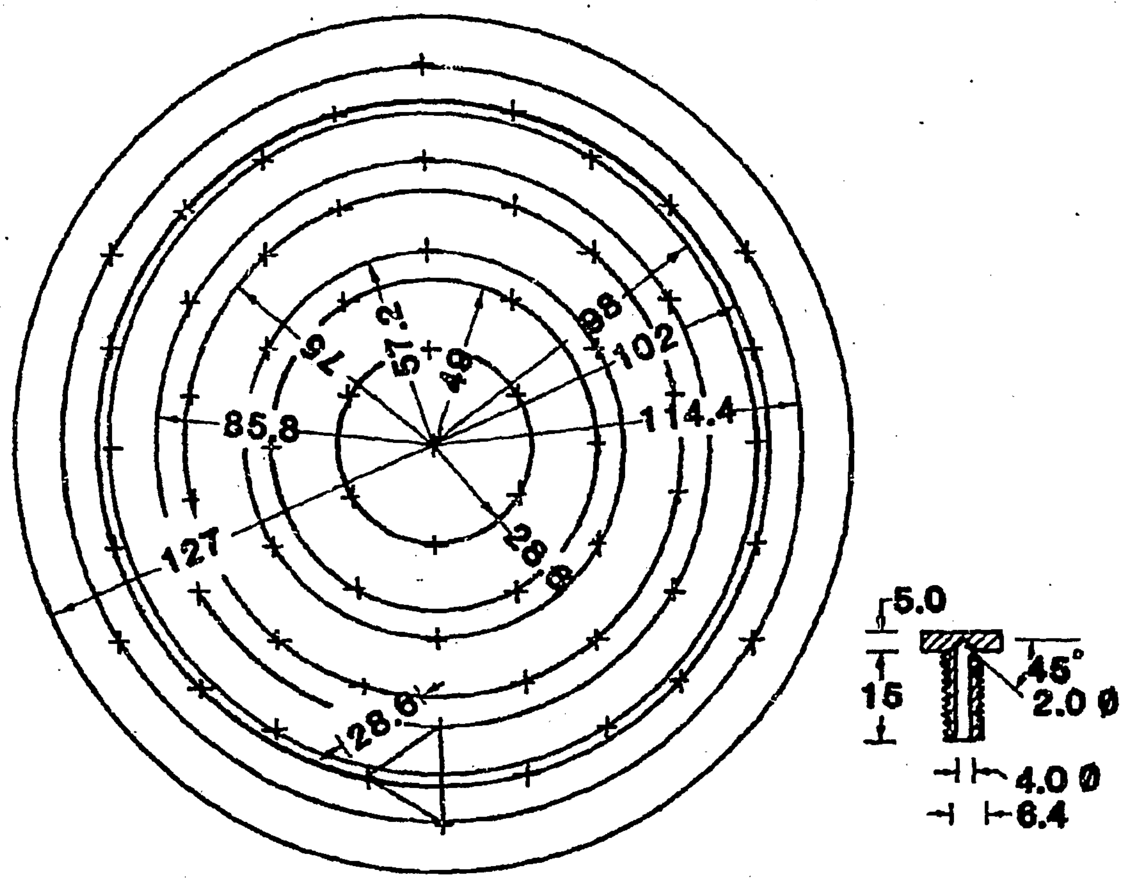

Figure 16. Arrangement of the bubble-caps on the distributor plate. All dimensions are in mm.

