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ACCELERATED EVAPORATION OF SALINE STREAMS IN SOLAR PANS

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LIST OF SYMBOLS & ABBREVIATIONS

Cl^-	:	Chlorides
COD	:	Chemical Oxygen Demand
ϕ	:	Diameter
^oC	:	Degree Celsius
FPC	:	Flat Plate Collector
FRP	:	Fibre reinforced plastic
INR	:	Indian Rupees
kW	:	Kilo watt(s)
l	:	Litre(s)
l/d	:	Litre(s) per day
m	:	Meter(s)
mm	:	Millimeter(s)
RePO	:	Regional Programme Office of UNIDO at Chennai
RH	:	Relative Humidity
TDS	:	Total dissolved solids
TNPCB	:	Tamil Nadu Pollution Control Board
UNIDO	:	United Nations Industrial Development Organization
W/m^2	:	Watt(s) per square meter
(Rate of exchange	:	1 US$ = INR 46.80)

EXECUTIVE SUMMARY

The surface discharge limits prescribed for TDS and chlorides for the treated industrial effluent are 2100 mg/l and 1000 mg/l respectively in the state of Tamilnadu, India. In order to contain the level of TDS in the effluent, tanneries of Tamilnadu are required by the pollution control authority to segregate the waste streams from soak and pickle sections, as the salt concentration in these is 3.5% to 6% and convey to conventional solar pans for natural evaporation. About 6 - 10000 litres of such highly saline effluent is discharged by these sections while processing one tonne of wet salted raw stock. Based on the average natural evaporation rate of 4.5 mm/d, the TNPCB has specified the solar pan area required for evaporation of 1 m^3 of saline effluent as 222 m^2. All tanneries in Tamilnadu therefore have constructed solar pans for evaporation of soak and pickle liquor generated by them.

Scarcity of land and its high cost have become serious constraints for expansion of the tanning industry. Besides the increasing salinity in soil and ground water in Vellore district of Tamilnadu, with the largest concentration of tanneries in India, has raised questions about the efficacy of existing solar pans. The need for enhancing the effectiveness of the solar pans has therefore been highlighted by the tanners and the pollution control authority.

In cooperation with Indian Institute of Technology, Madras and willing tanners, UNIDO has established two pilot accelerated solar evaporation systems under its Regional Programme with a view to enhance the rate of evaporation, thus reduce the area required for the purpose and at the same time improve salt recovery.

The first of these was commissioned in January 1999 at SSC tannery, Ambur. This system consisted of a flat plate collector (FPC) and sprinklers. The soak and pickle liquor was given chemical treatment to remove about 90% of suspended solids. The clarified liquor was first passed through the FPC when it heated up by about 2 to 3^0C. Thereafter it was sprinkled through the nozzles. When this process was repeated throughout a day, the volume of liquor evaporated ranged from 3500 to 4000 l/d.

The process was repeated until the concentration of TDS reached 10 - 12%, when it was sent to the conventional solar pans for natural evaporation and crystallization of salt.

The impact of various factors such mass flow rate, height of sprinkled liquor, solar radiation intensity, wind velocity and relative humidity was carefully monitored and recorded on an hourly basis for about 9 months from January to September 1999. The volume of effluent taken up for evaporation, the volume evaporated and that remained at the end of the operation during the day were recorded daily. The rate of evaporation achieved by the system ranged from 13 mm/d to 24 mm/d. The capital cost of the system was US $ 19600 due to its robust construction and many special features to monitor various parameters. The operational cost was US $ 1.03/m^3 of water evaporated exclusive of depreciation and US $ 1.97/m^3 inclusive of depreciation.

The experiments had established that the efficiency of the FPC and the sprinklers was more or less equal. With a view to reduce the cost of installation and operation, a simplified version was installed at ATH tannery, Melvisharam, consisting of units for chemical treatment of the saline liquor and only the sprinklers, for handling 20000 l/d. It consisted of four sections of sprinklers, each of about 250 m^2. The first section of sprinklers was commissioned in January 2001. During February and March 2001, this section was able to evaporate on the average about 3760 l/d. The average rate of evaporation was 15 mm/d. The capital cost of the system for all four sections was estimated at US $ 47800 and its operational cost at US $ 0.56/m^3 exclusive of depreciation and US $ 1/m^3 inclusive of depreciation.

Drifting of sprinkled effluent, sometimes in large volume away from the system, was observed during the experiments. To prevent drifting of the sprinkled effluent outside the system by wind, it will help to install the sprinklers in the middle of the system and restrict the height of the jet from sprinklers, along with the height of the sprinkler pipe network, to less than 2 m from ground level.

The salt recovered from the concentrated effluent at both locations – SSC, Ambur and ATH, Melvisharam – has been found to be clear crystals and its use in pickling operation has been demonstrated. Also, the suppliers of raw hides and skins are willing to take some quantity for use in preservation.

To compare the actual rate of natural evaporation of ground water, untreated saline effluent, chemically treated saline effluent and concentrated liquor from the accelerated evaporation system, some experiments were conducted in conventional solar pans between April and July 2001. The results obtained for these months were average evaporation rate of 7.5, 5.7, 6.6 and 7.4 mm/d for ground water, untreated saline effluent, chemically treated saline effluent and concentrated saline effluent, respectively.

The average rate of evaporation in the SSC system is 14.4 mm/d and that in ATH, Melvisharam, 15 mm/d. It is therefore safe to conclude that the rate of evaporation can be increased by 2 to 3 times in the accelerated system.

The accelerated solar evaporation systems have established that the solar pan area required can be reduced by about 40%. Moreover, the salt recovered is clean and fit for reuse either in the tannery or for preservation of hides and skins.

With increasing pressure on the tanners to deal with TDS in the effluent effectively, the accelerated solar evaporation system has been widely accepted in Tamil Nadu. For obvious reasons many tanners have shown preference for the simplified version of the accelerated solar evaporation system.

1. INTRODUCTION

Total dissolved solids (TDS), specifically chlorides, in effluent is a major concern for its discharge into the surface or its use for irrigation. Conventional treatment systems do not help reduce TDS in the industrial effluent. Taking advantage of the sunshine available for most part of the year, tanneries in Tamil Nadu, India, are required by the regulatory authority to segregate saline effluent from soak and pickle streams and evaporate it in solar pans. These streams containing TDS between 35000 and 60000 mg/l contribute the maximum dissolved solids to the combined tannery effluent. The average rate of evaporation from the surface of natural lakes and ponds of non-saline water in Vellore district, Tamil Nadu, is taken as 4.5 mm per day[1]. Based on this average rate of evaporation, the pollution control authority has prescribed 222 m^2 area of solar pan for evaporation of 1 m^3 of saline effluent per day. The volume of soak and pickle liquor generated while processing one tonne of raw material in a tannery ranges between 6000 and 10,000 litres[2]. And therefore the area of solar pan required for evaporating this volume of saline effluent is between 1333 m^2 and 2220 m^2. All operating tanneries in Tamil Nadu, numbering about 700, have constructed and maintained solar pans for this purpose. Scarcity of land and its high cost have become serious constraints to expansion of tanning industry. Besides, continuing increase in the salinity of soil and groundwater in the Vellore district, which has the largest concentration of tanneries in India, has raised questions about the adequacy and the efficacy of the solar pans. The need for augmenting the effectiveness of the solar pans by accelerating evaporation has been articulated by the tanners and the pollution control authority of Tamil Nadu.

Experimental studies to augment the evaporation in an improved system have been carried out in a pilot plant in SSC tannery, Ambur, Vellore district. Based on this, the effect of operational and meteorological parameters on the rate of evaporation of saline effluent in the improved system has been observed over many months. Drawing from the lessons learnt, a more basic, simplified, version has been implemented at ATH Leder Fabrik, Melvisharam. This report presents the results obtained and conclusions arrived at.

2. EXPERIMENTAL – SSC, AMBUR

2.1 System Description

It is well established that the rate of evaporation in conventional solar evaporation pans is influenced by temperature of liquid, area of contact between liquid and air, ambient temperature, solar radiation intensity, wind velocity and relative humidity. Accordingly any one or more of the following techniques can help increase the rate of evaporation:

- increasing the temperature of the effluent;
- increasing the area of contact between the liquid and air;
- heating the ambient air to higher temperature;
- reducing the humidity of air; and,
- increasing the velocity of air flowing over the liquid surface.

The last three options involve installation of complicated systems besides requiring high operational cost. However, the first two options can be exercised by employing simple and easy methods at affordable cost[3, 4].

The two important features of the system, established in Shafeeq Shameel & Co. (SSC) at Ambur, are flat plate collector and sprinkler network. The principle involved is to first increase the temperature of the effluent by passing it over a flat plate collector[5, 6] (FPC) as a thin film and then sprinkling it through nozzles to increase the area of contact of liquid with air.

Details of location of SSC tannery at Ambur and the location of the accelerated solar evaporation system in the tannery are given in Annexes 1 and 2 respectively.

2.2 Features of pilot plant

A schematic view of the improved system is shown in Fig. 1. The saline wastewater generated in soaking and pickling sections of the tannery is conveyed in separate channels. About 6000 l of saline effluent is collected in the collection sump. As the effluent contains organic wastes, it is brown in colour and malodorous. After suitable chemical dosing, it is pumped into a settling tank with hopper bottom. The capacity of the settling tank is 2500 litres. The effluent is held for 2 hours to allow complete settling.

