Chapter III

APPARATUS AND EXPERIMENTAL METHODS

3.1 The Design and Operation of a Vertical Film Test Rig

A vertical film test rig was designed and constructed. The assembly of the vertical film evaporator is shown in Fig 3.1. It consists of a preheater, an evaporating body, a feed tank and a feed pump, a storage tank, a steam entrainment seperator, thermometers, thermocouples and a potentiometer recorder. The simplified flow diagram is shown in Fig 3.2. The descriptions of the assembly are to follow.

One of the variables was the feed temperature which had to be kept constant for each experimental run. This was accomplished by means of a feed preheater. The preheater was a stainless steel cylindrical tank equipped with copper heating coil inside. The tank was constructed from a 6 inch stainless steel tube with a wall thickness of 1/8 inch. It was 4 inches in length. The heating part was constructed out of a copper tube 1/4 inch in diameter arranged in a 4.5 inch helical coil; steam was used as the heating medium. A Glass tube of 1/4 inch in diameter and 3.5 inch long was connected on

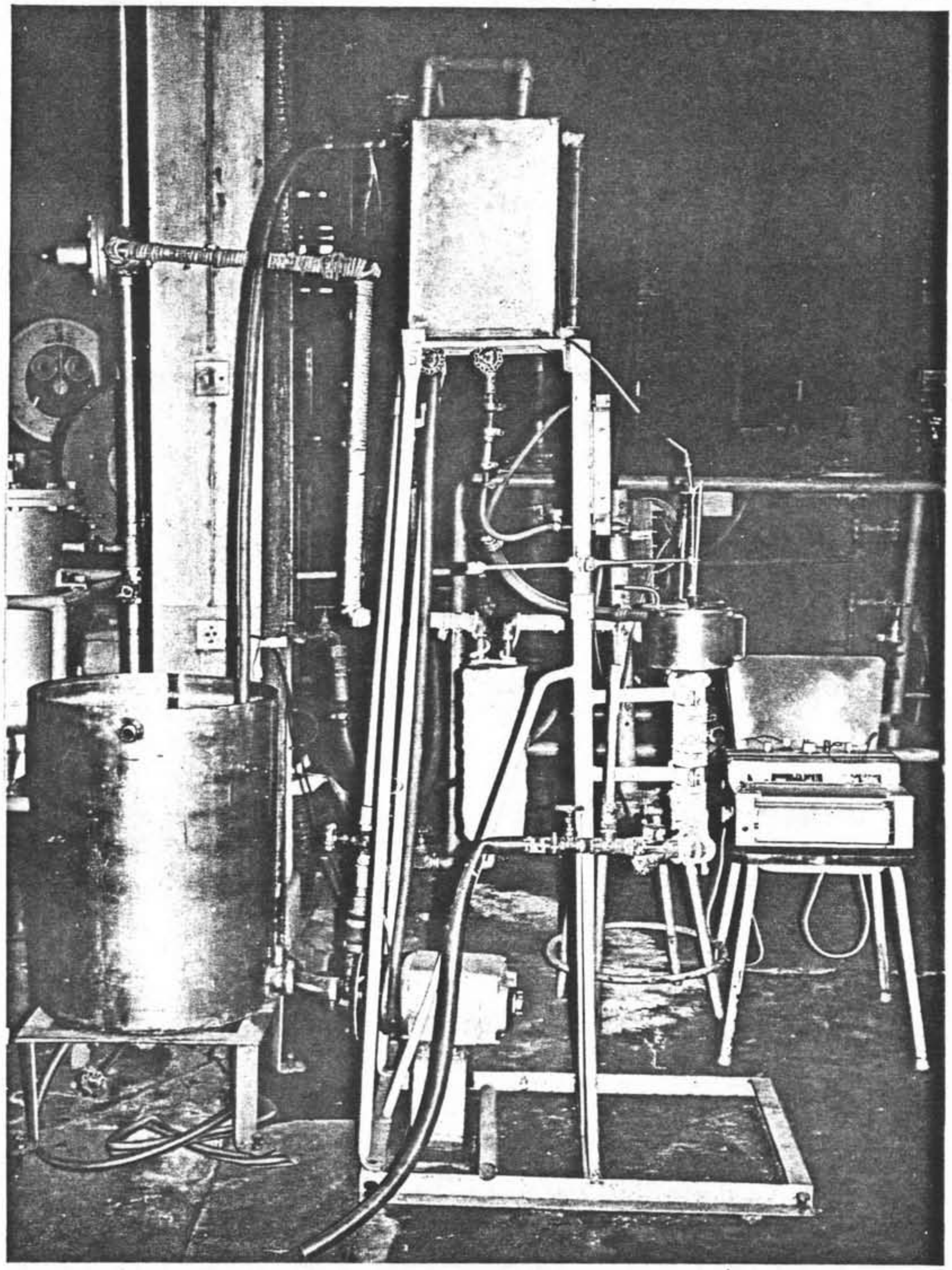


Fig. 3.1 A vertical film test rig

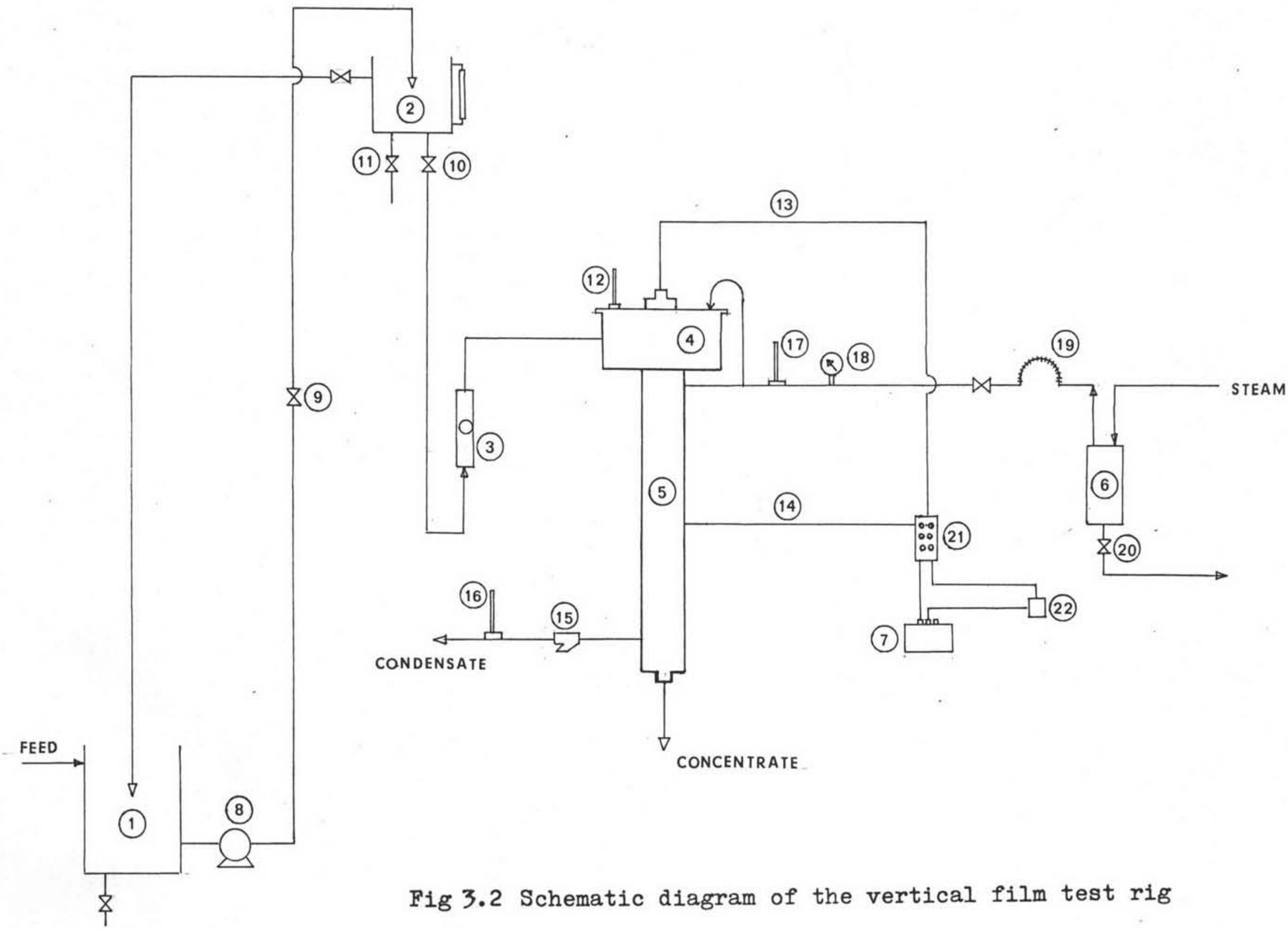


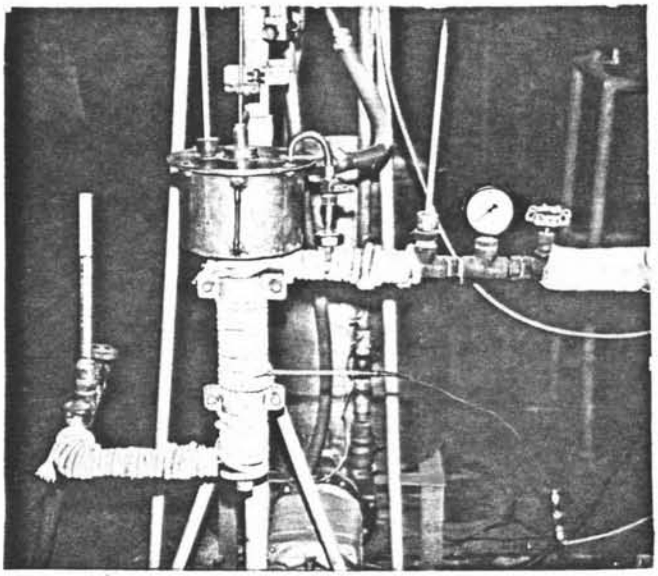
Fig 3.2 Schematic diagram of the vertical film test rig

1 Storage tank
2 Feed tank
3 Rotameter
4 Preheater
5 Evaporating body
6 Steam/entrainment separater
7 Potentiometer Recorder
8 Feed pump
9 Feed inlet valve
10 Feed valve
11 Drain valve
12 Feed temperature thermometer
13 Vapor temperature Thermocouple
14 Wall temperature Thermocouple
15 Steam trap
16 Condensate temperature thermometer
17 Steam inlet temperature thermometer
18 Pressure gauge
19 Flexible steam connector
20 Drain valve
21 Switch board
22 Ice container

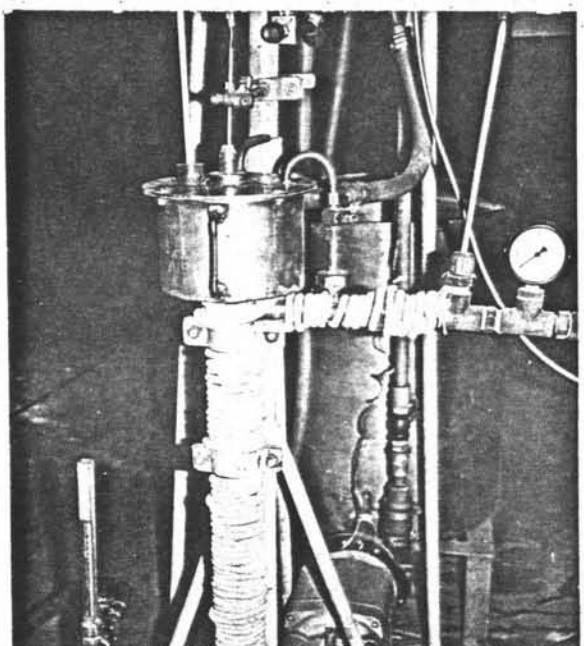
to the side of the tank to act as a sight glass indicating the feed level.

The evaporating body was vertical double pipe heat exchanger made of stainless steel tubes, connected to the preheater. There were two evaporating body used, a one-foot tube and a two-foot tube; they are shown in Fig 3.3. The inner pipe was 1/2 inch in diameter and 1/8 inch in thickness; the top of the pipe was machined to make an angle of 45° with vertical line. The outer pipe was 1½ inch in diameter and also 1/8 inch in thickness. A distributor was designed and constructed specially for spreading the feed over the interior surface of the inner tube. It was made of a 1/2 inch stainless steel block 7 inch long with a 1/4 inch hole bored through. The end of the distributor was machined to a 30° cone which would set on the top of the inner pipe described earlier. The distributor was held inposition centrally on the cover of the preheater. By turning the distributor on its fine screw thread, the opening between the distributor and the inner tube could be adjusted. The assembly is shown in Fig 3.4.

