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DESIGN, DEVELOPMENT AND EVALUATION OF SOLAR AUGMENTED EVAPORATION PONDS FOR TREATMENT OF SEGREGATED TANNERY EFFLUENTS (SOAK LIQUOR)

FINAL REPORT

PROJECT NO: US/RAS/92/120
CONTRACT NO: 98/121 P

Submitted to

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION
VIENNA, AUSTRIA

by

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MADRAS - 600 036

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LIST OF ABBREVIATIONS

ETP	-	Effluent treatment plant
FPC	-	Flat plat collector
PVC	-	Poly vinyl chloride
HDPE	-	High density polyethylene
RCC	-	Reinforced cement concrete
TDS	-	Total desolved solid
COD	-	Chemical oxygen demand
PAC	-	Poly aluminium chloride

EXECUTIVE SUMMARY

Tanneries in Tamil Nadu are required by regulation to segregate saline effluent from soaking and pickling sections of the beam house and evaporating the same in solar evaporation pans. However, it has been generally seen that the performance of the solar evaporation pans is not encouraging. The average rate of evaporation has been estimated at 3 - 5 mm/day in Vellore District of Tamil Nadu, where tanneries are concentrated. Under UNIDO's Regional Programme for Pollution Control in the Tanning Industry in South East Asia Region - US/RAS/92/120, UNIDO engaged Indian Institute of Technology, Chennai as a subcontractor for pilot demonstration of an accelerated solar evaporation plant of such saline effluent. The purpose of the plant was to accelerate the evaporation rate thereby reducing the area required for treating a given quantity of saline effluent and also improve the recovery of salt.

This report gives the following information on such a Solar Augmented Evaporation Pond for Treatment of Segregated Tannery Effluents (Soak Liquor).

1. Design and fabrication details of a 5000 l/day capacity system
2. Specifications of equipments used
3. Instrumentation and their calibration
4. Experimental procedure
5. Test results
6. Conclusions

The major experimental findings have been :

a. The system is 4 - 5 times more effective than a simple natural evaporation pond (based on 8 hours/day operation during sunshine period).

b. In 24 hours/day continuous operation the quantity of water evaporated gets doubled.

c. Flat plat collector and sprinklers are more or less equally effective.

d. Among all metereological factors solar radiation intensity, wind velocity and relative humidity have strong influence on the system performance.

e. There is a big scope to reduce the cost of the system to nearly 30%. The rough estimate and a schematic diagram for 20,000 l/day capacity system is given in the report.

1. PREAMBLE

This project is aimed at addressing the problems of land pollution by soak liquor in and around the tanneries.

Presently, shallow solar evaporative ponds are being used by the tanneries to evaporate the water in soak liquor and thereby retrieve the salt. This is not only a slow process but also requires vast lands for the evaporation of given quantities of soak liquor.

The project is aimed at accelerating the evaporation process with the added benefit of reducing the land area required for the evaporation of a given quantity of soak liquor.

The purpose of the project is to design, develop, fabricate and monitor a pilot plant to deal with 5000 litres per day of soak liquor.

The plant is located at Shafeeq Shameel and Co., Ambur, North Arcot District in Tamil Nadu.

Figures 1 and 2 show the location details.

2. PROJECT NO.

a) At UNIDO, Vienna : US/RAS/92/120
b) At I.I.T. Madras : MEE/98-99/123/FCP (UNIDO)/AMAN

3. METHODOLOGY

The methodology adopted is briefly explained below. Figure 2A shows the hydraulic flow diagram of the improved solar evaporative system, while Fig. 2B shows the process flow diagram. The required quantity of soak liquor from tank 'A' is passed to tank 'B' by gravity. The liquor from 'B' is passed over the collectors to raise the temperature of the liquid by a few degrees. As the soak liquor is passed over the flat plate collector, not only because of rise in temperature but also because of increased surface area, the mass transfer rate increases, which accelerates the evaporation of the water in the soak liquor. The heated soak liquor coming from the flat plate collector (**Fibre Reinforced Plastic**) is then collected in tank 'C'. The warm liquor from 'C' is then sprayed through several nozzles. The spray increases substantially the contact area between the liquid and the surrounding air to further enhance the evaporation rate. The liquid emerging from these sprays goes to collection tank 'B'. The process is

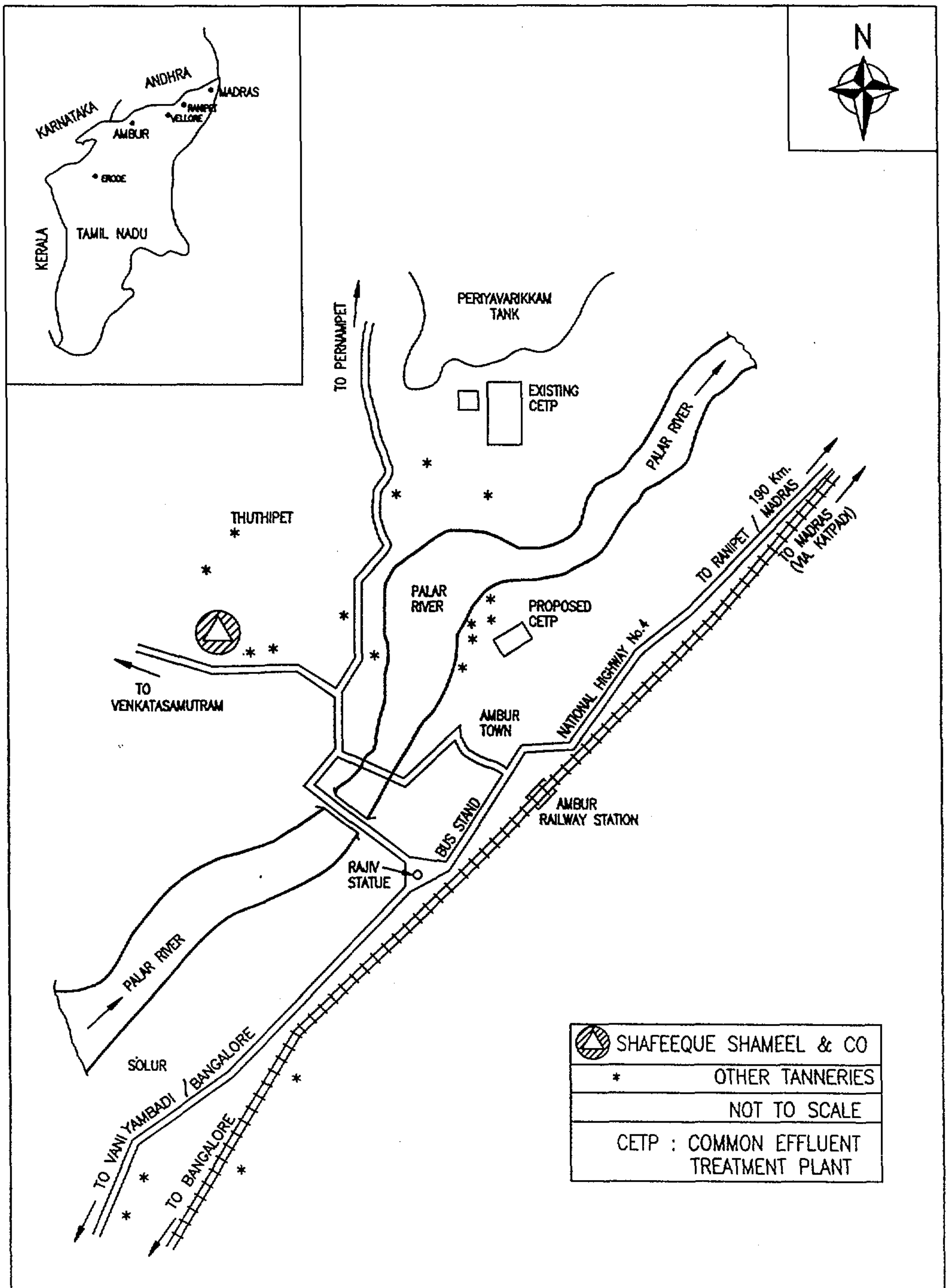
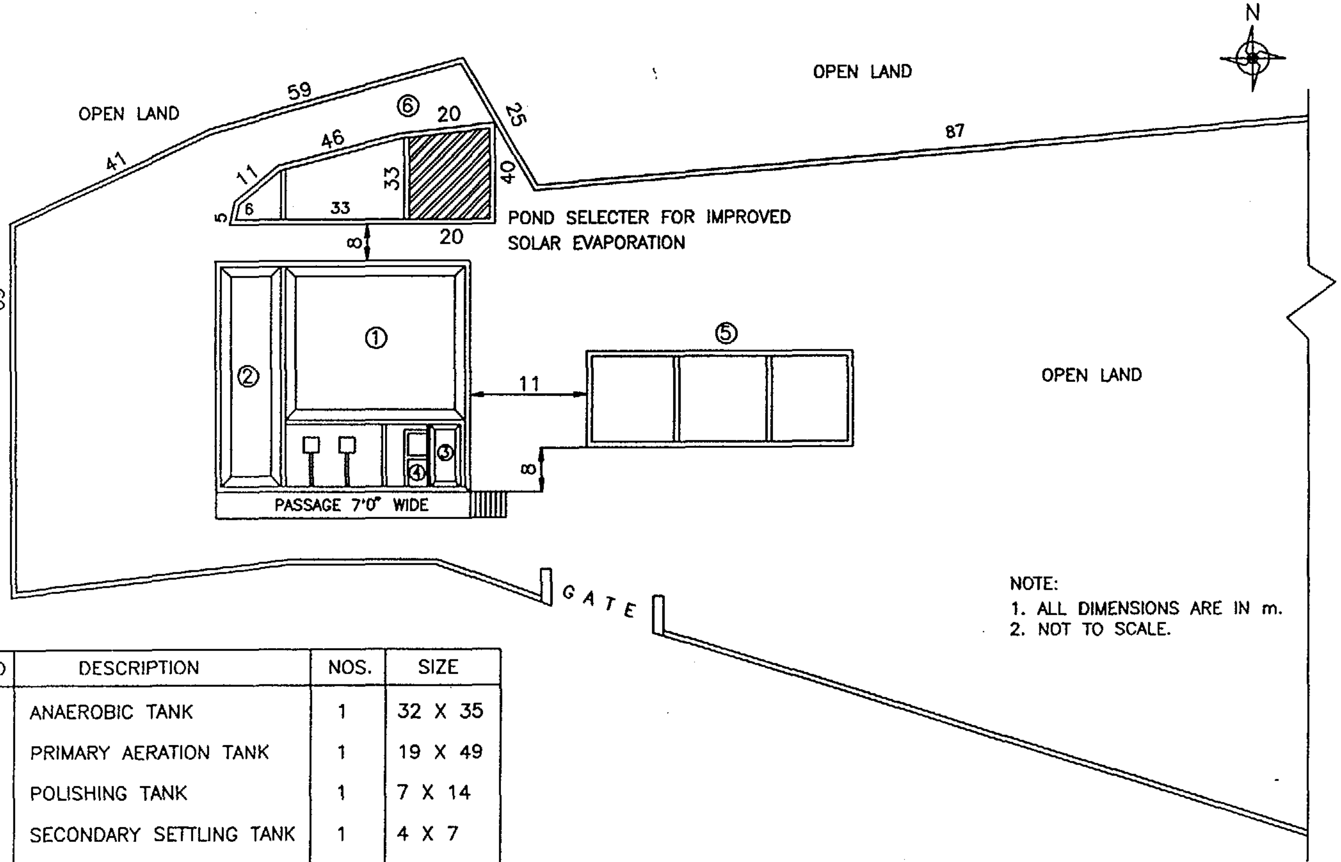


FIG. 1 LOCATION OF SHAFEEQ SHAMEEL & CO., AMBUR, N.A. DISTRICT



S.NO	DESCRIPTION	NOS.	SIZE
1	ANAEROBIC TANK	1	32 X 35
2	PRIMARY AERATION TANK	1	19 X 49
3	POLISHING TANK	1	7 X 14
4	SECONDARY SETTLING TANK	1	4 X 7
5	SLUDGE DRYING BEDS	1	13 X 17
6	SOLAR EVAPORATION PAN SELECTED FOR STUDY	1	20 X 40

FIG.2 LOCATION OF SELECTED SOLAR EVAPORATION PAN IN SHAFEEQ SHAMEEL TANNERY ETP AMBUR

continued until such time the salt concentration reaches around 10%, which is well below the saturation condition. Then it is sent to open shallow pans for natural evaporation.