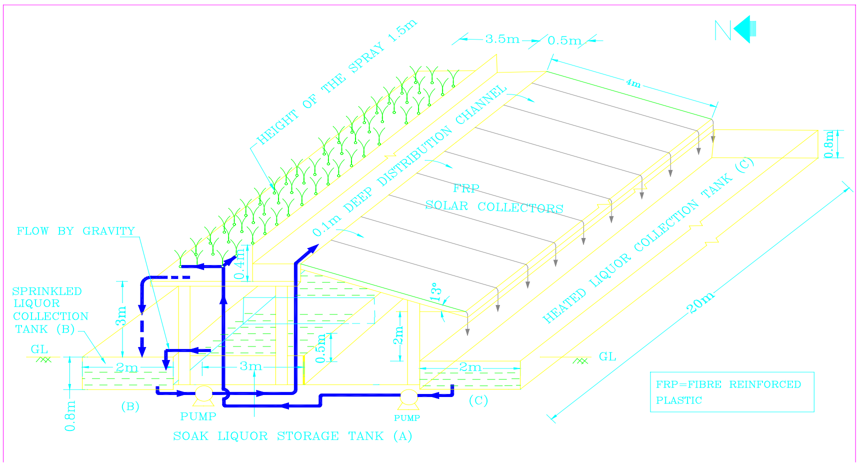

Fig. 1 Schematic view of the improved system

The supernatant is discharged into the shallow storage tank provided below the roof of the evaporation system. After three or four cycles, adequate volume of saline effluent is stored in the shallow storage tank A. Adjoining the storage tank and at a slightly lower level are two tanks – tank B, to collect liquid falling from the sprinkler platform and tank C, to collect the heated liquid flowing down the inclined flat plate collector.

To prevent corrosion, the material selected for the FPC is fibre reinforced plastic (FRP). FPC is oriented to face south. The surface azimuth angle and inclination of the collector are 0^o and 13^o respectively to realise maximum solar radiation over the entire year. It may be mentioned that this corresponds to the latitude of the location. The dimensions for the FPC and sprinkler system have been arrived at based on the following considerations:

- to suit the location, with the existing shallow pans and the volume of saline effluent to be treated daily;
- to avoid drying of liquid over FPC in fluid flow direction;
- to have uniform distribution of liquid over the FPC;
- to avoid excess height for the sprinkler platform; and,
- to take care of thermal expansion of the structure.

A hydraulic flow diagram of the system is provided in Fig. 2.

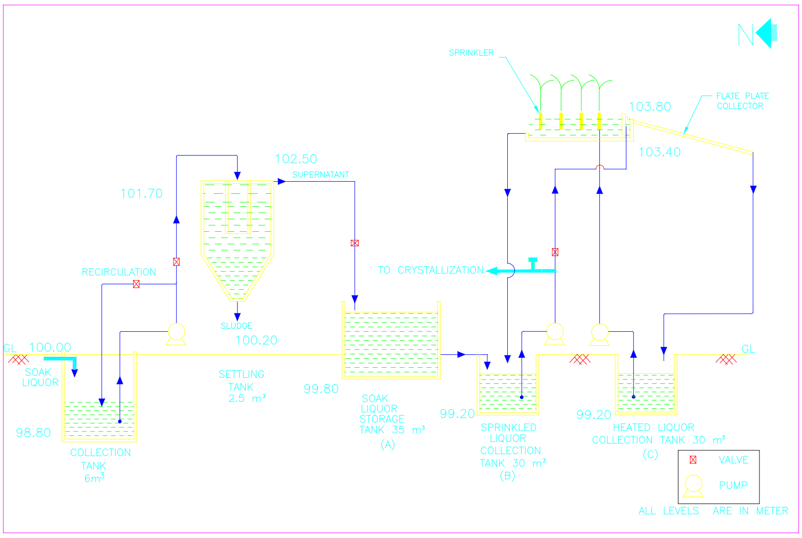

Fig. 2 Hydraulic flow diagram

Clarified saline effluent from tank A is transferred to tank B by gravity. Effluent from tank B is pumped to the distribution channel on the roof from where it flows over the inclined FPC as shown in Fig. 3. When flowing down the FPC, it heats up and the heated effluent is collected in tank C. The effluent is then pumped from tank C to the PVC pipe network and sprinkled through the nozzles as shown in Fig. 4. The flow rate is adjusted by operating a bypass valve to restrict the height of the jet to the desired level to ensure that the sprinkled liquid is not carried away by the wind. The sprinkled liquid falling on the platform flows down into tank B. This completes one cycle. The process is repeated till the salt concentration of the liquid reaches the level of about 10% to 12% (TDS - 100,000 to 120,000 mg/l). This level, far below the saturation concentration, has been selected to avoid the risk of crystallisation at any eventuality. The system was operated generally for 8 to 10 hours a day during the sunshine period and the volume taken for evaporation was 5,000 l/d. However when the system was operated for 24 hours a day, the volume of effluent taken for evaporation was about 10,000 l/d.

Data relating to TDS and chloride content in the initial saline effluent taken for treatment and in the final concentrated effluent on a particular day (duration of the treatment 24 hours) is given in Table 1.

Table 1: TDS and chloride in combined saline effluent (Duration of operation: 24 hours)

#	Parameter	Initial saline effluent	Concentrated saline effluent
1.	Volume, l	10,000	6,000
2.	Total dissolved solids, mg/l	56,619	90,089
3.	Chlorides, mg/l	30,457	47,117

Fig. 3 Distribution channel and flat plate collector

Fig. 4 Sprinkler

The location of pumps, electrical controls, valves, measuring equipment like flow meters, pressure gauges, etc. used in the system is shown in Fig. 5.

After its commissioning in January 1999, experiments were conducted in the system to find the effect of the following parameters on the rate of evaporation:

a) operational parameters like the mass flow rate and the jet diameter of sprinklers; and,
b) meteorological parameters like wind velocity, solar radiation intensity and relative humidity.

Fig. 5 Location of pumps, valves, electrical controls, etc.

Relative humidity was measured by hygrometer and the solar radiation intensity by pyrometer in conjunction with solarimeter integrator. Wind velocity was measured with digital anemometer. Initial temperature of the liquid at entry to the FPC, its final temperature while leaving the FPC and the temperature of the soak liquor after sprinklers were measured using mercury-in-glass thermometers. The flow rate was measured using rotameters. Samples were taken from the two tanks for measurement of concentration. Meticulous monitoring and recording of data were carried out. All the above measuring instruments in combination with respective accessories were calibrated before use.

2.3 Results and discussion

2.3.1 Pre-treatment of saline effluent

The saline effluent was dosed with poly aluminium chloride in order to settle suspended matter. Based on treatability studies, 200-300 ppm of poly aluminium chloride was found to be adequate for this effluent. The well-mixed effluent was transferred to a hopper bottom settling tank, where complete settling took place in about two hours. The supernatant was found to be free of bad odour. The pre-treatment resulted in the reduction of suspended solids by over 90% and total COD by nearly 65%. However, the values of TDS and chlorides, at 37,500 mg/l and 17,000 mg/l respectively, did not change through the chemical treatment.

The average results obtained from the physico-chemical treatment of the saline effluent are shown in Table 2.

Table 2: Effect of pre-treatment of saline effluent

Parameter	Saline effluent characteristics	
	Before treatment	After treatment
pH	7.5	7.2
Suspended solids	3,300 mg/l	200 mg/l
COD (total)	2,400 mg/l	850 mg/l

2.3.2. Performance of FPC

Fig. 6 shows the variation in the inlet and outlet temperature of saline effluent, when flowing over the FPC, with time. It can be observed from this that as expected, both the inlet and outlet temperature increases in the morning, reaching the peak value by noon and then starts decreasing.

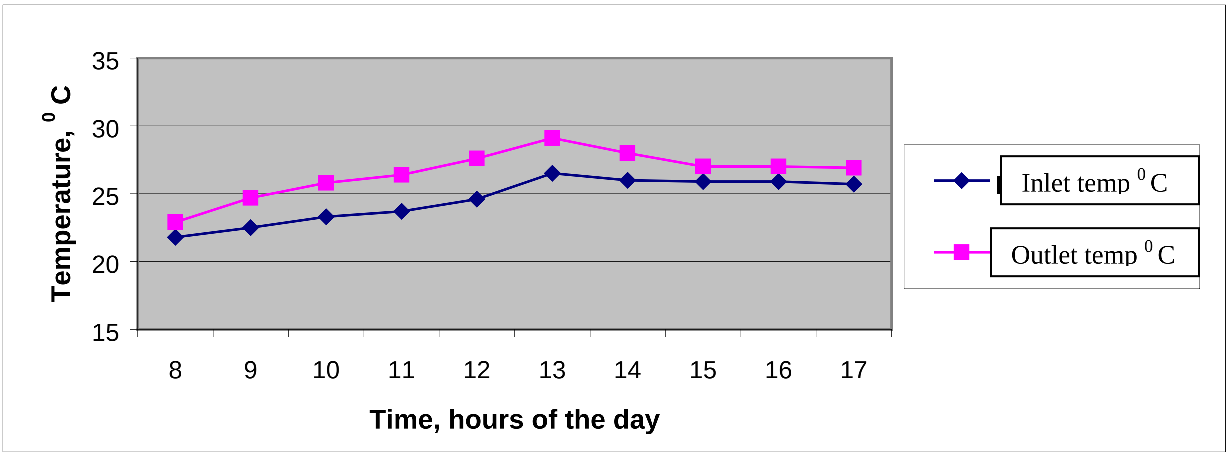

Fig. 6: Variation of inlet and outlet temperature of effluent

The monthly average temperature and total rainfall of Vellore for the years 1999 & 2000 are given in Table 3.