When the conical end of the distributor was in contacted with the upper part of the inner tube, the feed could not leak into the inner tube. The feed was allowed to flow down by tunning the distributor, thus raised it



(a)



(b)

Fig. 3.3 Evaporating body and preheater assembly

(a) 1 ft jacketed tube
(b) 2 ft jacketed tube

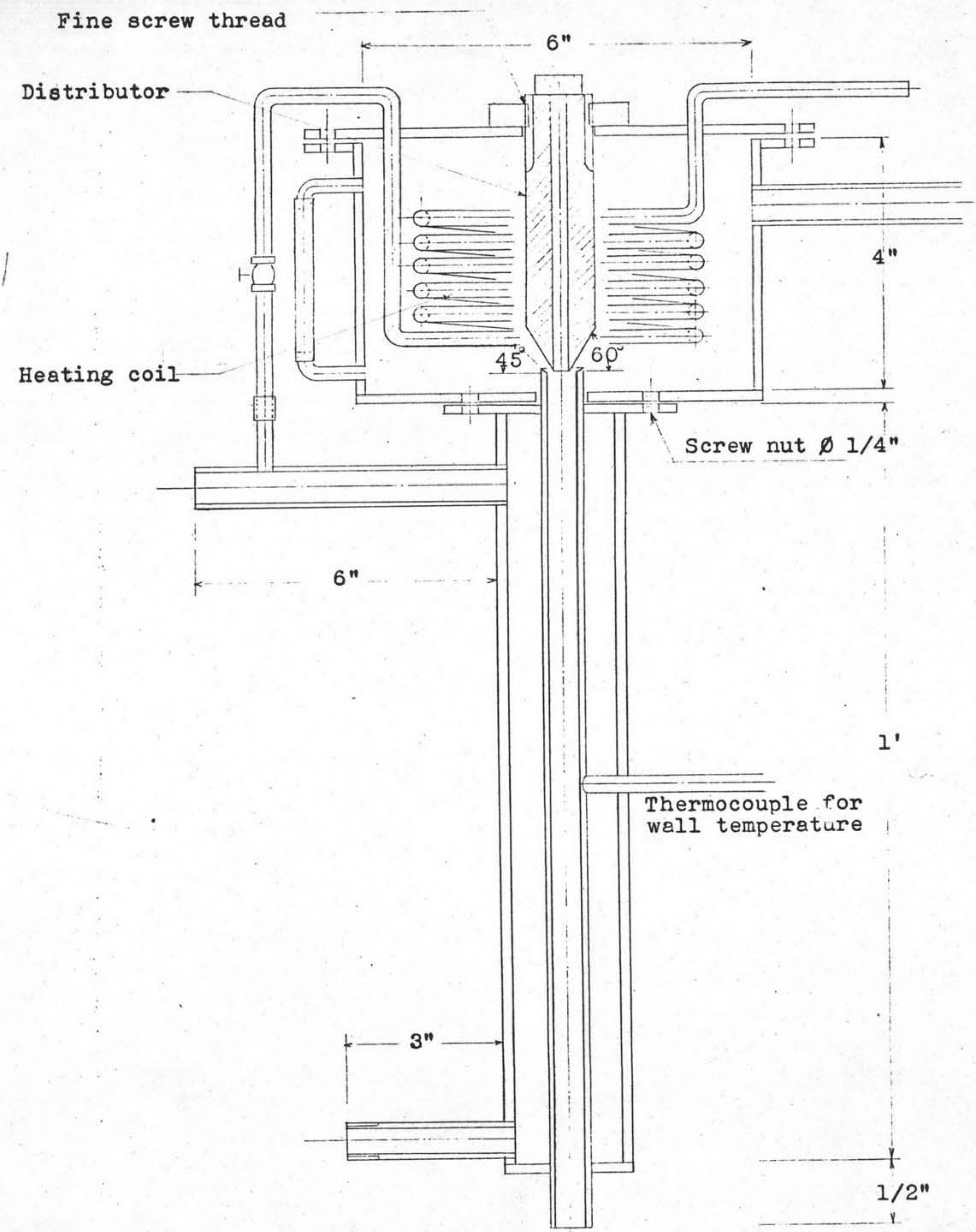


Fig. 3.4 Cross-section of evaporating body and preheater

upward. The feed would flow as a thin film wetting all the inner surface of the tube. The size of the opening, therefore, would control the thickness of the film.

The circulation system of the feed consisted of a storage tank, a feed tank and a feed pump. The storage tank was 17 inch in diameter and 24 inch high, and was constructed from stainless steel sheet of 1/16 inch thick. The tank had a drain line at the bottom and feed outlet. A centrifugal pump, powered by 3/4 H.P., had its suction line connected to this feed outlet. The solution would be pumped up to a feed tank.