4. OBJECTIVES / PLAN OF ACTION

This project, as in the original proposal, has been tackled in three phases. In the first phase of work, the location of the site was identified (refer Figs. 1 and 2). The capacity of the plant was fixed as 5000 litres per day. The design of the proposed system was completed. Working drawings were prepared.

In the second phase, technical specifications of the civil construction was given. The contractor was identified with the co-operation of RePO, UNIDO, Chennai. During the construction, technical guidance and supervision was provided by Indian Institute of Technology Madras, Chennai till the construction of the plant was completed.

During phase three, the plant operation was monitored and experimental studies were made by the Indian Institute of Technology Madras, Chennai.

5. DESIGN / EQUIPMENT SPECIFICATIONS

The major dimensions of the plant are as shown in the following Figures:

Fig. 3 Schematic View of the Solar Augmented Evaporation System
Fig. 4 Cross Sectional View of the Solar Augmented Evaporation System at X-X
Fig. 5 Details of Sloping Roof for Mounting Solar Panels
Fig. 6 Plan View - Arrangement of the Beams and Columns of the Solar Augmented Evaporation System

These dimensions are of the existing system, as of date, after completion of construction, fabrication and assembly works.

While Fig. 3 shows the overall schematic view of the system, Fig. 4 gives the sectional view of the plant. A careful perusal of the Figs. 3 and 4 will help in discerning the working of the plant. It may also be pointed out here that Fig.7A gives the plan of the location of the various soak liquor tanks. Fig. 7B gives the details of the piping net work of the plant.

The photographs of the four different views of the system are given in Annex 3.