Table 3: Monthly average temperature and total rainfall of Vellore for the years 1999 & 2000

Month	1999			2000		
	Temperature, ^{0}C		Total rainfall mm	Temperature, ^{0}C		Total rainfall mm
	Max	Min		Max	Min	
January	24.6	14.1	5.6	30.1	16.4	-
February	32.3	16.8	-	32.3	19.2	29.9
March	36.7	19.0	-	35.9	18.7	-
April	39.2	21.8	15.1	39.6	22.8	7.7
May	37.4	23.3	134.9	39.8	21.2	33.8
June	35.3	22.7	128.6	36.1	21.3	75.4
July	35.3	23.0	40.2	35.1	22.4	39.4
August	34.5	21.9	93.0	33.7	20.7	170.5

September	35.9	21.7	51.7	34.2	20.5	319.4
October	31.9	20.0	141.3	32.6	18.2	121.6
November	31.0	16.7	108.0	30.4	16.9	166.1
December	28.7	16.6	75.1	28.3	14.6	79.6

The primary objective of the experiments was to accelerate the rate of evaporation and increase the efficiency of solar pans to the extent feasible in the given situation. This called for a careful study of the impact of various factors, controllable operational parameters and meteorological factors that are beyond control, on the evaporation efficiency of the system. Indian Institute of Technology (IIT), Madras, was involved in the design and setting up of the system; and later in its operation and monitoring from January to December 1999. Relevant data was recorded hourly till September 1999.

The meteorological parameters varied widely from day-to-day. During the period of study, the maximum and minimum mean hourly rates of relative humidity was found to be 84% and 20%; and those of wind velocity, 2.42 m/s and 0.7 m/s, respectively. The peak value of solar radiation intensity was observed as 1083 W/m^2. To be able to study the effect of these parameters individually, data relating to two or three days when all parameters except the one to be studied were more or less equal were taken from the recorded data as shown below.

Experimentation was carried out with FPC and sprinklers, both together and individually, during the daytime, generally for 8 hours from 0900 h to 1700 h.

2.3.2 Effect of different parameters on the performance of the improved system

<u>Effect of mass flow rate</u>

For the given jet diameter, as the mass flow rate increases, the jet height increases and in turn the area of contact between liquid and air. But the increase of mass flow rate increases the thickness of the film of the flowing liquid. This will not help raise its temperature when it flows over the FPC. Consequently, the mass transfer rate decreases and so also the rate of evaporation. The results shown in Table 4 are the cumulative effect of the FPC and the sprinklers. As the net evaporation rate has increased with the increase in mass flow rate, it is inferred that the increase in evaporation by the sprinklers overrides the decrease in flat plate collector.

Table 4: Effect of mass flow rate on evaporation

Day	Mass flow rate, l/h	Jet		Average values of the day				Saline effluent evaporated	
		Diameter, mm	Height, m	Ambient temperature ^{0}C	Wind velocity, m/s	Solar radiation intensity, W/m^2	Relative humidity, %	Total, litre	Rate, l/h
1	5500	2	2.5	37	0.6	432.5	46	2200	275
2	4500	2	1.5	37	0.8	460.9	43	2000	250
3	3500	2	0.5	38	0.7	455.2	43	1900	238

Effect of nozzle diameter

To study the effect of nozzle diameter in the sprinkler, experiments were conducted with 1.0 mm ф, 1.5 mm ф and 2.0 mm ф nozzles. The total number of nozzles at 90 did impose a physical limitation. For the tabulated flow rate, the nozzles were inadequate, requiring a considerable volume of liquor to bypass the sprinklers when using 1.0 mm ф and 1.5 mm ф nozzles. Other disadvantages noticed while operating with 1.0 mm ф and 1.5 mm ф nozzles were frequent blocking and the height of the jet reaching 3 m or more, often carried away by the wind to the surface outside the plant. The details of the experimental data are given in Table 5. It was found that with 2.0 mm ф nozzles, the jet height was generally less than 2.0 m and the problem of blocking of nozzles was rare, for the tabulated flow rate.

Table 5: Effect of nozzle diameter on evaporation

Day	Jet		Mass flow rate, l/h	Average values of the day				Saline effluent evaporated	
	Diameter, mm	Height, m		Ambient temperature, °C	Wind velocity, m/s	Solar radiation intensity, W/m^2	Relative humidity, %	Total, litre	Rate, l/h
1	1	2.5	3500	29.8	0.8	419.3	41.5	1400	175
2	1.5	1.5	3500	35.0	0.6	503.6	45.0	1600	200
3	2	0.5	3500	35.0	0.7	455.2	43.0	1900	238

1. *Volume of soak liquor taken for treatment = 5000 litre.*
2. *Initial concentration (average) = 4%*

A question arose later as to why a higher diameter nozzle could not be used. To verify it, experiments were carried out with 2.5 mm ф using same flow rate but operating less number of nozzles. This resulted in decrease in evaporation rate.

After this initial experimentation, it was decided to operate the system with 2.0 mm ф nozzles with the height of the jet generally maintained between 1.5 m and 2.0 m for studying the effect of various parameters.

Effect of wind velocity

As the wind velocity increases, convective mass transfer from the liquid interface to air increases. Consequently, the rate of evaporation increases. Table 6 shows the effect of wind velocity on the rate of evaporation.

Table 6: Effect of wind velocity on evaporation

Day	Average wind velocity, m/s	Mass flow rate, l/h	Jet		Average values of the day			Saline effluent evaporated	
			Diameter, mm	Height, m	Ambient temperature, ^{0}C	Solar radiation intensity, W/m^2	Relative humidity, %	Total, litre	Rate, l/h
1	1.16	4000	1	3	26.4	388.5	20	1500	188
2	1.99	4000	1	3	27.3	397.3	21	2250	281

Effect of solar radiation intensity

The evaporation rate increases with the increase in solar radiation intensity as expected. Table 7 shows the effect of solar radiation intensity on the rate of evaporation.

Table 7: Effect of solar radiation intensity on evaporation

Day	Average solar radiation intensity, W/m^2	Mass flow rate, l/h	Jet		Average values of the day			Saline effluent evaporated	
			Diameter, mm	Height, m	Ambient temperature, ^0C	Wind velocity, m/s	Relative humidity, %	Total, litre	Rate, l/h
1	432.5	5500	2	2.5	37	1.3	43	2200	275
2	512.5	5500	2	2.5	35	1.4	41	2600	325

Effect of relative humidity (FPC only for 8 hours)

The lower the relative humidity, the higher the potential difference for mass transfer. Hence the rate of evaporation increases as the relative humidity decreases as shown in Table 8.

Table 8: Effect of relative humidity on evaporation

Day	Average relative humidity, %	Mass flow rate, l/h	Temperature, ^0C		Average values of the day		Saline effluent evaporated	
			Inlet	Outlet	Wind velocity, m/s	Solar radiation intensity, W/m^2	Total, litre	Rate, l/h
1	27	4500	30	31.7	1.5	481.5	1100	138
2	46	4500	31	33	1.6	485.0	800	100

2.3.3 FPC and sprinklers: Individual performance

The individual performance of the FPC and the sprinkler system too was studied. By opening and closing the appropriate valves, the system was operated with only flat plate collector or sprinklers and the effect of operational and meteorological parameters studied.

As the mass flow rate of liquor increases the evaporation rate decreases in the FPC. Higher the solar radiation intensity and higher the wind velocity, higher is the evaporation rate. The performance of the collector was found to increase with decrease in relative humidity and it was observed that such increase in evaporation rate is comparatively more than that caused by other influencing meteorological parameters.

With increase in mass flow, the rate of evaporation in the sprinklers increased. Also, solar radiation intensity and wind velocity have positive influence over the rate of evaporation caused in the sprinkler system.

The system was put to 24-hour operation for a brief period and the combined and individual performance of the FPC and the sprinklers were studied. The results can be seen in Tables 9 & 10.

Table 9: Performance of sprinklers operating for 24-hour period

Day	Mass flow rate l/h	Average values of the day				Saline effluent evaporated	
		Ambient temperature, °C	Wind speed, m/s	Solar radiation intensity, W/m^2	Relative humidity, %	Total, litre	Rate, l/h
1	5500	30	1.5	372.45	67	2250	94
2	4500	31	1.1	392.70	66	2000	83

1. *Volume of effluent taken for treatment = 10,000 l.*
2. *Initial concentration (average) = 4%*

Table 10: Performance of system operating both FPC and Sprinklers for 24-hour period

Day	Mass flow rate, l/h	Average values of the day				Saline effluent evaporated	
		Ambient temperature, °C	Wind speed, m/s	Solar radiation intensity, W/m^2	Relative humidity, %	Total, litre	Rate, l/h
1	5500	31	1.2	432.0	66	4000	167
2	5500	31	1.4	364.2	64	3750	156

1. *Volume of effluent taken for treatment = 10000 l.*
2. *Initial concentration (average) = 4%*

Data generated from the many trials indicate that: -

- the volume of effluent evaporated in 24 hours with both the FPC and the sprinklers in operation is from 3500 to 4000 litres;
- the volume of effluent evaporated in 24 hours with only sprinklers in operation is about 2000 litres;
- the volume of effluent evaporated in the 8-hour period from 0900 to 1700 hours, with both the FPC and the sprinklers in operation, is about 2000 litres.

From this data, the following inference can be drawn:

- Other parameters remaining same, the effect of sprinklers and FPC are more or less equal on evaporation of liquid.
- The volume of effluent evaporated during the 8-hour period from 0900 to 1700 hours in a day is more or less equal to that in the remainder of the day.

2.3.4 Recovery of salt

The salt recovered has been found to be clean, free of bad odour and white in colour. The active NaCl content of the recovered salt has been found to be 96%. The recovered salt has been used by the tannery in pickling operation with satisfactory results. Part of it is taken by rawhide dealers for preservation of hides and skins.

2.3.5 Operational data

Though the plant was commissioned in January 1999, in the initial three months, for attending to teething problems, etc. the system did not operate regularly daily. However, from April

1999, regular daily operation of the system was done until December 1999. From January to March 2000, the system operated only sporadically, again due to maintenance problems and the reduced and intermittent soaking activity in the tannery. The responsibility for operation and maintenance of the system was taken over by the tannery itself since April 2000 and thereafter it has been operating regularly. For various reasons, mainly rain, maintenance, power failure, etc. the system was generally operated for about 8 hours a day. Also the volume of saline effluent from the tannery did not warrant its operation generally for more than 12 hours. From September 1999, however, only data relating to the volume of effluent taken for evaporation, the volume evaporated and the hours of operation, daily, has been recorded by the tannery.