A square 10X10 inch and 14 inch high tank was constructed from a stainless steel sheet of 1/16 inch thick; it was used as a feed tank. The tank also had a feed inlet from the pump, a drain line, an overflow line to the storage tank and a feed outlet to the evaporator. A glass tube of 9/16 inch in diameter and 12 inch long was connected to the tank acting as a level gauge.

In order to prevent wet steam entering the process, a steam/entrainment seperator was connected to the steam supply line. It was a cylindrical vessel 4 inch in diameter and 12 inch long made of mild steel pipe of 0.212 inch thick. The vessel had a steam inlet, a steam outlet and a drain line. One part of the inlet line was outside which was visible, the second part which went to the bottom of the tank was inside. When the wet steam entered, saturated steam which was lighter would rise up and flowed through the outlet line. The condensate was collected, and was blowed off by the drain line.

3.2 Temperature Measurements

Four mercury thermometers were used for the measurement of inlet temperatures of steam and the feed, and outlet temperatures of concentrated and condenaate. The measuring range of the thermometer was 0-100 ^{o}C with a pricision of 0.1 ^{o}C.

Two chromel-alumel thermocouples were used to measure the temperatures at the evaporating body; one for measuring the inner pipe wall temperature, and another for measuring water vapor temperature. A hole of 1/4 inch was drilled at the mid-section of the evaporating body through the outer wall. A 1/4 inch diameter stainless steel tube was inserted in the hole, and was attached to the inner tube surface. A thermocouple was inserted into this stainless steel tube and placed against the wall of the inner tube to measure the wall temperature. To measure water vapor temperature, the thermocouple was put through a 1/4 inch glass tube which was place at the center of the inner pipe. The temperatures were recorded in terms of emf (millivolts) by a SEFRAM PARIS Potentiometer Recorder. The emf readings were converted to degrees fahrenheit by a calibrating charts of the thermocouples.

Heat loss had a large effect on the process of evaporation, and so, had to be minimized. The evaporating body and the pipe lines were insulated with insulation chords. The steam entrainment seperator was insulated with a 1 inch sheet of fiber glass.

3.3 Preparation of Calibration Curves and Charts

3.3.1 Calibration of Rotameter.

A rotameter was used to indicate the feed rate entering the evaporator. The meter has an attached scale of 15 divisions; each divides into 10 subdivisions.

The rotameter was calibrated by varying the rate of feed flowing through the meter. The flow rates were calculated by recording the quantity of feed collected in one minute. The corresponding meter reading from the attached scale for each flow rate was also read and recorded. The calibration data were shown in Table A.1 and were plotted in Fig A.1-A.4.

3.3.2 Calibration of Chromel-Alumel Thermocouple

The thermocouple was calibrated with a potentiometer recorder by varying the temperature of water in which the thermocouple was immersed. The millivolts that were read from the recorder at various temperatures were plotted versus temperature differences in degree fahrenheit. The reference junction was kept at 32^{o}F. The calibration curve was shown in Fig A.5.

3.3.3 Calibration of Brix Refractometer

A refractometer of KFUJI, Japan No.9591, was calibrated using sucrose solutions of known concentrations, to insure that concentrations of sucrose solutions could be represented by the reading of the hand refractometer. The results were shown in Fig A.6.

3.4 Experimental Variables

The process variables under studied are:

1. Feed rate of solution; six feed rates were used, they were about 15.8, 29.7, 46.2, 62.0, 78.7 and 95.0 lb/hr.

2. Feed temperature; seven feed temperatures were used, they were about 86, 104, 122, 140, 158, 176 and 194^{o}F.

3. Steam inlet temperature; five mean temperatures of steam were used, i.e. 235, 259, 272, 284 and 293^{o}F.

4. Length of vertical heated tube; two lengths of heated tube were used, i.e. 1 and 2 ft.

5. Viscosity of feed; the liquids were water and sucrose solutions of concentration of 5, 10 and 15 Brix.

3.5 Experimental Methods

3.5.1 The Measurement of Viscosities of Sucrose Solutions

Viscosities of sucrose solutions were measure by using Oswald Viscometer. Sucrose solutions at concentration of 5, 10, 15 and 20 Brix were prepared. For each concentration, the measurement were made at 30, 40, 50, 60 and 70°C. The same solutions were to be used to study the effect of viscosity on the film heat transfer coefficient.