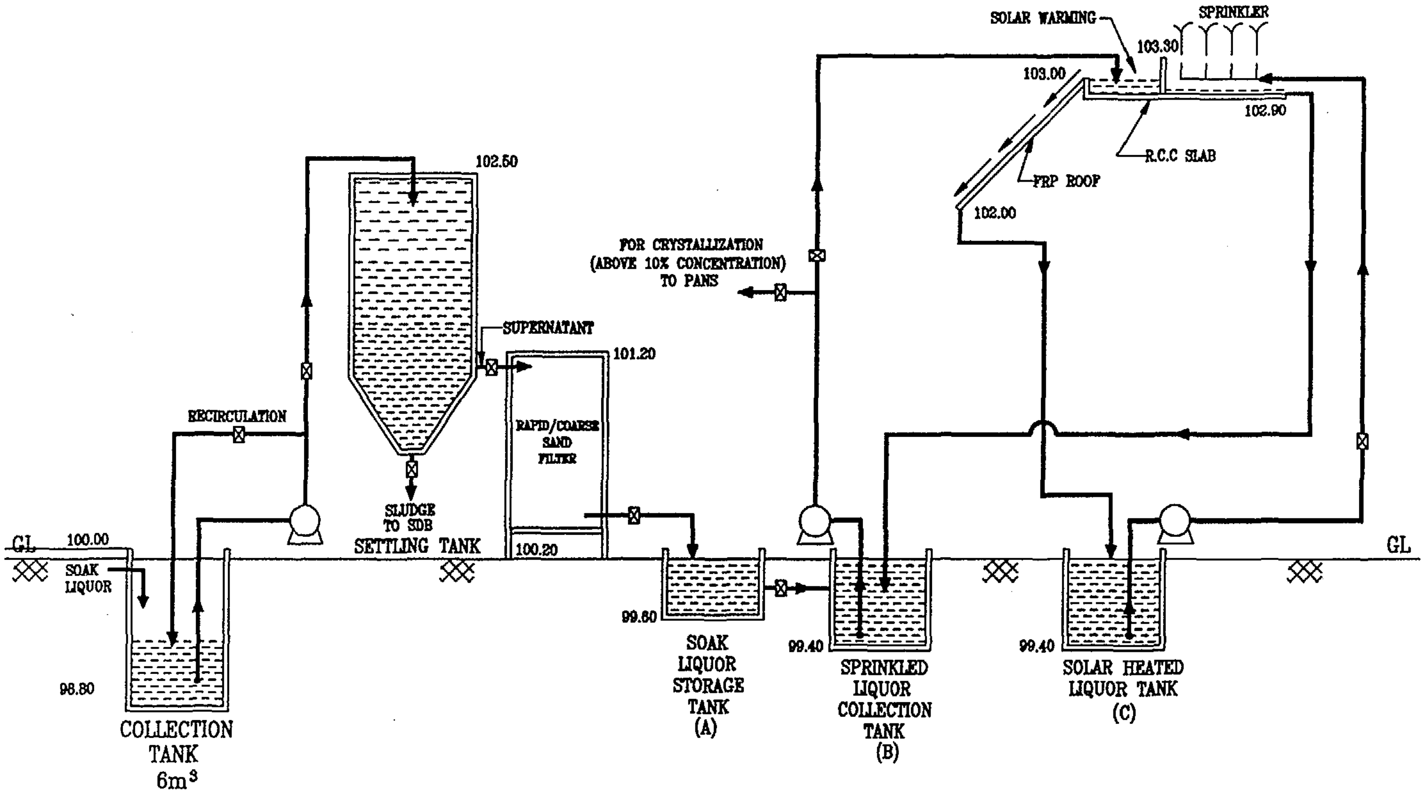


FIG. 2A HYDRAULIC FLOW DIAGRAM OF
IMPROVED SOLAR EVAPORATION SYSTEM

⊠ VALVE
PUMP
ALL LEVELS ARE IN m

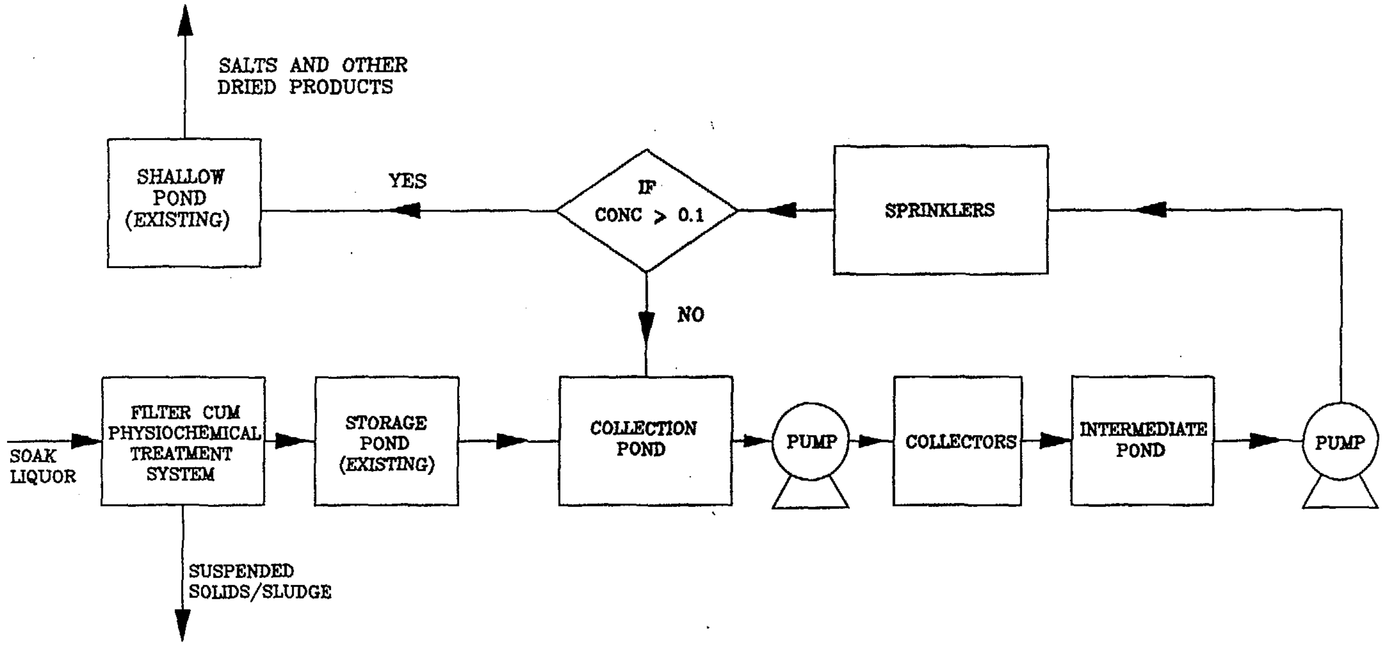


FIG. 2B PROCESS FLOW DIAGRAM OF THE SOLAR AUGMENTED EVAPORATION SYSTEM

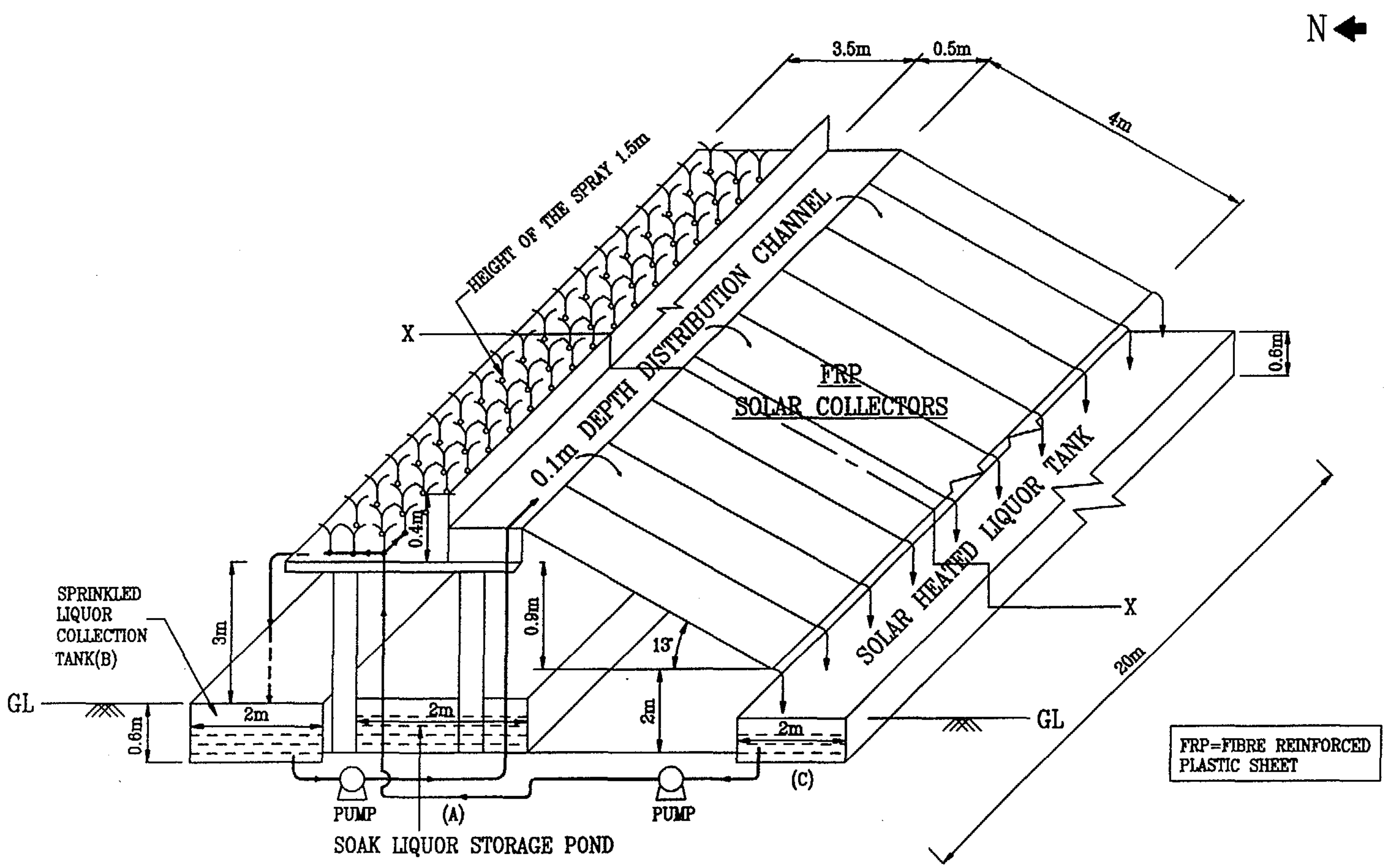


FIG.3 SCHEMATIC VIEW OF THE SOLAR AUGMENTED EVAPORATION SYSTEM

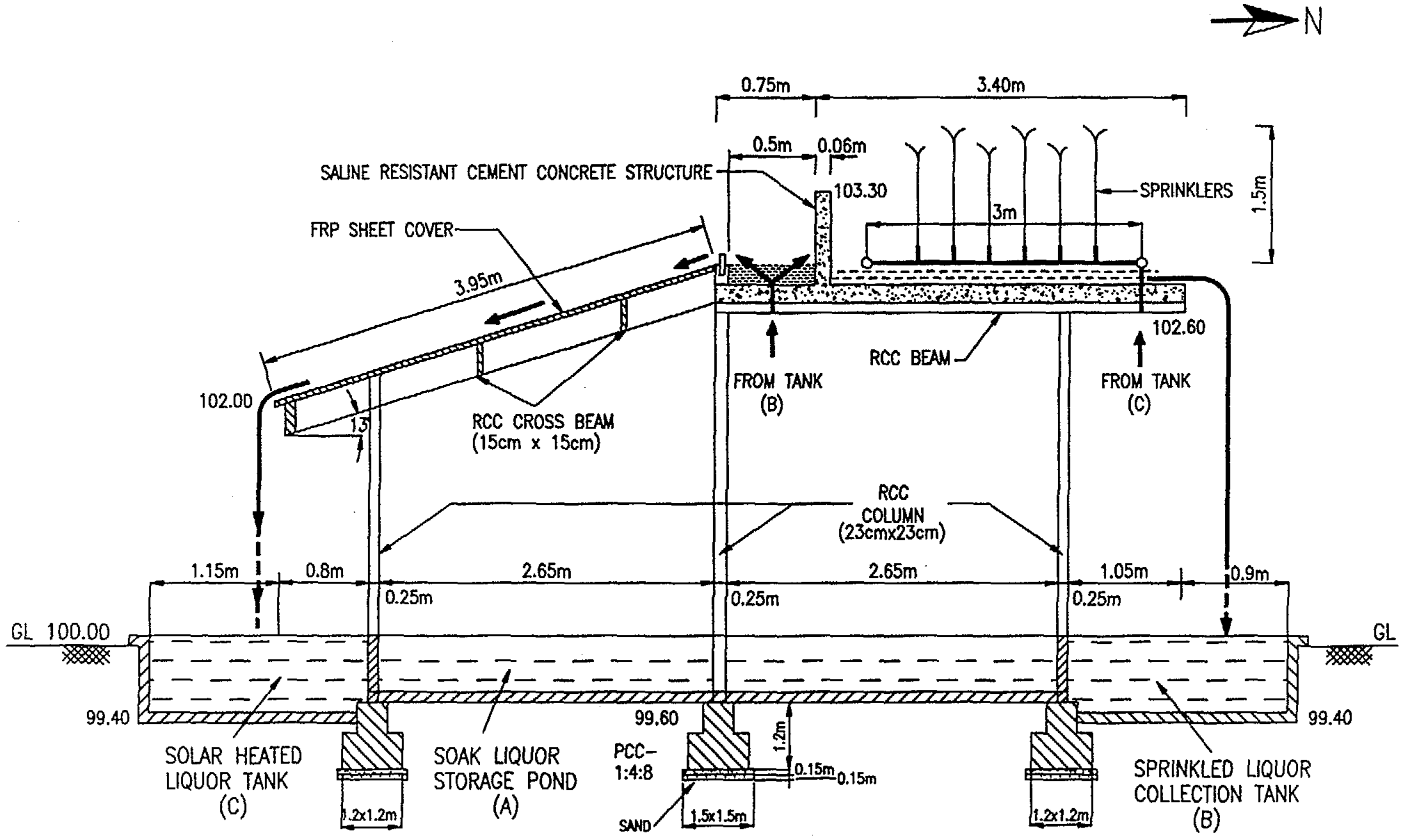


FIG.4. CROSS SECTIONAL VIEW OF THE SOLAR AUGMENTED EVAPORATION SYSTEM AT X-X

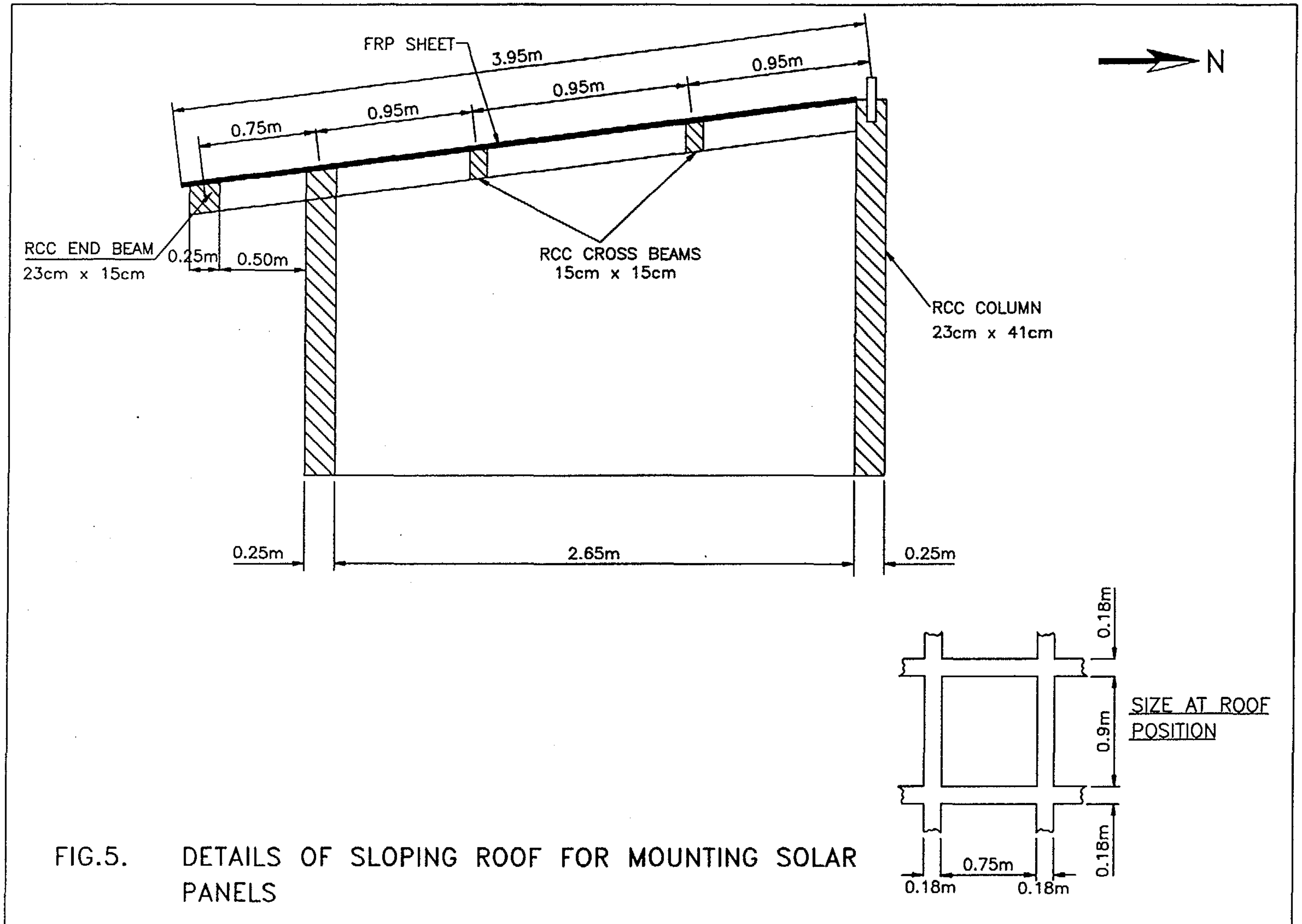


FIG.5. DETAILS OF SLOPING ROOF FOR MOUNTING SOLAR PANELS

Reinforcement details

		cms
Column	Foot 1.2m x 1.2m	23x23
Tie beam	All-round	23x23
Roof Beams	A1-A19, A1-B1, A4-B4, A7-B7, A10-B10, A13-B13, A16-B16, A19-B19	23x30
Roof Beams	B1-B19	23x40
Roof Beams	E1-E19, B1-F1, B19-F19, B4-E4, B7-E7, B10-E10, B13-E13, B16-E16	23x28
Roof Beams	E4-F4, E7-F7, E10-F10, E13-F13, E16-F16	23x15
End Beams	F1-F19	23x15
Par cola Beams	C1-C19, D1-D19	15x15
Par cola Beams	All intermediates	15x15