The month-wise daily average values for the volume of effluent taken for process, volume evaporated and average hours of operation have been computed from the data available and presented in Table 11, Fig. 7 (April to December 1999) and Table 12 (April to October 2000).

Table 11: Performance of the system during April to December 1999

Month	Average volume of effluent treated per day, Litre			Hours operated (Daily average)	Average rate of evaporation l/h
	Inlet	Remaining	Evaporated		
April	4798	2910	1888	7.6	248
May	5940	3760	2180	7.7	283
June	5440	3846	1594	7.8	204
July	5731	4123	1608	7.9	204
August	5667	4004	1663	9.3	179
September	5909	3818	2091	10.9	192
October	5480	3920	1560	8.2	190
November	5500	4010	1490	8.2	182
December	5540	4050	1490	8.2	182

The evaporation rate of the system during the period April to December 1999 can be seen in Fig. 7. It was observed that the evaporation rate was strongly influenced by the mass flow rate, the area of contact of liquid with air and solar radiation intensity.

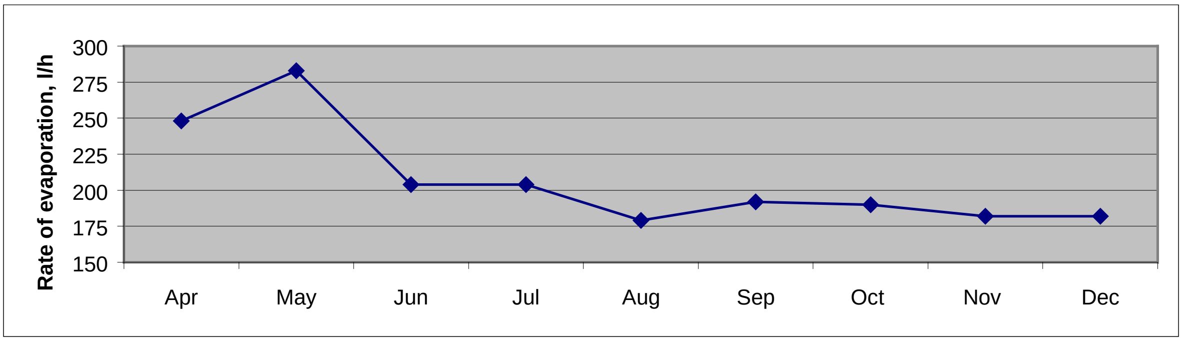

Fig. 7: Performance of system during April to December 1999 based on daytime operation (8 hours)

Table 12: Performance of the system (April – October 2000)

Month	Average volume of effluent treated per day Litre			Hours operated (daily average)	Average rate of evaporation l/h
	Inlet	Remaining	Evaporated		
April	10045	6193	3852	13.2	292
May	7227	4784	2443	10.9	225
June	6230	4350	1900	7.9	237
July	6076	4380	1696	8.1	210
August	5937	4406	1531	7.8	198
September	5680	4160	1520	7.3	207
October	5700	4200	1500	7.7	194

2.3.6 Rate of evaporation

The total area of the evaporation surface comprising the FPC and the sprinkler platform is 240 m^2. The average normal rate of evaporation in Vellore district is 4.5 mm/day. The volume of water that can be evaporated in a surface area of 240 m^2 (240 x 0.0045 = 1080 l) is 1080 litres. It has been inferred that the volumes of effluent evaporated during the day, generally between 0900 hours and 1700 hours and the remainder of a day are more or less equal. Applying this factor, the volume evaporated during 0900 hours to 1700 hours of the day could be doubled to obtain the total volume of liquid evaporated in a day. Accordingly, the average volume of effluent evaporated in a day has been inferred and shown in Table 13.

Table 13: Inferred performance of the system (April – October 2000)

#	**Month**	**Average volume of effluent treated per day, litre**			**Rate of evaporation mm/ day**
		Sunshine period (based on recorded data)	Non sunshine period (inferred data)	Total	
1.	April	2907	2907	5814	24.23
2.	May	2148	2148	4296	17.90
3.	June	1924	1924	3848	16.03
4.	July	1675	1675	3350	13.96
5.	August	1570	1570	3140	13.08
6.	September	1665	1665	3330	13.88
7.	October	1558	1558	3116	12.98

The month-wise performance of the accelerated evaporation system in terms of rate of evaporation (mm/day) for the period April to October 2000 is shown in Fig. 8.

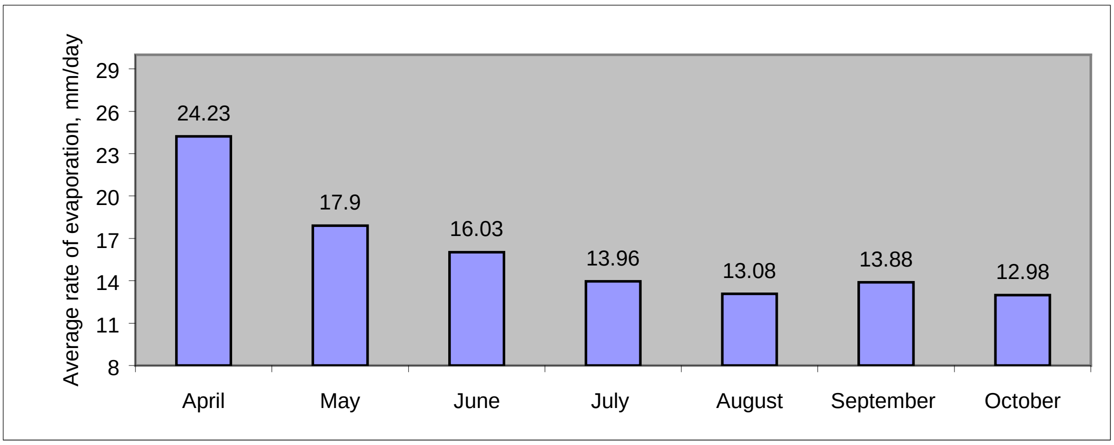

Fig. 8 Month-wise performance of accelerated evaporation system (April to October 2000)

The rate of evaporation of saline effluent in the improved system during the months of April to October 2000 ranges from 13 to 24 mm/day. The average rate of evaporation is 15.91 mm/day. In other words, the performance of the improved system is more than 3 times that of the conventional solar pans.

2.3.7 Area required – conventional Vs improved system

After the salt concentration in the saline effluent is increased to about 10-12% by treatment in the FPC and the sprinklers, it is taken to conventional solar evaporation pans for crystallisation of salt. At this level of concentration, 5000 l of saline effluent is reduced to 2000 l. With an average evaporation rate of 4.5 mm/day, for evaporation of 2000 l of concentrated effluent every day, the minimum pan area required is 445 m^2. The total area required for the improved system thus is 685 m^2 (240 m^2 for the FPC and the sprinklers and 445 m^2 of conventional solar pans for the evaporation of concentrated effluent). As against this, for evaporation of 5000 l of effluent, an area of about 1110 m^2 is required, on the basis of published average rate of evaporation of 4.5 mm/day in a conventional solar pan. It is thus inferred that the total area required for the improved system is about 60% of that required in a conventional solar pan.

2.4 Cost of operation

It is estimated that the operational cost of evaporating 1 m^3 of saline effluent is US $ 1.03 (excluding depreciation). Details of the calculation of operational cost are given in Annex 3.

Based on the results of the experiments conducted over the past many months, the inference drawn from the data collected and with a view to reduce the cost - both capital and operational - a simplified system with only sprinklers was designed for installation in another tannery.

3. SIMPLIFIED VERSION OF THE SYSTEM – ATH LEDER FABRIK, MELVISHARAM

The simplified version of the accelerated solar evaporation system, with sprinklers only, had been commissioned at ATH Leder Fabrik in Melvisharam in January 2001. In this tannery wet salted cow calf skins are processed to finished leather for use in footwear and leather goods manufacture. The system consists of a receiving sump, a settling tank with hopper bottom, a filter bed with layers of coarse and fine sand and pebbles, a storage tank for clarified effluent, sprinkler pipeline network and conventional pans for further evaporation of concentrated saline effluent. The system operational since January 2001 is under close observation. The location of the ATH Leder Fabrik and of the accelerated system installed there are at Annexes 4 and 5.

3.1 Methodology

Fig. 9 shows the layout of the simplified system. The process flow diagram may be seen in Fig. 10.