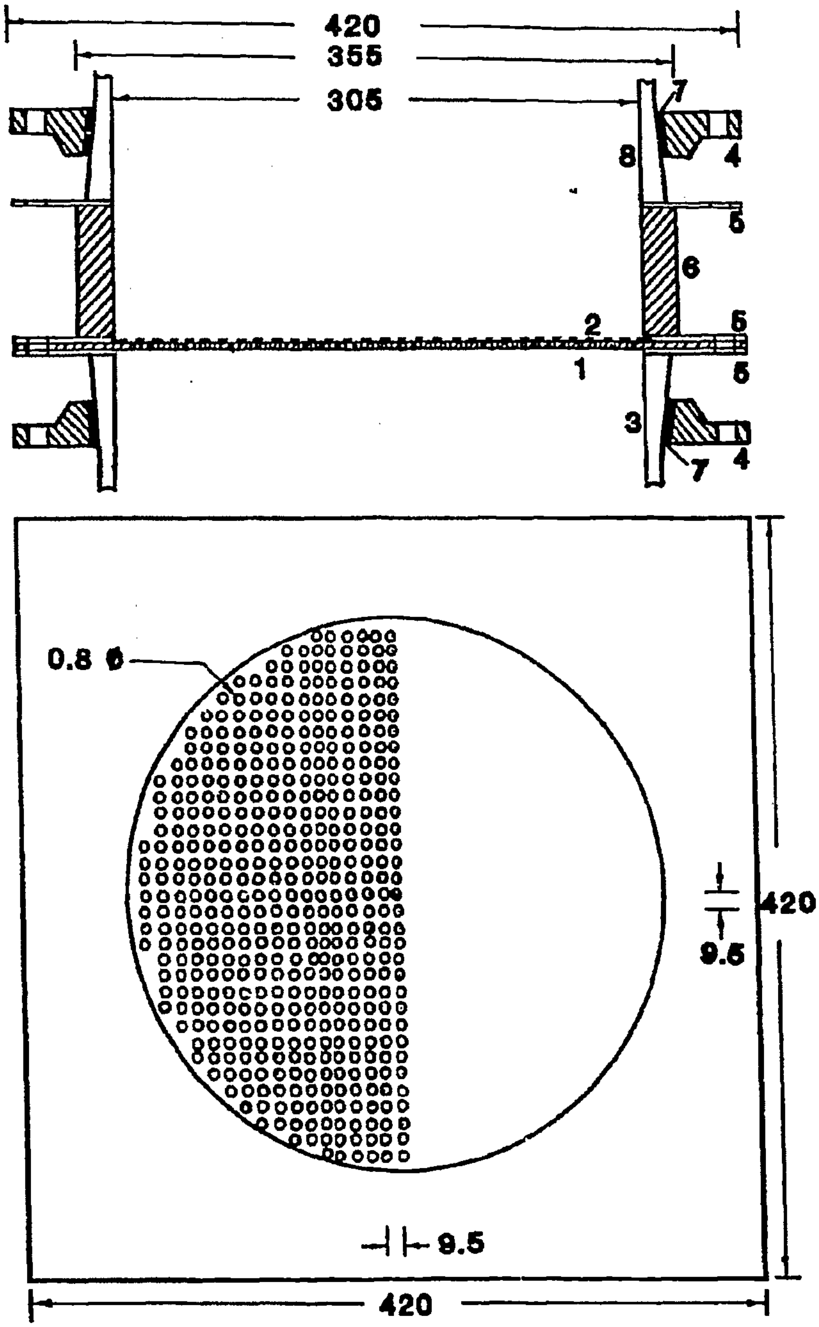

Figure 17. Design details of the perforated gas distributor plate for the 30.5 cm diameter slurry bubble column. (1) perforated plate distributor, (2) stainless steel wire cloth, (3) bottom conical section, (4) flange, (5) gasket, (6) metal insert, (7) soft inserts, and (8) glass column. All dimensions are in mm.

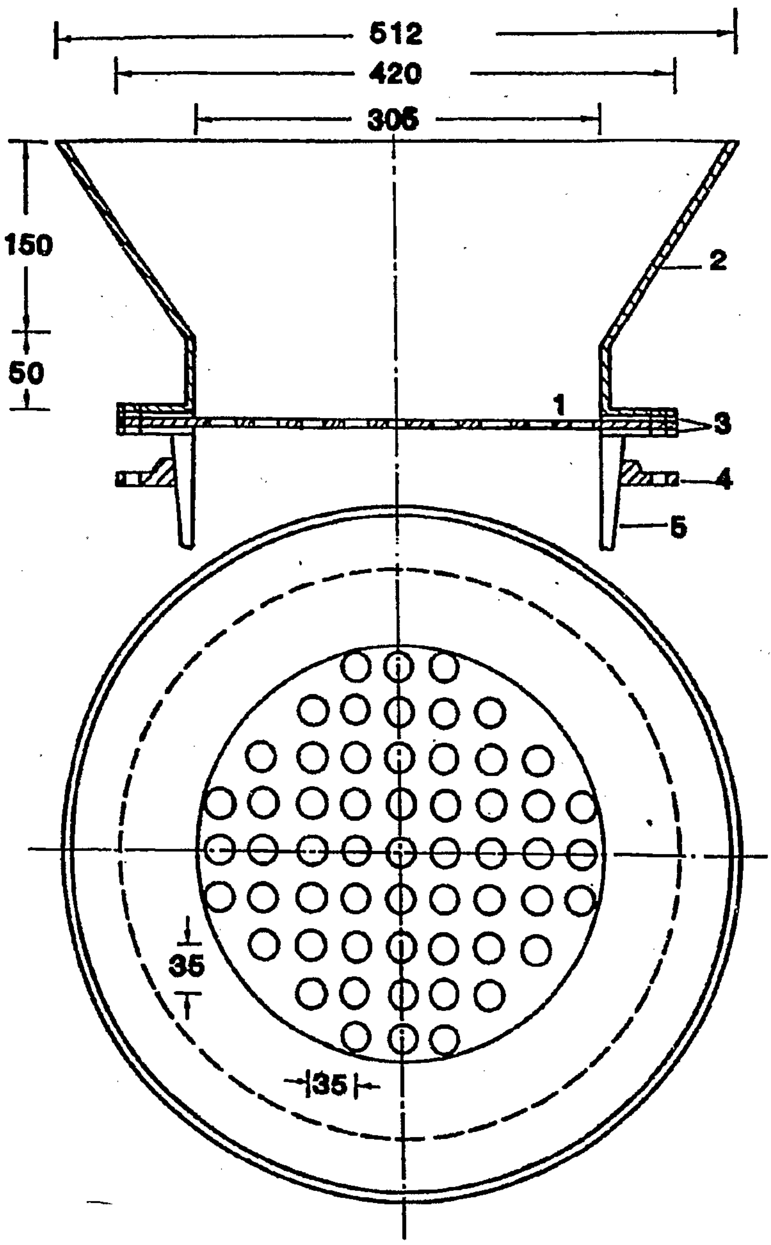

Figure 18. Design details of the diverger section at the top end of the 30.5 cm diameter slurry bubble column. (1) stainless steel perforated plate, (2) diverger section, (3) gaskets, (4) flange, and (5) glass column. All dimensions are in mm.

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