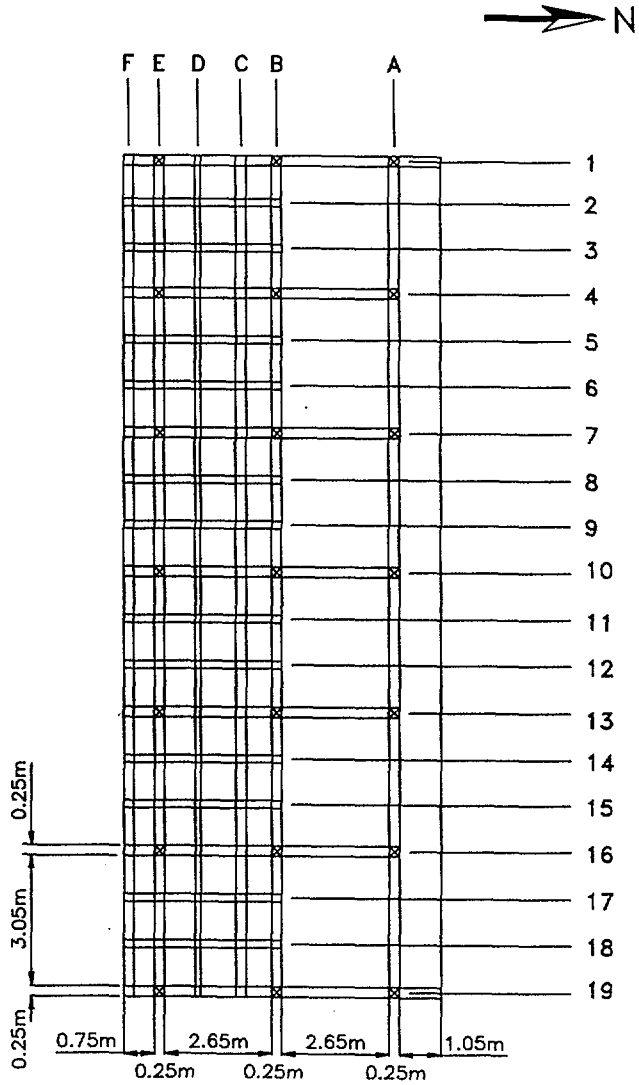


FIG.6. PLAN VIEW–ARRANGEMENT OF THE BEAMS AND COLUMNS OF THE SOLAR AUGMENTED EVAPORATION SYSTEM

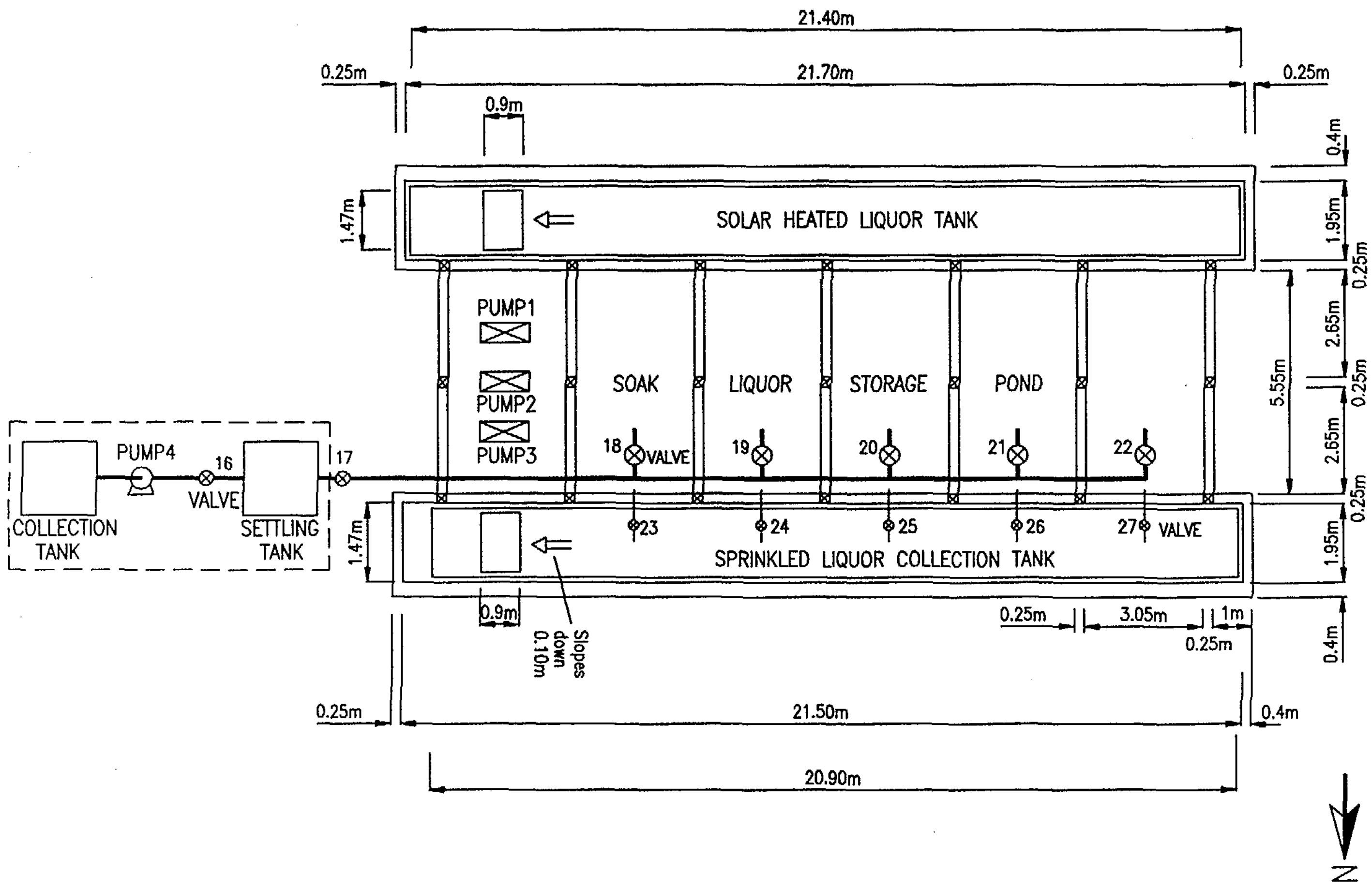


FIG.7A. PLAN VIEW OF THE SOAK LIQUOR TANKS

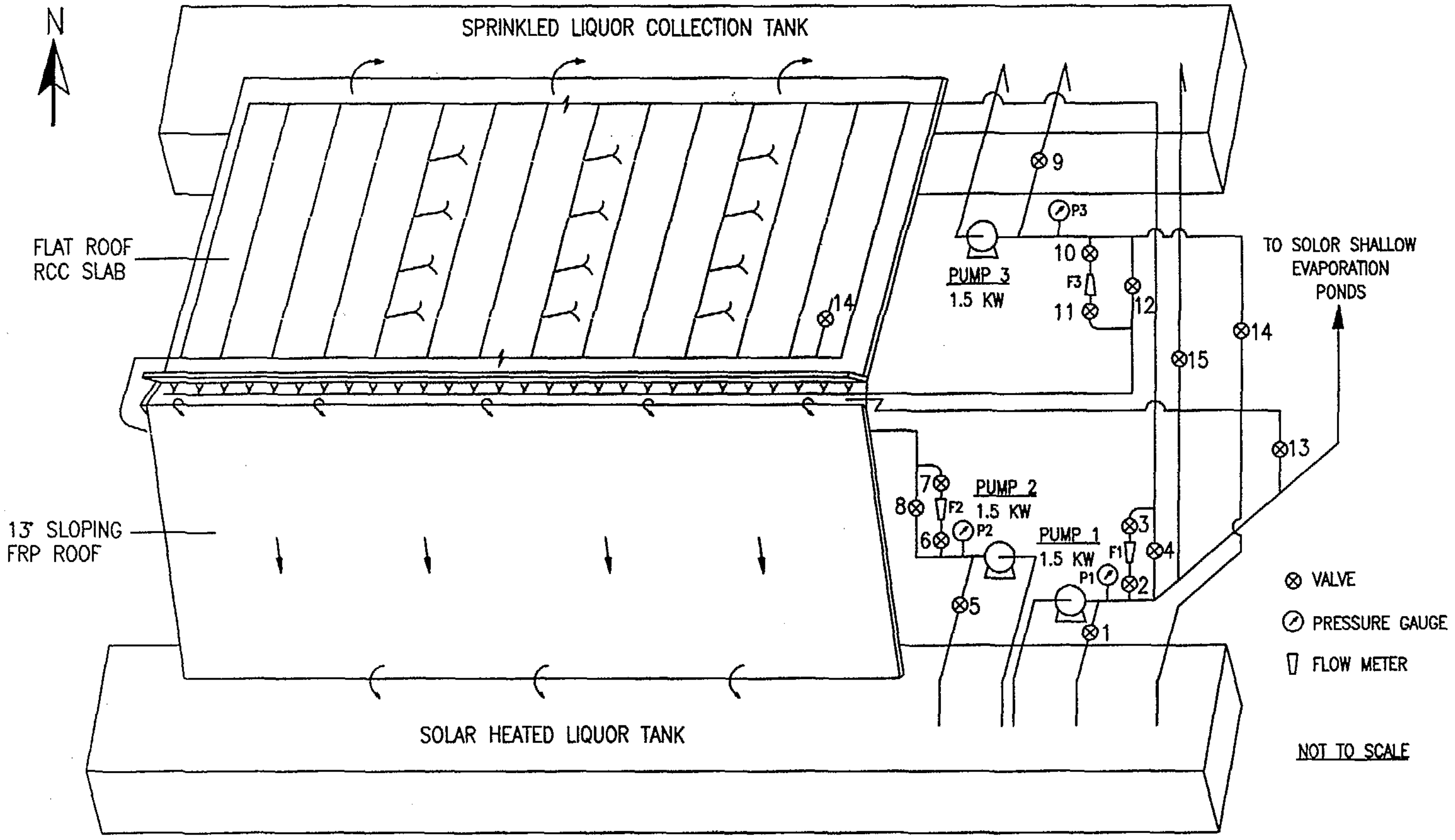


FIG.7B. PIPING NETWORK DIAGRAM

6. EXECUTION

Based on the design, the identified civil contractor carried out the civil construction of the system. The construction had been carried out as per our specification and under our supervision. After the civil construction, FRP (**Fibre Reinforced Plastic**) collectors were mounted. HDPE / PVC pipes, the pumps, pipe lines, valves and spray nozzles were installed. Measuring and monitoring equipment were installed for operation, maintenance and analysis of the system.

7. CALIBRATION

7.1. Calibration of pressure gauges

The pressure gauges are calibrated using a dead weight tester shown in Fig. 8A known pressures are created in the hydraulic system of the dead weight tester by adding dead weights on a piston of known area of cross section. The pressure thus created is recorded by the pressure gauge to be calibrated. The actual pressure applied on the tester is increased in steps of 1.0 kg/cm^2 for pressure gauges of the range 0-15 bar. A plot of actual pressure to the gauge pressure is found to be linear. Pressures can be measured upto an accuracy of 0.2 bar.

7.2. Calibration of thermometers

All the thermometers are carefully calibrated with reference to standard thermometers. In-situ conditions are adopted so that unexpected errors are avoided. Fig. 8B shows the scheme of calibration of the thermometers. A professional thermostatic bath is used to keep the temperature constant within $\pm 0.1^{\circ}C$.

7.3. Calibration of rotameter

Rotameters are used to measure the flow rate. The calibration of rotameter is done in an open circuit as shown in Fig. 8C, using soak liquor as the flow medium. The flow rate of soak liquor through the rotameter is maintained constant and the time taken, in seconds, for collecting a known quantity of the liquor in a measuring jar is noted. The procedure is repeated for the different flow rates.

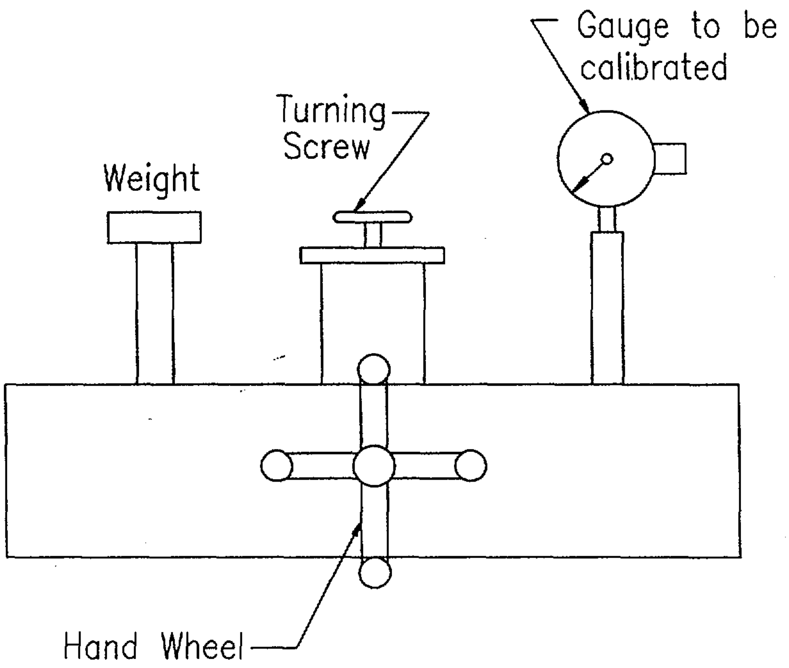


FIG.8A CALIBRATION OF PRESSURE GAUGE (DEAD WEIGHT TESTER)