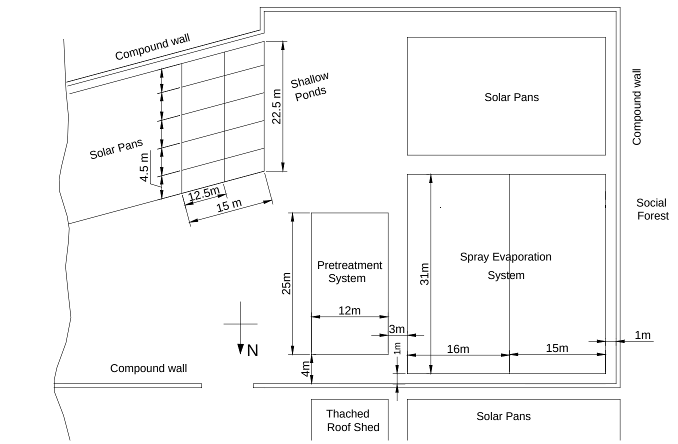

Fig.9: Layout of simplified system in ATH Leder Fabrik

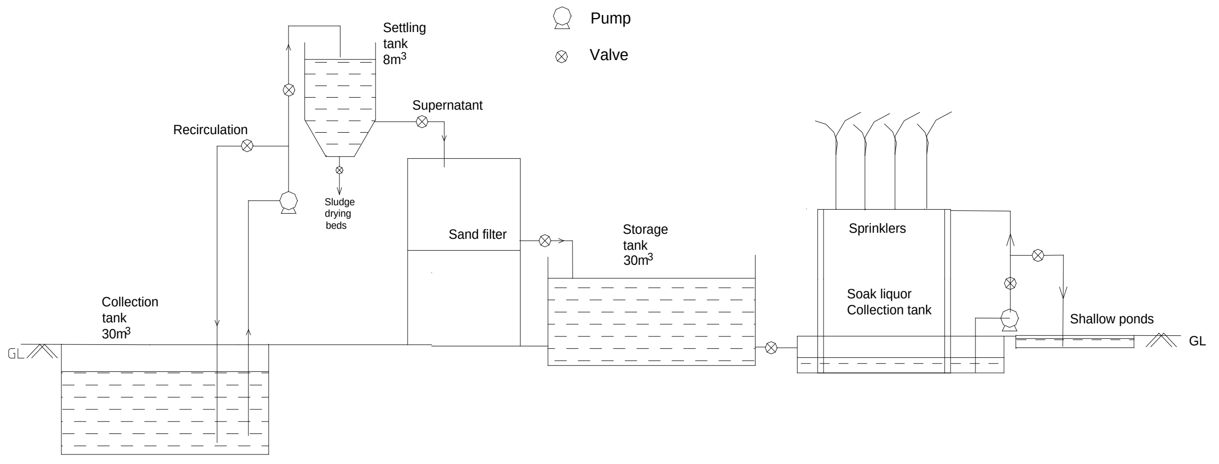

Fig. 10: Process flow diagram of the simplified system

Soak and pickle liquor from the tannery is collected in a tank. It is then treated with lime, alum and polyelectrolyte. The chemically treated liquor is held in the settling tank for about three hours to enable settling of suspended solids at the hopper bottom. Later, clarified supernatant is taken to a storage tank by gravity through a sand filter bed and the settled sludge is removed from the bottom through a valve.

About 20,000 litres of clarified liquor is transferred to the sprinkler floor by gravity. It flows into the channel and collects in the reservoirs at either end of the channel. The liquor in the reservoirs is pumped to the piping network. The pumped liquor is sprinkled through the holes in the cross bar pipeline in the form of jets. The contact area between the liquor and the air is increased. The sprayed liquor falls on the floor, flows into the channel and collects in the reservoirs. To facilitate smooth flow of liquid to the reservoir both the channel and the floor beneath the sprinkler network have been given appropriate slope. The process of pumping and sprinkling of the liquor is repeated till the TDS concentration reaches the desired level of 10-12%. The concentrated liquor is then pumped into the shallow solar pans for further evaporation and eventual recovery of crystallized salt.

3.2 Basic design details

The area occupied by the sprinkler section of the accelerated solar evaporation system operating in SSC, Ambur is 80 m^2. It has been observed that when operating the sprinklers alone over a 24-hour period, about 2000 litres of effluent are evaporated. Though, apart from the salt concentration of liquor under treatment, different factors such as location, ambient air temperature, wind velocity, relative humidity, etc. influence the rate of evaporation, this data, namely, evaporation of 2000 litres in 24 hours by sprinklers erected on a floor area of 80 m^2 was taken as the rough basis for designing the simplified solar evaporation system in ATH Leder Fabrik, Melvisharam.

The average discharge of saline effluent from this tannery is about 20 m^3/day. Accordingly, the system was designed to meet this requirement.

3.2.1 Sprinkler section

It was planned to have four sections of sprinklers, each on an area of about 240 – 250 m^2. The first of the four sections became operational in January 2001 and the second section in June 2001. These two sections are currently operational.

A section of the already existing solar evaporation pans was identified as suitable location for erecting the sprinkler network. Pillars for supporting the pipeline network, sectional view of the sprinkler section and of the pipeline network may be seen in Figs. 11, 12 and 13 respectively. Three holes, each of 1.5 mm diameter, were drilled in the distributor pipes (cross bar) of 25mm ϕ to act as nozzles. The spacing between holes is so done that one hole is at the centre of the cross bar pipe and the other two are equidistant on either side.