3.5.2 The Experiments Using Water as Feed

3.5.2.1 The measurement of heated wall temperature

Because the heated wall temperature was not normally known, measurements were required at this stage to investigate the effects of feed rate and steam inlet temperature on the heated wall temperature. It was expected that a general relationship could be established. The experimental runs were carried out using a 1 ft long heated tubes and operating at steam inlet temperatures of

235, 259, 272, 284 and 293°F. For each of these temperature, the feed rate was varied at 15.8, 29.7, 46.2, 62.0, 78.7 and 95 lb/hr. Feed temperature was kept constant at 93°F.

3.5.2.2 Variations of vapor phase temperature along the length of the evaporating body

Vapor temperatures were measured at 1 inch interval along the length of the heated tube. Measurements were made at the constant feed rate of 46.2 lb/hr. and feed temperature 93°F, using 1 and 2 ft heated tube. For each tube, the steam inlet temperature were varied at 259 and 272°F.

3.5.2.3 Dependence of the film heat transfer coefficient on liquid rate, feed temperature, steam inlet temperature and length of heated tube

Several experimental runs were performed to study the effects of feed rate, feed temperature, steam inlet temperature and length of heated tubes on the film heat transfer coefficient.

A 2-ft heated tube was used, and operated at steam inlet temperatures of 272 and 284°F. For each temperature, the feed rates used were at 15.8, 29.7, 46.2, 62.0, 78.7 and 95.0 lb/hr. Feed temperature were kept constant at 93 and 198°F. This set of experimental runs was designed to investigate the effect of feed rates on h_m.

The effect of feed temperature was studied using a 2 ft heated tube operating at a steam inlet temperature of 284°F. Feed rates were kept constant at 46.2 and 95 lb/hr. For each feed rate, the feed temperature was varied between 93 and 198°F.

The effect of the steam inlet temperature was studied in a similar manner. Both 1 and 2 ft tubes were used, and the feed rates were kept constant at 29.7 and 46.2 lb/hr. For each feed rate, the steam inlet temperatures used were increased successively at 235, 258, 272, 284 and 293°F. Feed temperature was kept constant at 93 and 198°F.

3.5.3 The Experiments Using Sucrose Solutions as Feed

It was observed from 3.5.2.1 that the heated wall temperature depended solely on the steam inlet temperature. The results, therefore, would be applicable as well when sucrose solutions were used in place of water. Also the variations of vapor phase temperatures were small. It was reasonable, therefore, that the temperature at the center of the tube was used to represent the vapor phase temperature in this experiment.

The experiments were carried out using a 2 ft heated tube operating at a steam inlet temperature of 284 ^{o}F. Sucrose solutions at concentrations of 5, 10, and 15 Brix were used. Their viscosities were previously measured. For each solution, the feed rate was varied between 15.8 and 95 lb/hr. Feed temperature was kept constant at 93 ^{o}F.

3.6 Experimental Procedures

Steam used in the experiment was supplied by a 1/2 ton boiler; it needed about half an hour after starting up to generate steam at 50 psi in a supply line. In the mean time, the apparatus shown in Fig 3.2 was adjusted ready for an experimental run. All valves were opened to allow flows of steam and the feed into the preheater. Steam flowed in the heating coil of the preheater and in the jacket of an evaporating body. A feed from the storage tank was pumped to the feed tank where the level was kept constant by means of an over flow; the flow into this tank was controlled using a valve. The feed tank was connected to a valve and a rotameter before going to the preheater.

The liquid was then fed into the preheater until the desired level was reached. The feed valve was then closed. The temperature in the preheater was raised to the desired temperature. The feed valve was subsequently opened and the distributor was turned upward to let the liquid flow down by gravity through the opening as a thin film on the heated tube inner surface. The feed rate was controlled by this opening. However, the feed valve was used to control the flow into the preheater such that the level of liquid in the heater was kept constant. The flow rate could be read from the rotameter.

When the evaporation took place, the vapors rised upward and passed through the hole in the distributor. The concentrate flowed downward under gravity along the heated surface of the vertical tube to a drained tank. It took about half an hour for the system to be at a steady state. After that, readings were made 3 times at about 10 minutes interval; this was also a check on the steady conditions. The reading were taken for the followings: feed rotameter reading, feed temperature, pressure and temperature of steam inlet; concentrate temperature and flow rate, condensate temperature and flow rate, vapor phase temperature, and concentration of feed and concentrate.