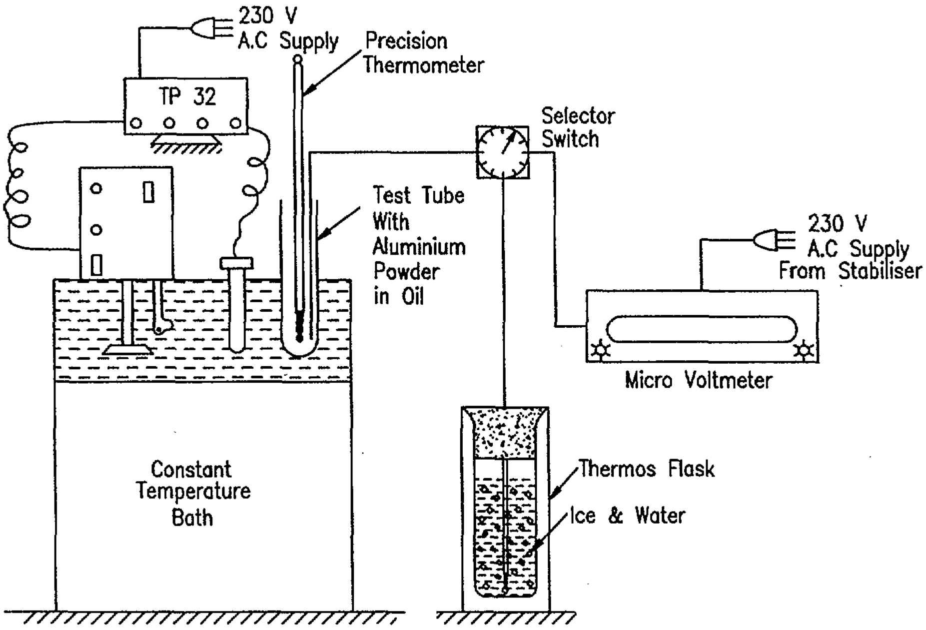


FIG.8B CALIBRATION OF THERMOMETER

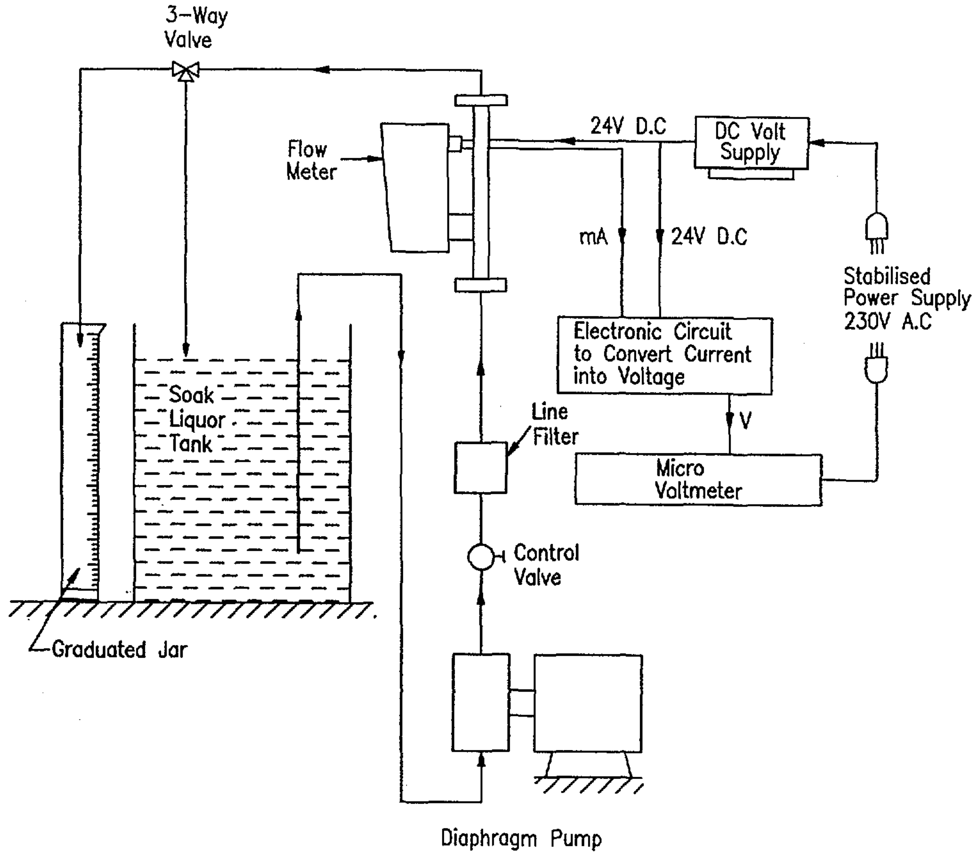


FIG.8C. OPEN CIRCUIT CALIBRATION OF ROTAMETERS

7.4. Calibration of anemometer

Anemometers are used to measure the wind velocity. The calibration of anemometer is done by installing the anemometer in a wind tunnel.

7.5. Calibration of psychrometer

Psychrometers are used to measure the dry bulb temperature and wet bulb temperature. The calibration of psychrometer is done with the help of climatic chamber where desired atmospheric conditions can be created and maintained.

7.6. Calibration of the collection tanks

The tanks A and B were calibrated by pouring the measured quantity of soak liquor into them and marking for every 250 litres upto 10,000 litres.

8. EXPERIMENTAL PROCEDURE

As mentioned earlier, Figs. 7A and 7B show the actual pipe line diagram with valves and pumps. The soak liquor from the tannery is collected in the collection tank and is mixed with polyaluminium chloride. Centrifugal pump (pump 4) transfers soak liquor through the valve 16 to the settling tank hopper. Sludge and dirt settle at the bottom of this tank. The clear soak liquor floats at the top of the tank. The clear soak liquor is transferred to the soak liquor storage ponds through valves 17, 18, 19, 20, 21 and 22.

8.1. Simultaneous operation of FPC and Sprinklers

At the starting of the experiment, the soak liquor from the storage pond is transferred to the sprinkled liquor collection tank (northern side channel) using one valve at a time among the valves 23, 24, 25, 26 and 27. The centrifugal pump 3 is started and the liquor is allowed to pass to the distribution channel through valve 12. The flow rate can be adjusted with the help of the by-pass valve 9. Its flow rate is measured by the flow meter F_3 by keeping valves 10 and 11 open and closing the valve 12.

The soak liquor from the distribution channel flows over the inclined FRP sheet, heated by solar radiation. The soak liquor flowing over the FRP sheets gets heated up. The heated liquor is collected in "solar heated liquor tank". The screw pump (either 1 or 2) is operated and the heated soak liquor is passed to sprinklers by opening valve 4 (in the case of pump 2, through valve 8). The flow rate can be adjusted by the by-pass valve 1. The flow rate can be measured from the flow meter F_1 by opening valves 2 and 3 and closing valve 4 (in the case of pump 2, the flow rate can be adjusted by valve 5 and it can be measured from flow meter F_2 by opening the valves 6 and 7 and closing valve 8). This completes one cycle. The system is run continuously by repeating these processes till the desired soak liquor concentration reaches a magnitude of around 10% which is below the saturation concentration.

8.2. Operation of the system with FPC only

While performing experiments with FRP collector alone, valve 4 is closed and the soak liquor is by-passed to sprinkled liquor collection tank through valve 15. From here it is pumped by pump 3 and passed to distribution channel through valve 12. The system is run continuously and it is stopped when it reaches the desired concentration level.

8.3. Operation of the system with Sprinklers only

During experimentation with the sprinkler system alone, valve 12 is closed and the soak liquor is by-passed to solar heated liquor tank through valve 14. Now, pump 1 or pump 2 is operated and the soak liquor is allowed to pass through the sprinklers through valve 4 (in the case of pump 2 through valve 8). The system is run continuously until it reaches the desired concentration as explained earlier.

9. EXPERIMENTATION

Experiments are conducted to find the effect of the following parameters on the evaporation rate

(1) operational parameters like mass flow rate and the jet diameter of sprinklers and
(2) meteorological parameters such as

- Relative humidity
- Wind velocity
- Ambient temperature
- Dry bulb and wet bulb temperatures
- Solar radiation intensity

Relative humidity is measured by Hygrometer, also it is verified and counter checked with wet and dry bulb thermometers. The solar intensity is measured by the Pyranometer in conjunction with solarimeter integrator. Wind velocity is measured with digital anemometer.

Initial temperature of the soak liquor (t_1) at entry to the FRP collector, final temperature (t_2) of liquor leaving the FRP collector and the temperature of the soak liquor after sprinklers (t_4) are measured using mercury-in-glass thermometers. Soak liquor sample is taken from the two tanks for concentration measurements. These observations are made every one hour and recorded.

10. PRECAUTIONS

a. Pressure gauge is to be checked frequently, so that the system pressure does not exceed 6 bar to safeguard the piping network.

b. After completing experiments, soak liquor from the pipe lines should be drained off in order to avoid salt deposition in the pipe.

c. Phenol is added occasionally to avoid any unwanted biological growth.

d. Before starting, it is ensured that there was no soak liquor/ rain water in collection tanks and distribution channel from previous day's experiments

e. MIO paint was used to coat all the cement structure to prevent corrosion due to seepage of chlorides.

f. Pumps are checked for priming.

g. Screw pump is checked to make sure that the belt is rotating freely with no obstruction.

11. RESULTS AND DISCUSSION

Experiments were carried out on the plant with the following arrangements:

I. Experimentation with simultaneous heating and spray system evaporation arrangements. The results out of this experimentation will give the cumulative effects of solar heating and spray evaporation.

II. Independent experimentation with FRP collector heating only. The results from this experiment will give the effect of only solar heating on the evaporation rate.

III. Independent experimentation with spray system only. The results from this experiment will give the effect of only spray system on the evaporation rate.

These experiments were carried out from January 99 to June 99. During February, the plant was shut to paint the cement structure, storage tank etc., with corrosion resistance MIO paint, to prevent seepage of chlorides through the concrete to safe guard the cement structure and steel reinforcement in it.

As was presented in our second Progress Report in December 1998, the experiments with presettling system using chemical dosing was carried out. The typical performance results from the tests are shown in Table 11.1.

Table 11.1 Performance of Physio-chemical treatment and settling

	Raw soak waste water (average)	Soak waste water with chemical dosing [Alum 200 ppm + Poly Aluminium chloride (PAC) 100 ppm] and 3 hours settling (Average)
pH	7.5	7.2
Suspended solids in mg/l	3300 mg/l	200 mg/l
COD (total) mg/l	2400 mg/l	850 mg/l
TDS mg/l	37500 mg/l	37500 mg/l
Chlorides	17000 mg/l	17000 mg/l

The FRP collector heating system and spray evaporation system were experimented together, apart from experimentation to find the effects of solar heating and spray evaporation on the system performance independently. The system is performing well as per design. The concentrated liquor coming from the evaporation system was sent to natural solar ponds. Upon evaporation of water content in the concentrated liquor the dried salt colour was brownish.

The colour of the salt is attributed to suspended solids in it. So, to avoid the brownish colour, the plant is to be equipped with a sand filter or another settling system or combination of both. To decide about the above, laboratory experimentation was carried out in IIT by adding lime, alum, Ferric chloride and ferrous sulphate. From these experiments it is observed that addition of alum gives a fairly clear salt. The addition of lime also gives more or less the same result. Hence, keeping economy as the criteria, it is suggested to use lime as additive for second stage presettling using the existing hopper-presettling system itself.

11.1 Combined flat plate collector and sprinklers system

Table 11.1.1 shows the effect of mass flow rate on the evaporation rate. For the given jet diameter, as the mass flow rate increases, height of the jet increases, thereby, the contact area between the soak liquor and air increases, consequently the evaporation rate increases. But, the increase of flow rate, increases the thickness of the film of liquor flowing on the collector. This will decrease the rise in temperature of the liquor as it flows over the collector, which reduces the mass transfer rate from liquor to air. Therefore the evaporation rate should decrease. The results shown in the table is the cumulative effects due to both solar heating and spray evaporation. As the net evaporation rate increases with the increase mass flow rate, it is inferred that the increase in evaporation rate due to spray system over-compensates the decrease in evaporation rate over the flat plate collector. It may be pointed out here that the results tabulated correspond to only 8 hour operation of the plant between 9 a.m. and 5 p.m.

Table 11.1.2 gives the effect of nozzle diameter on evaporation rate. For a given mass flow rate, as the nozzle diameter increases, the evaporation rate increases. This is rather a baffling result as the evaporation rate should have really decreased with the increase in jet diameter, in view of the explanations in the previous paragraphs. There were 90 nozzles in the system. They could not accommodate the tabulated flow rate when 1.0 and 1.5 mm nozzles were used. To maintain safe pressures in the system quite some liquid had to be by-passed. Thus, only a part of the total liquid was passing through nozzles. This perhaps is the only reason to explain the reduction in the evaporation with the decrease in jet diameter. Because of the difficulty of not being

Table 11.1.1 Effect of mass flow rate (FPC and Sprinklers)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Mass flow rate, l/hr	Jet diameter, mm	Jet height, m	Average air temperature, °C	Average wind velocity, m/s	Average solar intensity, W/m2	Average relative humidity, %	Soak liquor evaporated, litres
1	2.5.99	5500	2	2.5	37	0.6	432.5	46	2200
2	3.5.99	4500	2	1.5	37	0.8	460.9	43	2000
3	4.5.99	3500	2	0.5	38	0.7	455.2	43	1900

Table 11.1.2 Effect of Nozzle Diameter (FPC and Sprinklers)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Jet diameter, mm	Jet height, m	Mass flow rate, l/hr	Average air temperature, °C	Average wind velocity, m/s	Average solar intensity, W/m2	Average relative humidity, %	Soak liquor evaporated, litres
1	6.2.99	1	2.5	3500	29.8	0.8	419.3	41.5	1400
2	12.5.99	1.5	1.5	3500	35	0.6	503.6	45	1600
3	4.5.99	2	0.5	3500	35	0.7	455.2	43	1900

able to accommodate the total flow through the nozzles in all subsequent experiments, only 2 mm jets were used. The results in table 11.1.2 is not a real indicator of the jet diameter. What is reported here is only the attempt made to find the effect of nozzle diameter. No concrete inferences could be arrived at because of operational constraints in the experiments. However, when 2.5 mm nozzles were used in the system, the jet height became less than 50 cm. This was of no use. As 2 mm nozzles did the job well it was decided to use these nozzles in the system.