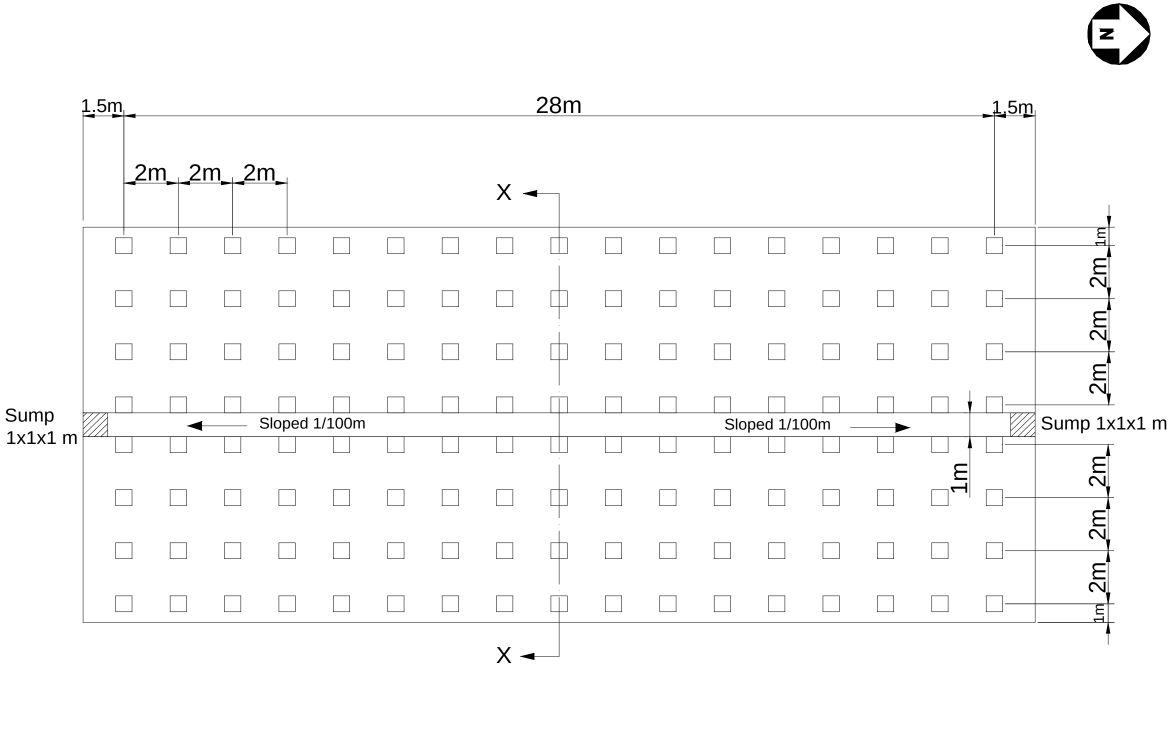

Fig.11: Pillars for supporting pipeline network

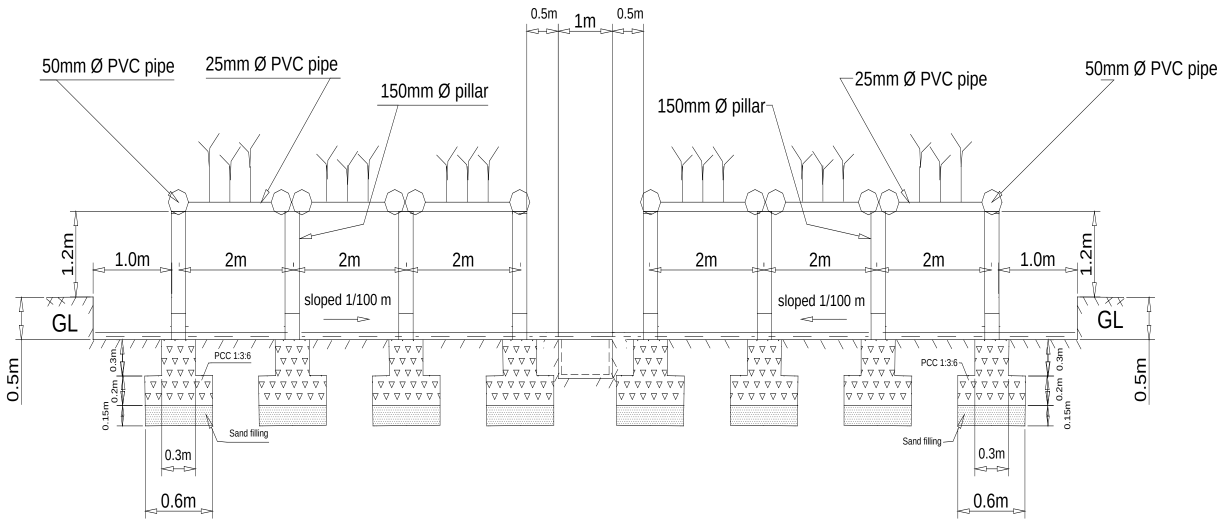

Fig. 12: Sectional view of sprinkler section

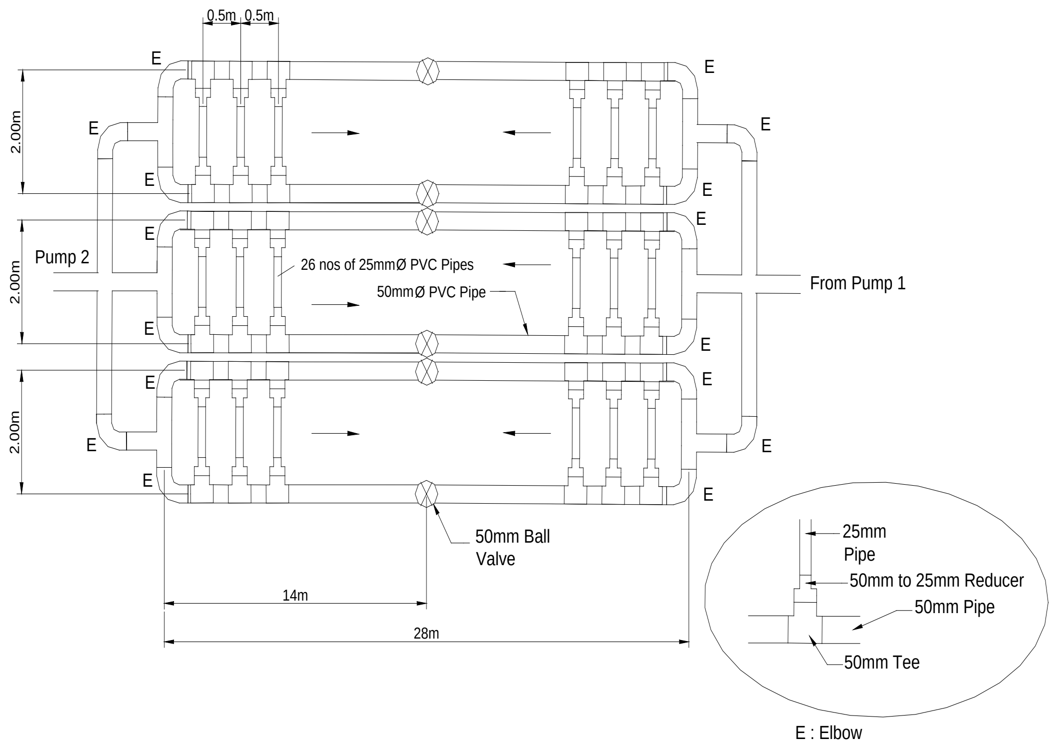

Fig. 13: Pipeline network

3.2.2 Pre treatment of saline effluent

The pre treatment section comprises of the following work stations:

<u>Collection tank</u>

A sump of dimension 4 m x 4 m x 2 m with reinforced cement concrete (RCC) walling on all four sides receives saline effluent from the tannery. The capacity of this sump is 30 m^3.

Settling tank

Fig. 14 shows the design of the settling tank. It is a RCC tank with a hopper bottom and has an arrangement for addition of chemicals. The saline effluent from the collection sump is pumped to this tank for chemical treatment and settling of suspended matter. The capacity of this tank is 8 m^3.

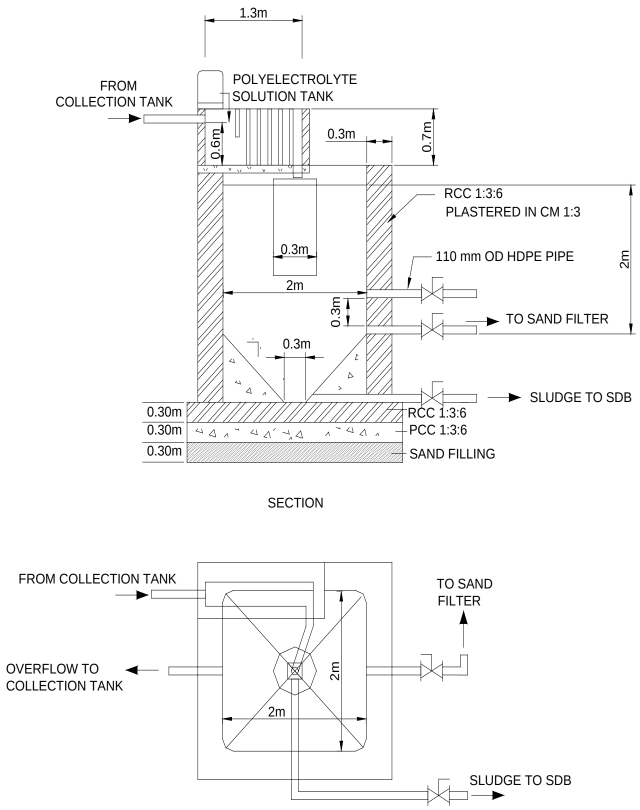

Fig. 14: Design of the settling tank

Sand filter

Sand filter is a tank with layers of sand of different particle sizes and pebbles. The level of the sand filter with respect to the pre-settling tank is maintained in such a way that the supernatant resulting from the physico-chemical treatment in the hopper bottom pre-settling tank flows into the sand filter by gravity.

Storage tank

The storage tank with dimension 4 m x 4 m x 2 m stores the clarified saline effluent from the sand filter. The flow of liquor from the sand filter to the storage tank is by gravity. The capacity of the storage tank is 30 m^3.

Calibration

The channel together with the two reservoirs was calibrated by letting in a known volume of water into the tank. Markings were done for 250 l, 500 l, 750 l upto a maximum of 20,000 l.

3.3 Operational procedure

The saline effluent in the collection tank is dosed with lime and alum. Based on laboratory trials, the quantities of lime and alum added range from 400 – 700 ppm and 300 – 400 ppm respectively. The recirculation arrangement helps to mix the added chemicals effectively. The liquor is pumped to the hopper bottom-settling tank. The pumped liquor is taken through a serpentine path where polyelectrolyte @ 2.5 ppm is added. The chemically treated liquor is retained in the settling tank for about 3 hours to facilitate settling. After settling, the clear supernatant is drained from the top of the hopper bottom tank into the sand filter from where it flows into the storage tank. The sludge from the hopper bottom tank is taken to the sludge drying beds. The solids accumulating on the top layer of the sand bed, about 25 mm, is removed once in 15 days and replaced by fresh sand. A known volume of saline liquor from the storage tank is drained into the sprinkler floor. The liquor flows into the channel and collects in the two reservoirs on either end of the channel. The liquor in the reservoirs is pumped to the sprinkler network and sprayed through the holes in the cross bar pipes. The height of the jet is controlled by using the by-pass valve. The liquor sprayed through the holes falls on the sprinkler floor and flows into the channel to reach the reservoirs again. This completes one cycle. The process of circulation is repeated until the concentration of the saline effluent reaches the required level. Finally, the concentrated saline liquor is pumped out to conventional solar pans for further evaporation and recovery of salt.

3.4 Performance of the system

The system is in regular operation from February 2001. Operational data obtained for the period February to March 2001 is presented in Annex 6.

3.5 Results and discussion

The pre-treatment system is effective. 98% of reduction of suspended solids is achieved. The liquor, after the physico-chemical treatment is clear in appearance. There has not been any problem of clogging in the sprinklers. The recovered salt too is clear.

The diameter of the holes in the cross bar pipes is 1.5 mm. Initially two holes were drilled in each cross bar pipe. As the pressure was adequate, a third hole was drilled thus making the total number of holes on each cross bar pipe three. The jet height was maintained at around 2.0 m.

The sprayed liquor after falling on the floor drained into the channel immediately. The slope provided on the floor beneath the sprinklers was found to be effective.

The sprayed liquor was sometimes found to be carried away by the wind. This was evident from the wall on the northern side of the sprinkler sections becoming wet with the drifting liquor when the direction of the wind flow was towards north.

From the operational data given in Annex 6, the following observations can be made:

- The volume of liquor evaporated varies from day to day.
- As the salt concentration increases, the volume of liquor evaporated decreases.
- A part of the sprayed liquor, carried away by strong currents of wind, falls outside the floor and does not reach the channel for recirculation. This is evident by the loss of salt mass.

3.6 Findings

The plant has been performing well. Operational data containing details of volume of saline effluent taken each day, volume evaporated in 24-hour period, TDS in the effluent at the start and at the end of the 24-hour period, salt balance, etc, are given in Annex 6. The average volume of saline effluent reduced by a sprinkler section is 6700 l/d. Drifting of the sprayed liquor due to strong currents of wind accounts for a part of this volume. The average volume of effluent drifting away from the system and the resultant average volume evaporated, for February and March 2001, have been calculated and presented at Annex 6 on the basis of TDS balance. The average volume of liquor evaporated per day, after accounting for drifting, worked out to 3760 litres. The spillage ranged from 206 l/d to 5472 l/d with an average of 2940 l/d as per Annex 6.

At this rate of performance, the operational cost of evaporating 1 m^3 of saline effluent in the simplified system is US $ 0.56 (excluding depreciation). Details of the operational cost are in Annex 7.

The natural evaporation rate in summer months is generally higher than the average rate of 4.5 mm/day. The mean evaporation rates in Vellore district during the months February and March for the years 1999, 2000 and 2001 as reported by the Climatological Section of the India Meteorological Centre, Chennai are furnished in Table 14.

Table 14: Natural evaporation rate

Month	**Rate of evaporation – mm/d (mean value)**		
	1999	**2000**	**2001**
February	4.6	4.8	5.2
March	6.0	6.2	6.5

With an average evaporation rate of 5.85 mm/d for the period February and March 2001, the volume of liquor to be evaporated in a conventional pan of area 250 m^2 – area occupied by a sprinkler section – would be 1,462.5 l. With a volume of 3,760 l evaporated by a sprinkler section in a day, it can be concluded that the system is 2.6 times more efficient than conventional solar evaporation pans.

It should be emphasized here that the spillage of saline effluent outside the system should be eliminated. In this regard, it will help to install the sprinklers at the centre of the system and ensuring that the height of water jet from the sprinklers, along with the height of sprinkler pipe network, does not exceed 2 m.

The concentrated saline effluent, sent to the conventional solar pans, yields salt of good quality. Its use in pickling operation in the tannery has been demonstrated. Also it is taken away by the raw hide dealers for preservation of raw material.

4. ADDITIONAL EXPERIMENTS – SSC, AMBUR

With a view to verify the actual natural rate of evaporation, experiments were carried out to find the rate of evaporation of the following in conventional solar pans:

- ground water
- untreated saline effluent
- chemically treated (clarified) saline effluent
- concentrated saline effluent from accelerated solar evaporation system

These rates of evaporation were compared with those achieved in the accelerated solar evaporation system at SSC, Ambur and in the simplified system at ATH Leder Fabrik, Melvisharam while treating similar saline effluent under identical conditions.