Table 11.1.3 describes the effect of wind velocity on the performance of the evaporation system. As the wind velocity increases, convective mass transfer from the liquor interface to air increases. Consequently the evaporation rate increases.

Table 11.1.4 shows the effects of intensity of solar radiation on the evaporation rate. As one would expect, the evaporation rate increases with an increase in solar radiation intensity.

11.2 Flat plate collector system only

Table 11.2.1 shows the effect of mass flow rate on the flat plate collector evaporation rate. As the mass flow rate decreases, the thickness of the liquor film flowing over the Flat Plate Collector (**FPC**) decreases. Hence, for the same length of solar flat plate collector and given period, the rise in temperature realised by the soak liquor is high. Because of this, the mass transfer rate is increased from the liquor to air, thereby increasing the evaporation rate. The temperatures shown in the table are the average temperatures over the operating period. However, the temperature rise of the liquor as it flows over the collector, around mid noon, is of the order of 3.5 degrees.

Table 11.2.2 shows the effect of solar radiation intensity on the performance of the system. The two results entered in the table are such that all other parameters are more or less the same except for the difference in solar radiation intensity only. It can be seen that the evaporation rate increases with the increased solar radiation intensity.

Table 11.2.3 shows the effect of the relative humidity on the system performance. Here, again the two results are selected from experiments on such days during which all other parameters were more or less the same, but for the difference in the values of relative humidity. It can be seen that the performance is a function of relative humidity. The performance increases rapidly with decrease in relative humidity.

Table 11.1.3 Effect of Wind Velocity (FPC and Sprinklers)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Average wind velocity, m/s	Average air temperature, °C	Average relative humidity, %	Mass flow rate, l/hr	Jet diameter, mm	Jet height, m	Average solar intensity, W/m2	Soak liquor evaporated, litres
1	23.1.99	1.16	26.4	20	4000	1	3	388.5	1500
2	19.1.99	1.99	27.3	21	4000	1	3	397.3	2250

Table 11.1.4 Effect of Solar Radiation Intensity (FPC and Sprinklers)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Mass flow rate, l/hr	Jet diameter, mm	Jet height, m	Average air temp., °C	Average wind velocity, m/s	Average solar intensity, W/m2	Average relative humidity, %	Soak liquor evaporated, litres
1	06.5.99	5500	2	2.5	37	1.3	432.5	43	2200
2	14.6.99	5500	2	2.5	35	1.4	512.5	41	2600

Table 11.2.1 Effect of Mass flow rate (FPC only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Mass flow rate, l/hr	Average Temp. of soak liquor entering the flat plate collector t_{in}, °C	Average Temp. of soak liquor leaving the flat plate collector t_{exit}, °C	Average wind velocity, m/s	Average solar intensity, W/m^2	Average relative humidity, %	Soak liquor evaporated, litres
1	9.6.99	5500	32	33.2	1.6	432.3	30	800
2	1.2.99	4500	28.8	30.4	1.5	479.4	27.7	1000
3	4.2.99	3500	30.4	32.5	1.5	435.4	28.7	1100

Table 11.2.2 Effect of Solar Radiation Intensity (FPC only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Mass flow rate, l/hr	Temp. t_{in}, °C	Temp. t_{exit}, °C	Average wind velocity, m/s	Average solar intensity, W/m^2	Average relative humidity, %	Soak liquor evaporated, litres
1	1.2.99	4500	28.8	30.4	1.5	479.4	27.7	1000
2	12.6.99	4500	33.5	35.1	1.7	590.4	30	1250

Table 11.2.3 Effect of Relative Humidity (FPC only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Mass flow rate, l/hr	Temp. t_{in}, °C	Temp. t_{exit}, °C	Average wind velocity, m/s	Average solar intensity, W/m2	Average relative humidity, %	Soak liquor evaporated, litres
1	3.2.99	4500	30	31.7	1.5	481.5	27	1100
2	15.6.99	4500	31	33	1.6	485.0	46	800

Table 11.2.4 Effect of Wind Velocity (FPC only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 5%

Sl. No.	Date	Mass flow rate, l/hr	Temp. t_{in}, °C	Temp. t_{exit}, °C	Average solar intensity, W/m2	Average air temp., °C	Average wind velocity, m/s	Average relative humidity, %	Soak liquor evaporated, litres
1	8.6.99	5500	32	32.8	458.8	32	3.3	54	2600
2	10.6.99	5500	32	33.2	432.3	33	1.2	55	800

Table 11.3.1 Effect of Mass flow rate (Sprinklers only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Mass flow rate, l/hr	Jet diameter, mm	Jet height, m	Average air temperature, °C	Average wind velocity, m/s	Average solar intensity, W/m^2	Average relative humidity, %	Soak liquor evaporated, litres
1	27.4.99	4500	2	1.5	36	0.7	469.9	50	1000
2	25.4.99	5500	2	2	37	0.9	462.5	45	1300

Table 11.3.2 Effect of Nozzle Diameter (Sprinklers only)

Quantity of soak liquor taken for treatment = 5000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Jet diameter, mm	Jet height, m	Mass flow rate, l/hr	Average air temperature, °C	Average wind velocity, m/s	Average solar intensity, W/m^2	Average relative humidity, %	Soak liquor evaporated, litres
1	9.5.99	1.5	2	4500	37	1.2	488.2	48	800
2	27.4.99	2	1.5	4500	36	0.7	469.9	50	1000

Table 11.2.4 gives the effect of wind velocity on the performance. Again in this table, the experimental values selected are those that correspond to days of substantial different wind velocity and at the same time the other properties being more or less the same. It can be seen that the performance is a strong function of wind velocity. With the increase in wind velocity the performance increases substantially.

11.3 Sprinklers system only

Table 11.3.1 shows the effect of mass flow rate on the evaporation rate of sprinklers system alone. For the same reason explained above, as the mass flow rate increases the evaporation rate increases.

Table 11.3.2 gives the effect of nozzle diameter of the sprinklers on evaporation rate. As the jet diameter increases the evaporation rate increases for the same reason explained above. This may not be a realistic comparison, as 1.5 mm diameter nozzles could not handle the given mass flow rate without by-passing.

11.4 Continuous operation for 24 hours in a day

Tables 11.4.1 and 11.4.2 show the results of continuous operation of the system for 24 hours in day. While Table 11.4.1 gives the results when both flat plate collectors and sprinklers were in operation, Table 11.4.2 gives the results only when sprinklers were on and the flow over the flat plate collectors was stopped.

In these tests, 10,000 litres of soak liquor was taken as against the normal practice of 5000 litres. This was necessary to see that the channels had sufficient liquor to be dealt by the pumps.

The first Table shows that around 4000 litres of water could be evaporated in 24 hours. This quantity is nearly twice compared to earlier results presented for 8 hours day time operation. The results in the second Table reveal that the water evaporated is around 2000 litres when only the sprinklers were on. The observation that can be made between these two results is that both the flat plate collectors and the sprinklers are equally effective. Because, with only sprinklers around 2000 litres is evaporated in a day, while with flat plate collectors and sprinklers, double the quantity is evaporated. The inferences that can be drawn is, it is advisable that the system is operated for 24 hours using both FPC and sprinklers.

Table 11.4.1 24 hours / day operation (using both FPC and Sprinklers)

Quantity of soak liquor taken for treatment = 10000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Mass flow rate, l/hr	Average wind speed, m/s	Average ambient temperature, °C	Average relative humidity, %	Average solar intensity, W/m^2	Energy meter reading, kW/hr	Soak liquor evaporated, litres	Remarks
1	28.8.99 - 29.8.99	5500	1.2	31	66	432	65	4000	without using AC in the observation room
2	02.9.99 - 03.9.99	5500	1.4	31	64	364.2	81	3750	with AC on in the observation room
3	26.8.99 - 27.8.99	5500	1.5	32	62	511.5	42	3400	without using AC & 16 hours operation - 9 a.m to 12 midnight, 5 a.m to 6 a.m.

Table 11.4.2 24 hours / day operation (using Sprinklers only)

Quantity of soak liquor taken for treatment = 10000 litre. Initial concentration (average) = 4%

Sl. No.	Date	Mass flow rate, l/hr	Average wind speed, m/s	Average ambient temperature, °C	Average relative humidity, %	Average solar intensity, W/m^2	Soak liquor evaporated, litres
1	4.9.99 - 5.9.99	5500	1.5	30	67	372.45	2250
2	8.9.99 - 9.9.99	4500	1.1	31	66	392.7	2000

11.5 Power Consumption

Given in the above two tables are the energy meter readings. The electrical energy is consumed by the centrifugal and screw pumps and the air-conditioner in the observation room. To get the energy consumption only by the system, the experimentation was first done with air-conditioner in the observation room being put off. The energy consumed per day is 65 kWh. The second day, energy meter reading is taken with air-conditioner on. It is observed that 81 units were consumed. It can be said that air-conditioner consumed 16 units and the system 65 units for operation.

At the rate of Rs. 3 per unit of electricity the energy consumption cost is around Rs. 200 per day.

12. CONCLUSION

The objective of the experimentation was to find out the effect of various parameters on the system performance. The parameters that affect the performance can be classified into two :

i) those which can be controlled during experimentation

ii) those which cannot be controlled, but yet have a big influence on the system performance.

The parameters that fall in the first category are the mass flow rate through the system and jet diameter of the sprinklers. The parameters that belong to the second category are the ambient temperature, wind velocity, solar radiation intensity and relative humidity - these, as one can see, are the meteorological properties.

The experiments have been conducted more or less regularly during the past six months. In this period, the parameters that belong to the second category varied over a large extent. In compiling the results to find the effect of various parameters, such results that belong to days of similar meteorological properties, to the extent possible have been selected.

It can be said that the results provided in this report are only limited. To get a thorough and complete understanding of the effects of all parameters on the system performance, the system must be run continuously for another six months, or even longer, which will probably include various possible values for the meteorological properties.

In the tables upto 11.3.2 in which the results are tabulated, the last column is always the quantity of water evaporated in a working period of around 8 hours, between 9 am and 5 p.m.

The following further quantifies the results that are tabulated. For example, in table 11.1.1, in the first experiment conducted on 2.5.99, the following results are given.

Quantity of soak liquor taken for treatment in the morning	=	5000 litres

(In all the experiments, the quantity of soak liquor taken for treatment in the morning is around 5000 litres)

Initial concentration	=	4%
Water in soak liquor evaporated in 8 hours	=	2200 litres
Concentrated liquor in the system at the end of the day	=	2800 litres
Final concentration	=	7.1%

The concentrated solution which has reached the concentration of 7% is further concentrated to around 10% by passing only through the sprinklers for 3 to 4 hours in the night to bring it to around 10% concentration. This liquor is then passed on to open natural solar pans for crystallization.

The results of continuous operation has revealed that the system on an average can evaporate around 4000 litres of water per day while both the flat plate collectors and the sprinklers are on. With only the sprinklers on, water evaporated is around 2000 litres. It can be concluded from these results that both the sprinklers and the flat plate collectors are equally effective and that it is advisable that the system is operated continuously for 24 hours. On an average, this system consumes 65 units of electricity per day of operation.

a. Advantage of the System

Supposing, just natural evaporation ponds were only used, the quantity of liquor that would have evaporated in the same 8 hours, over the same exposed area equal to the area of the flat plate collector, sprinkler platform and various channels totalling to 240 m^2, would be a maximum of 480 litres. This figure is arrived based on the literature and our own experiments that natural evaporation rate is around 4 - 6 mm / m^2 / day.

This plant has evaporated 2200 litres in 8 hours on 240 m^2. Therefore, the plant is atleast 4 to 5 times more efficient than simple natural evaporation. However, during 24 hours/day continuous operation the quantity of water evaporated is double of that evaporated in 8 hours day time operation.

b. Cost Reduction Potential

i) This system is the first system of its nature, designed, operated and tested. In designing the system, extra precautions were taken in the construction to make it stronger than what perhaps the optimum design would require. As far as the civil construction goes, the foundation, the pillars and roof structure used are too heavy that there is a big scope to reduce them to such an extent that about 50% of the cost can be saved through reduction in materials. The structure was elevated by 2 m with a hope that the heated liquor falling from the collectors through the height of 2 m would also help in increasing the evaporation rate. However, the simultaneous experiments that are being conducted with a small scale model has revealed that this falling film adds very little to the system performance. Hence, in the modifed design there is no need to keep the collector structure so high over the ground level. This modification would certainly reduce the civil construction cost substantially.

ii) The FRP sheets used as flat plate collectors are exceedingly costly. It was thought that these sheets would be of immense value in view of the salinity of the soak liquor continuously flowing over it. But the test conducted over the past six months have revealed that the FRP joints not only develop frequent leaks. but also develop undulations because of thermal fatigue. These FRP sheets can be replaced in the modified design by thin ferro-cement structures. This will reduce the cost of the flat plate collectors very susbstantially.

iii) In the system, two screw pumps are used to circulate liquor from the flat plate collectors to the sprinklers. These screw pumps are very costly compared to the same capacity centrifugal pumps. Some trials conducted on the system have revealed that centrifugal pumps can satisfactorily do the same job that the screw pumps are presently doing. The cost of each screw pump is nearly 3 - 4 times that of the centrifugal pump. It is suggested that in the modified system, the screw pumps can be conveniently replaced by centrifugal pumps to get the cost advantage.

iv). This is a pilot plant and it is meant for thorough investigation through experimental measurements. Rs. 1.6 lakhs had been earmarked towards the measuring devices incorporated in the system. There is no need for these measuring devices in the future plants. Thus this amount can be totally saved.

v) The system has also used large pipelines and very many valves to accommodate various permutations and combinations to be selected during experimentation. As the required information, with regard to design and fabrication, has already been obtained from this system, a sizable reduction can be made in the future plant by reducing the unnecessary pipelines and number of valves.

vi) The amount of Rs. 6.1 lakhs sanctioned for Indian Institute of Technology, Madras, Chennai was towards buying various measuring devices, overheads, travel, payment to staff, towards literature, contingency etc. 75% of this amount is not necessary for the future plant.

Taking all the above practical reductions into consideration, it can be conclusively said that the future plants of the same capacity can be built with just 30% of the present total sanctioned project amount.

13. ROUGH ESTIMATE FOR 20,000 LITRE / DAY CAPACITY SYSTEM

Figure 9 shows the schematic of a large system meant for treating 20,000 litres of soak liquor per day. It is envisaged that the flat plate collector area required is around 250 m^2. In this system, the FRP sheets are replaced by chicken meshed ferro-cement thin slabs. Also, the sprinklers platform is eliminated and in place of which only the pipes carrying the nozzles are supported on few cantilever beems. The rough cost estimate of the plant given below is prepared keeping in mind the cost reduction potential mentioned earlier.

<u>Rough Estimate for 20,000 litre / day Capacity System</u>

1.	Civil work with anti-corrosive paint	10.0 lakhs
2.	PVC pipes, pipe fitting, valves	1.0 lakhs
3.	Nozzles	0.5 lakhs
4.	Electrical wires, appliances, fittings including labour	1.0 lakhs
5.	Centrifugal Pumps 5 HP - 4 Nos.	1.5 lakhs
6.	Miscellaneous	1.5 lakhs
	Total	15.5 lakhs

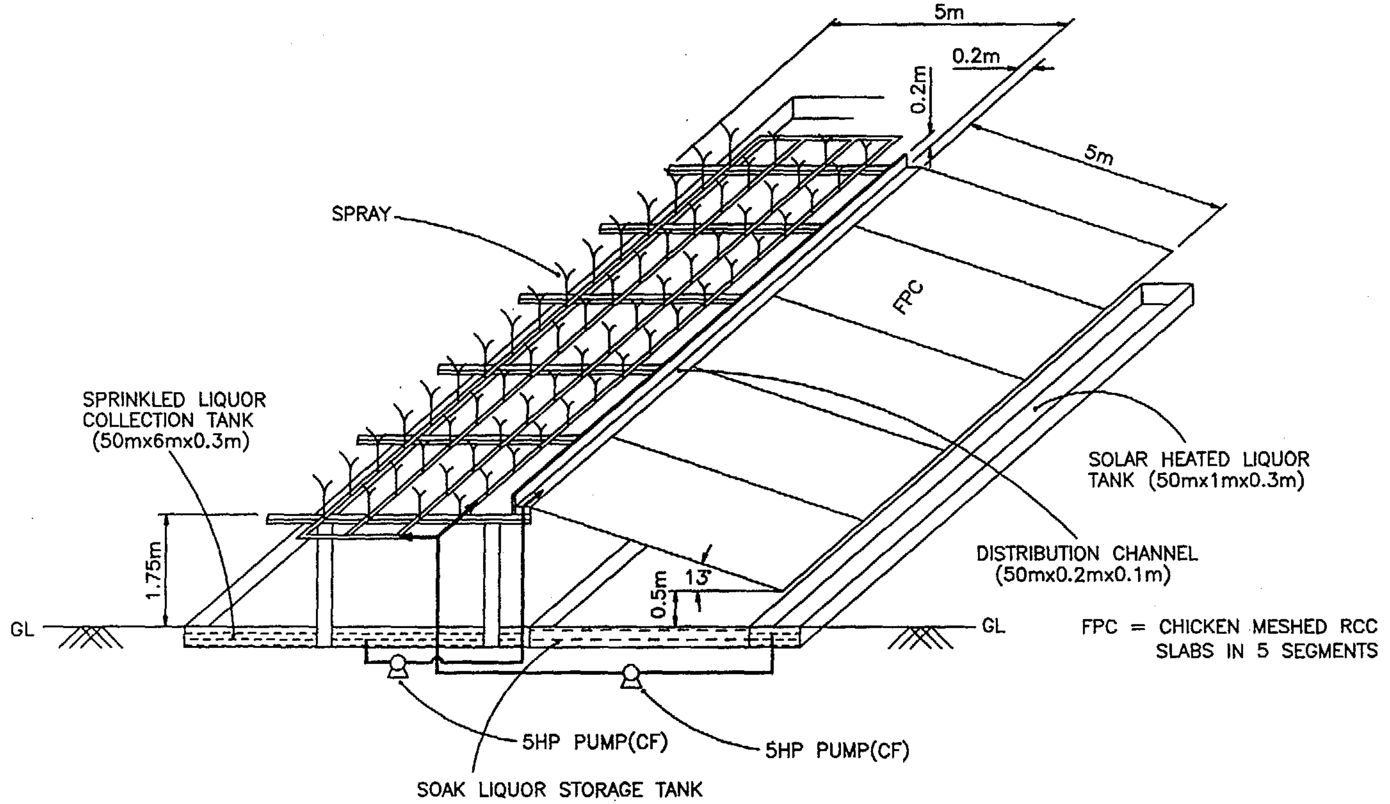


FIG.9 SCHEMATIC OF THE 20,000 LITRES/DAY CAPACITY SYSTEM

SOLAR AUGMENTED EVAPORATION PONDS FOR TREATMENT OF SEGREGATED TANNERY EFFLUENT (SOAK LIQUOR)

DESIGN CRITERIA / SPECIFICATIONS

(Refer Figs. 2 to 5)

Location	:	Shafeeq Shameel & Co, Ambur, India
Segregated flow of soak liquor	:	5,000 l/day

Existing drainage, screens upto the selected existing Solar Evaporation pan will be utilised.

The location of the selected Solar pan area is shown in Fig. 2

Characteristics of Soak liquor

pH	:	7.0 - 8.0
TDS	:	30,000 - 60,000 mg/l
SS	:	4500 - 7000 mg/l
Chlorides	:	15,000 - 24,000 mg/l

1. Collection Sump

Cement masonry water tight tank or chemical resistance tank of capacity 6000 l is provided to receive soak liquor near the selected Solar Pan.

2. Pump 4

To pump the soak liquor to settling tank/recirculation

Capacity	:	3 m^3/h
Total Head	:	5 m
Suction	:	2 m
Delivery	:	3 m
Type of pump	:	Centrifugal impeller material = Polypropylene or FRP
Speed	:	1440 rpm

3. Chemical Dosing

For simple operation of the chemical dosing, Alum 200 - 300 ppm and Poly aluminium chloride 2 - 3 ppm will be added in the collection tank and thoroughly mixed using pump by recirculation.

4. **Settling Tank**

Settling tank will be used for batch operation (i.e. 2.5 m^3/batch)

Effective volume of settling tank	:	2.5 m^3
Detention time	:	2 h

(i.e. 1 hour would be sufficient as per lab studies)

Shape	:	Circular with hopper bottom
Size	:	1.5 m dia 1.2 m depth on cylindrical portion 1.2 m depth on hopper bottom
Make	:	FRP or RCC to suit local condition

Two batch operation during day time (i.e. 9.00 a.m. to 5.00 p.m.)

5. **Storage Tank (A)**

Part of existing Solar Pan (20 m x 6 m x 0.4 m) will be used for strong clarified water upto about 50 m^3 in compartments. Necessary cement work to strengthen and partition will be made. Plan is shown in Fig. 7.a.

6. **Solar Heated Liquor Tank (C)**

Size	:	20 m x 2 m x 0.25 m (average)

A chamber of 2 m x 1 m x 0.6 m will be provided at the south west corner of tank 'C'.

Construction	:	Water tight chamber with cudappah flooring and sulphate resistant cement plastering.

7. **Pump 2**

Purpose	:	Pumping from Solar heated liquor tank to Spray system.
Type	:	Screw pump (Anticorrosive impeller and casing)
Capacity	:	7.5 m^3/h
Max. Pressure	:	6 bar
Appx. Power	:	2.25 kW
Speed	:	1450 rpm

8. **Pipes**

(a) HDPE / PVC 5 cm dia. / 6 kg
(b) HDPE / PVC 2.5 cm dia / 6 kg

9. Valves

Material	:	Polypropylene
Type	:	ball valves
Size	:	5 cm and 2.5 cm

10. Spray and Distribution channel Platform

Overall size	:	20 m x 4 m
Distributing channel	:	20 m x 0.5 m x 0.1 m
Spray area	:	20 m x 3.5 m
Height over ground level	:	3 m
Supporting RCC Pillars	:	2 x 7 = 14 Nos.

11. FRP Solar Collector

Size	:	20 m x 4.0 m (slope area)
Slope	:	13° to horizontal butting against Distributor Channel and supported by 7 RCC pillars towards the lower end.
Specification	:	Rigid 5 mm thick, dull black, flat, water tight surface facing south and bottom with reinforcement hooks and support.

12. Solar Heated Liquor Tank

Size	:	20 m x 1 m x 0.25 m (average)

A chamber of 2 m x 2m x 0.6 m will be provided at one end of the tank.

13. Pump 1

Purpose	:	Pumping liquor from Tank B to distributor channel
Type	:	Centrifugal
Mat	:	FRP casing, Teflon impeller
Capacity	:	5 - 10 m^3/h
Head	:	3 - 5 m
Appx. Rating	:	1 kW

14. Distribution System for sprinkles

Headers	:	5 cm dia HDPE / PVC
Distributor pipe	:	2.5 cm dia HDPE / PVC
Nozzles for Spray	:	1 to 3 mm - 120 Nos.
Piping arrangement	:	As in Fig. 7.b.