4.1 Experiments conducted using trays

First, an attempt was made to verify the rate of solar evaporation of ground water, untreated saline effluent and chemically treated saline effluent in plastic trays in SSC, Ambur. These experiments were started on 13 February 2001 and continued till 11 March 2001 to complete one cycle of drying. The dimensions of the tray were 440 mm x 260 mm x 150 mm. Data on these experiments is given in Annex 8. The average rate of evaporation of different liquors during this period is given below:

- Ground water (evaporated in 17 days) 6.9 mm/d
- Untreated saline effluent (evaporation was not complete even after 26 days) < 3.9 mm/d
- Chemically treated saline effluent (evaporated in 23 days) 4.6 mm/d

A thick layer of dirty salt was found on the surface of the untreated saline effluent and beneath this was a sludge-like substance. The appearance of the salt resulting from evaporation of untreated and treated saline effluent in these tray experiments is shown in Fig. 15.

Fig. 15: Appearance of salt obtained from evaporation of treated and untreated saline effluent

4.2 Experiments in conventional solar pans

4.2.1 Preparation of experimental solar pans

Four evaporation pans each of size 2m x 2m x 0.3m height were constructed in SSC, Ambur. The flooring was made seepage-proof. A scale was fixed in each pan to measure the height of liquor column. The typical cross section of these experimental solar pans is given in Annex 9.

The following liquors were taken for the experiment:

1. Ground water
2. Untreated saline effluent
3. Chemically treated saline effluent
4. Concentrated saline effluent from accelerated evaporation system

A view of the experimental solar pans is given in Fig. 16.

Fig. 16: Experimental solar evaporation pans

It took about 3 days to collect 25 m^3 of saline effluent needed for all the experiments.

4.2.2. Operational data

Three cycles of experiments of natural solar evaporation of ground water, untreated saline effluent, chemically treated saline effluent and concentrated saline effluent from the accelerated evaporation system were done in these experimental solar pans. These liquors were let upto a liquor column depth of 200 mm. The volume of liquor let into each pan was approximately 800 l. At 0830 hours every day, the liquor column height was read from the scale fixed to the wall of the pans. TDS was determined by drawing 25 ml of liquor from each tank at 0830 hours everyday. If complete evaporation had taken place in 25 days, the volume of liquor drawn for testing would have been 625 ml, which is less than a litre. This volume is too small to affect the liquor column height. A hygrothermometer was used to measure the minimum and maximum temperature and relative humidity.

The first cycle was started on 28 March 2001. After 14 days of operation, it rained intermittently for three days from 11/04/01. Hence this experiment was discontinued. After the rains, these pans were cleaned and dried before commencing the next cycle of experiment. In the next cycle of experiments, these pans were covered with plastic sheets during rain to prevent rain water entering the pans. Second cycle of experiment was done from 22 April to 28 May 2001 and the third cycle was done from 11 June to 8 July 2001. In the 2^{nd} and 3^{rd} cycles the liquors were completely evaporated. The relevant data is given in Annex 10. The summary of the average rate of evaporation of these liquors in the three cycles is given in Table 15.

Table 15: Average rate of evaporation in conventional solar evaporation pans

Pan No.	Type of liquor	Duration, days			Avg. evaporation rate, mm/d			
		Cycle-1 (rain-affected)*	Cycle-2	Cycle-3	Cycle-1 (rain-affected)*	Cycle-2	Cycle-3	Avg. in cycles 2 & 3
1.	Ground water	14	25	26	6.79	7.36	7.88	7.5
2.	Untreated saline effluent	14	>33	>27	5.79	<5.64#	<5.81#	<5.7#
3.	Chemically treated saline effluent	14	32	25	6.71	6.09	7.08	6.6
4.	Concentrated saline effluent from the accelerated evaporation system	10	24	17	6.11	7.06	7.69	7.4

* The effluent did not reach crystallization stage
# The concentrated liquor is not completely dry but looks like sludge

A thin layer of salt deposits on the surface of the concentrated saline effluent after reaching crystallization stage, which retards further evaporation. This layer of salt needs to be removed. Despite the higher concentration of TDS in the concentrated saline effluent, its rate of evaporation was higher than that of chemically treated saline effluent. This is attributable to the removal of salt layer from the surface of concentrated liquor as and when it is formed.

The characteristics of residual matter resulting from evaporation of untreated saline effluent are given in Table 16.

Table 16: Characteristics of residual mater from untreated saline effluent

S. No.	Parameters	Value
1.	Moisture	19%
2.	Chloride as NaCl	63%
3.	Insolubles	15%

The chloride levels of untreated, treated and concentrated saline effluent at which crystallization was observed are given in Table 17.

Table 17: Chloride level at crystallization stage

Pan No.	Type of liquor	Chlorides
2.	Untreated saline effluent	184,960 mg/l
3.	Treated saline effluent	194,190 mg/l
4.	Concentrated saline effluent	200,440 mg/l

4.3 Performance of the accelerated system in SSC, Ambur

Experiments in the accelerated system in SSC, Ambur were carried out during the same period of conventional solar pan experiments. 20 m^3 of treated saline effluent was let into the sprinkled liquor collection tank for the experiment. The volume was measured using the graduated scale fixed in this tank. The nozzle dia was 2 mm and the jet height was maintained between 1.5 and 2 m. The system was operated round the clock. The operation continued till the TDS concentration reached about 20%. The operational data is given in Table 18.

Table 18: Operational data for experiments in SSC, Ambur

Day	At 0830 hours		Evaporated volume, l	Rate of evaporation, mm/d	Other remarks
	Volume, l	TDS, mg/l			
Trial 1					Average temp.: 37 ^{0}C and relative humidity: 47%
28/03/01	20,000	72,300	-	-	
29/03/01	16,500	88,296	3,500	14.58	
30/03/01	13,250	109,921	3,250	13.54	
31/03/01	10,000	145,642	3,250	13.54	
1/4/01	7,000	207,973	3,000	12.50	Windy in the afternoon
Average rate of evaporation in trial 1(4 days)				13.54	

Trial 2					Average temp.: 34^{0}C and relative humidity: 52%
23/04/01	20,000	69,200	-	-	
24/04/01	16,500	84,179	3,500	15	
25/04/01	12,500	110,220	4,000	17	
26/04/01	9,000	153,478	3,500	15	
27/04/01	5,750	240,296	3,250	14	
Average rate of evaporation in trial 2(4 days)				15.25	
Average rate of evaporation in both the trials				14.4	

4.4. Performance of the simplified version of the system in ATH Leder Fabrik, Melvisharam

As already described, the average rate of evaporation during February-March 2001 in the simplified version of accelerated solar evaporation system was **15 mm per day** after accounting for the effluent that drifted away from the system due to wind. The volume of effluent drifted was calculated on the basis of TDS balance, given in Annex 6.

4.5 Conclusions drawn from additional experiments

4.5.1. The average evaporation rates of ground water, untreated saline effluent, chemically treated saline effluent and concentrated saline effluent from accelerated evaporation system in the conventional pans during the period April 2001 to July 2001 are 7.5, 5.7, 6.6 and 7.4 respectively. Accordingly for evaporation of 1 m^3 of such liquors, the area required is 133 m^2, 175 m^2, 152 m^2 and 80 m^2. 80 m^2 includes the area needed for the system and that for evaporation of concentrated liquor.

4.5.2. The average annual rate of evaporation has been prescribed as 4.5 mm/d in Tamil Nadu, India. However, from actual experiments during the months April to July 2001, considered peak summer months, the rates of evaporation have been obtained for ground water, untreated saline effluent, treated saline effluent and concentrated saline effluent. From these experiments it has been observed that compared to the area required for evaporation of ground water, the untreated saline effluent will require 32% more, the chemically treated saline effluent, 14% more and the concentrated effluent from the accelerated system will require 40% less area (inclusive of the improved system and corresponding conventional pan area required).

4.5.3. Accordingly, adopting the published average rate of evaporation of clean water in the year as 4.5 mm/d and the corresponding solar pan area required for evaporating 1 m^3 ground water as 222 m^2, the average area required for evaporating other types of liquors will be as follows:

Untreated saline effluent:	222 + 32% = 293 m^2, say 290 to 300 m^2
Chemically treated saline effluent:	222 + 14% = 253 m^2, say 250 to 260 m^2
Accelerated system:	222 – 40% = 133 m^2, say 130 to 140 m^2

It is therefore concluded that the solar pan area required by accelerated evaporation system will be less by 40%.

4.5.4. The presence of suspended and possibly some organic matter in saline effluent retards the rate of evaporation. Also, the salt recovered is dirty and contains impurities. The NaCl content in the residual matter obtained from the evaporation of untreated saline effluent is 63%. On the contrary, chemical treatment of saline effluent enables removal of suspended matter and evaporation of clarified saline effluent is quicker and yields clean salt. The rate of evaporation increased by 0.8/0.9 mm/d during the period of experiment (April to July 2001). In other words, the increase in evaporation rate due to chemical treatment is 16%.

4.5.5. The chloride concentration at which crystallization occurs is observed to vary from 185,000 to 200,400 mg/l.

4.5.6. The average rate of evaporation in the accelerated system at SSC during the period, March to April 2001 is 14.4 mm/d. The average evaporation rate of treated saline effluent in the simplified version of the accelerated solar evaporation system in ATH Leder Fabrik at Melvisharam as observed during February and March 2001, after duly accounting for drifting of sprinkled liquor, is 15 mm/d. It is therefore concluded that the rate of evaporation in the accelerated solar evaporation system is 2 to 3 times more than that in the conventional system.

5. CONCLUSION

- The evaporation efficiency of the FPC and the sprinklers is more or less equal.
- The capital and operational cost of the system is considerably reduced if it comprises of only sprinklers.
- Among the various meteorological factors, solar radiation intensity, wind velocity and relative humidity have strong influence on the system’s performance.
- The accelerated evaporation system is about 2 to 3 times more effective than a conventional solar evaporation pan.