Annex : 2

SPECIFICATION OF EQUIPMENT

1. **Solarimeter with base and screen**

Make	:	Kipp and Zonen
Wavelength range	:	0.3 mm to 2.5 mm
Sensitivity	:	8 mV/g cal - cm^2 min 115 mV/W cm^2
Internal resistance	:	10 ohm
Accuracy	:	1%
Diameter screen	:	30 cm
Height	:	11 cm
Weight	:	3.7 kg including base and screen
Weight of solarimeter only	:	0.8 kg

2. **Solarimeter integrator - CCI**

Make	:	Kipp and Zonen
Counting rate	:	20 counts per g cal. cm^{-2} for solarimeter with calibration constants between 7 and 9.9 mV
Input range	:	0 - 20 mV
Accuracy	:	better than 0.5% ± one count
Linearity	:	better than 0.3% f.s.d
Input resistance	:	25000 ohms
Mains supply	:	220 or 115 V ± 10% 50 - 60 HZ
Power consumption	:	17 W
Weight	:	8.6 kg
Dimensions	:	44 x 30 x 12 cm

3. **Hygrometer**

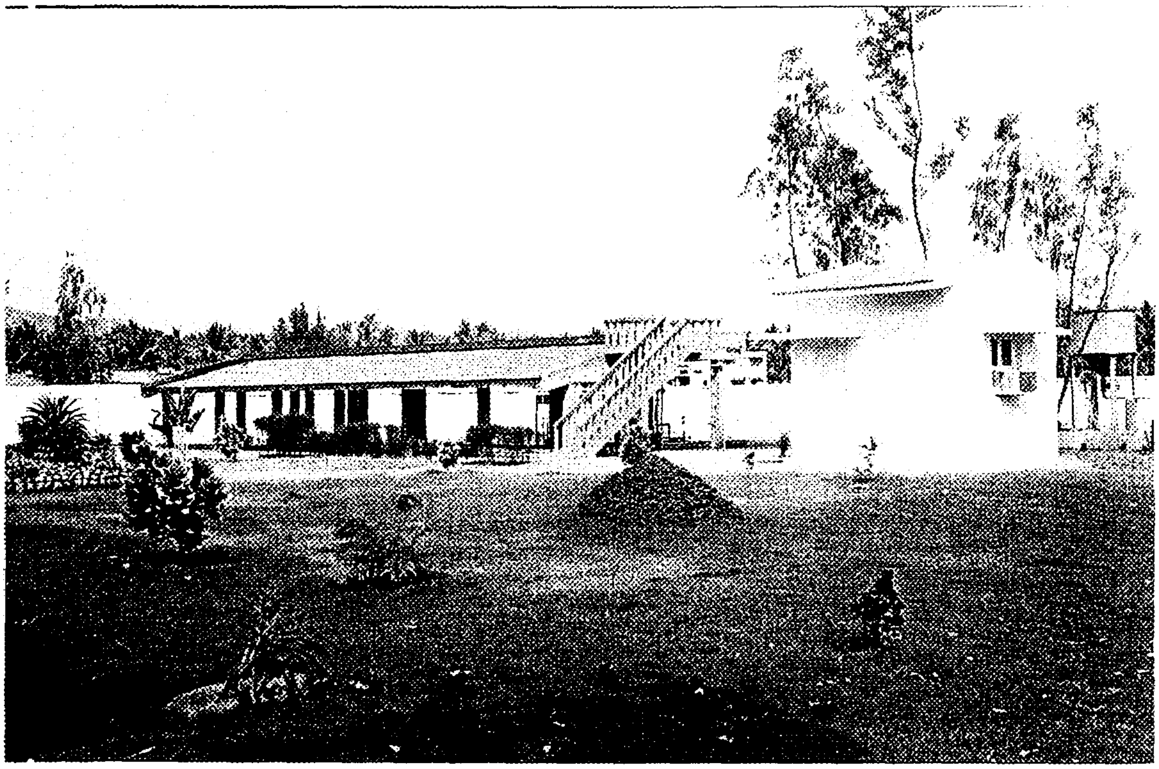
Make	:	Barigo
Dial	:	50 mm ϕ
Accuracy	:	1%
Range	:	0 to 100%
Weight	:	100 gm

4. **Anemometer**

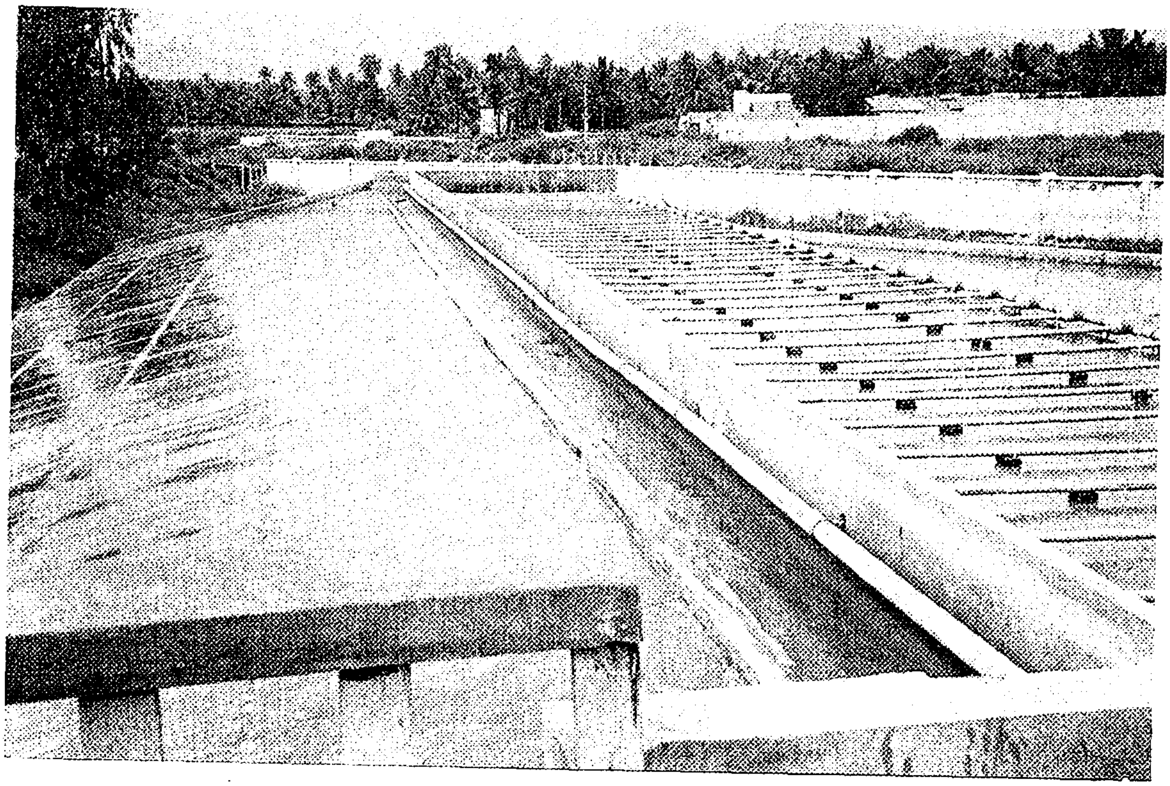
Type	:	Digital
Accuracy	:	0.1 m/s
Weight	:	100 g
Dial Dimension	:	75 mm

5. **Wet and dry bulb thermometer**

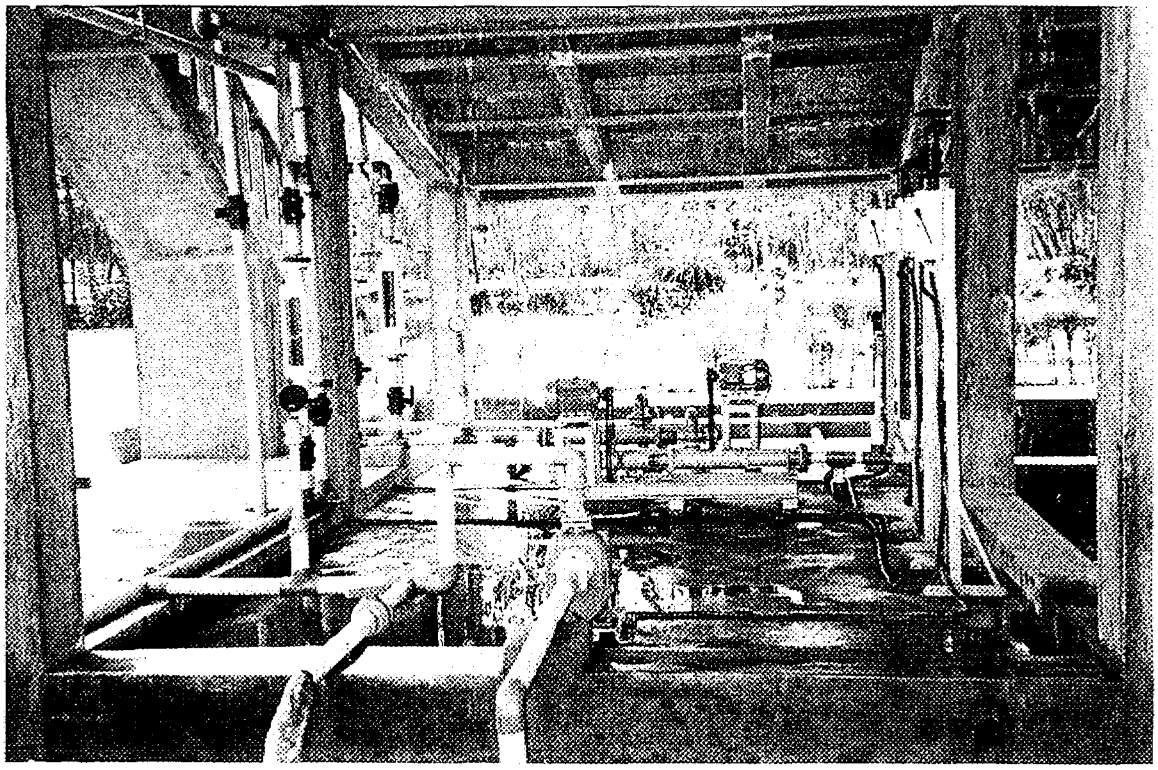
Type	:	Alcohol in glass thermometer
Accuracy	:	0.1°C
Weight	:	200 g
Length of thermometer	:	15 mm



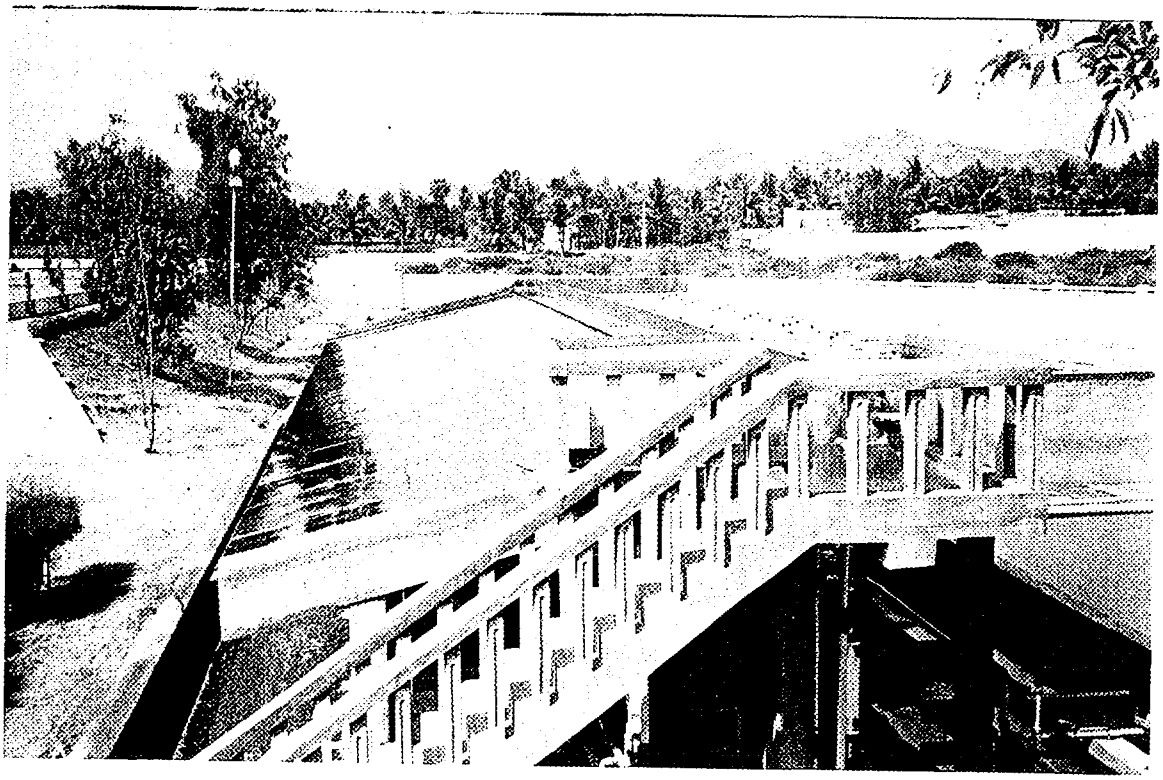
PICTORIAL VIEW OF THE PLANT



SOAK LIQUOR FLOW OVER SPRINKLER



LOCATION OF PUMPS, GAUGES, ETC.



SOAK LIQUOR FLOW OVER FRP COLLECTOR