- The area required for solar evaporation pan can be reduced by about 40% by introduction of the chemical clarification of saline effluent and treatment of the clarified liquor in the simplified accelerated solar evaporation system.
- The salt recovered is clean and fit for reuse in the tannery or in preservation of raw hides and skins.

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- Mr. Mladen Bosnic, TEH Project, Croatia
- Mr. K.V. Emmanuel, National Expert, RePO

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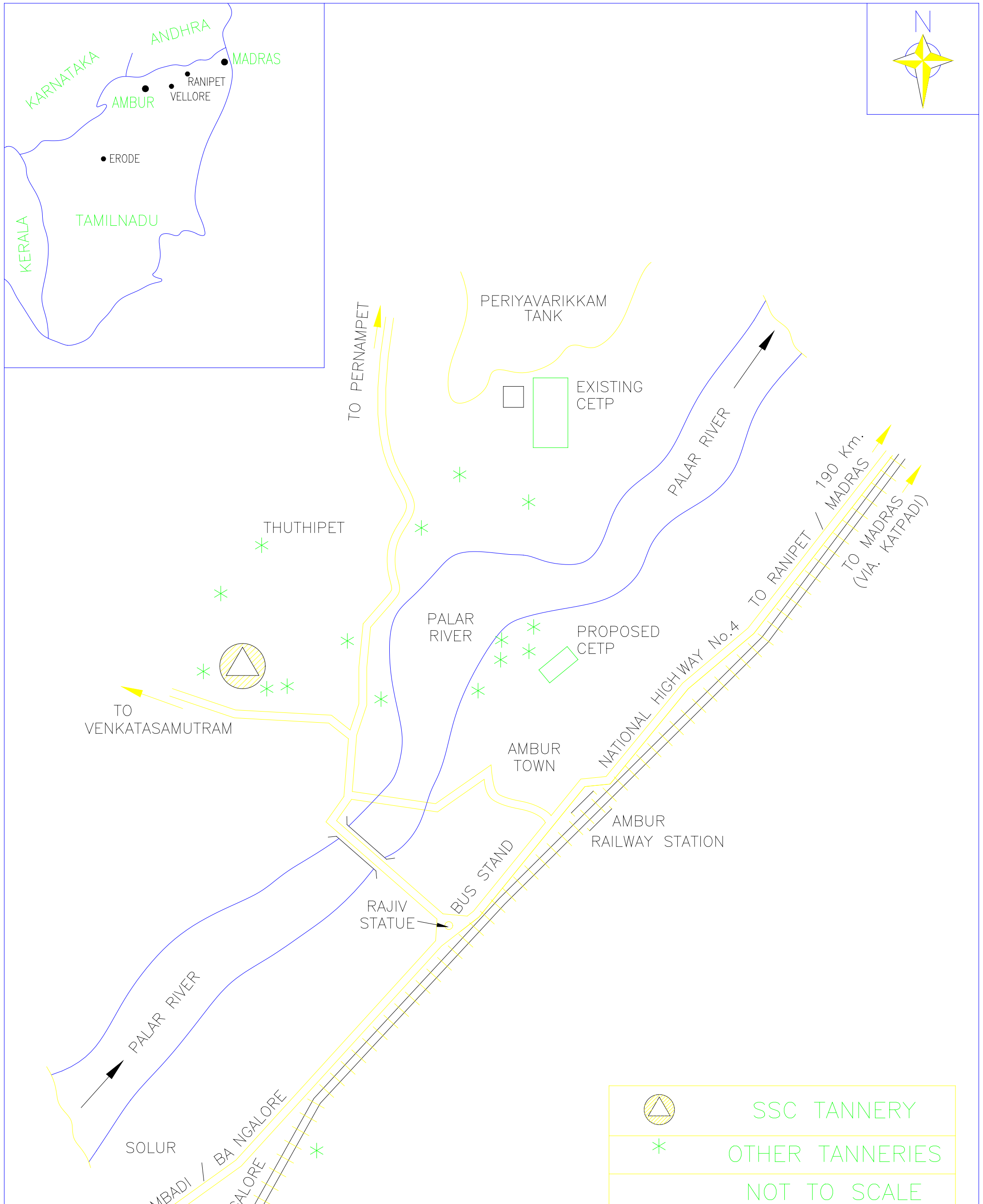

ANDHRA
KARNATAKA
MADRAS
RANIPET
VELLORE
AMBUR
ERODE
TAMILNADU
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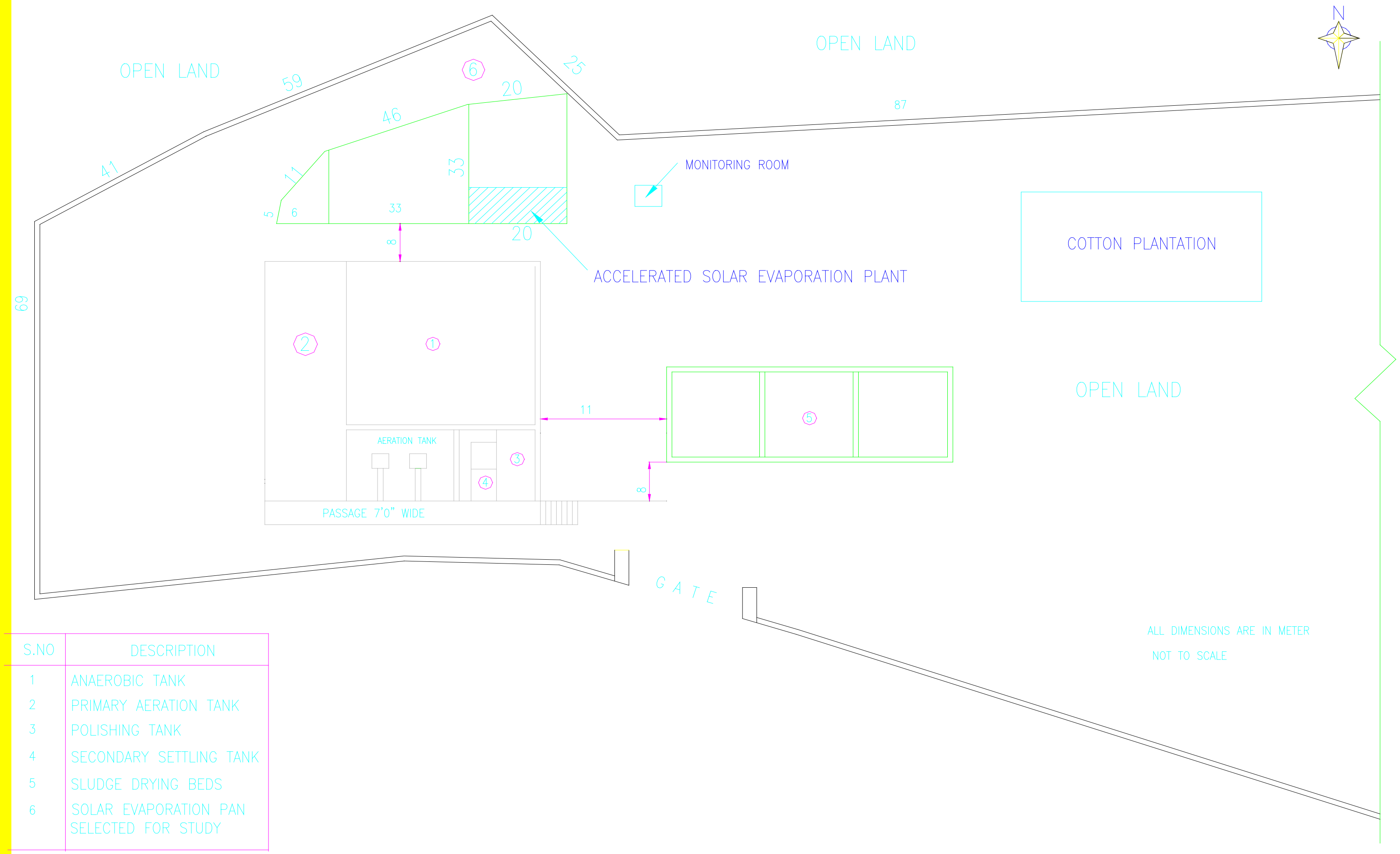
N
TO PERNAMPET
PERIYAVARIKKAM TANK
EXISTING CETP
PALAR RIVER
190 Km.
TO RANIPET / MADRAS
TO MADRAS (VIA. KATPADI)
THUTHIPET
PALAR RIVER
PROPOSED CETP
NATIONAL HIGHWAY No.4
TO VENKATASAMUTRAM
AMBUR TOWN
AMBUR RAILWAY STATION
BUS STAND
RAJIV STATUE
PALAR RIVER
SOLUR
SSC TANNERY
OTHER TANNERIES
NOT TO SCALE



S.NO	DESCRIPTION
1	ANAEROBIC TANK
2	PRIMARY AERATION TANK
3	POLISHING TANK
4	SECONDARY SETTLING TANK
5	SLUDGE DRYING BEDS
6	SOLAR EVAPORATION PAN SELECTED FOR STUDY

ANNEX 2: LOCATION OF ACCELERATED SOLAR EVAPORATION SYSTEM IN SSC TANNERY

Annex 3

Calculation of operational cost – Plant in SSC, Ambur

1. Basis

Volume treated/day	5000 l/d
Volume evaporated/day (FPC & sprinkler)	2000 l + 2000 l = 4000 l
Volume evaporated/day (conventional pans)	1000 l
Area occupied by system (FPC & sprinkler)	240 m^2
Area of conventional pans for evaporating concentrated liquor	222 m^2

Total	**462 m^2**

2. COST OF TREATMENT

2.1 Capital cost – Civil work

	Amount in INR.
Civil work – tanks, sumps, plant, etc.	214,900
Civil work – conventional pans (222 m^2 @ INR. 1100/m^2)	244,200
Sub total	**459,100**
Depreciation @ 5%	22,955

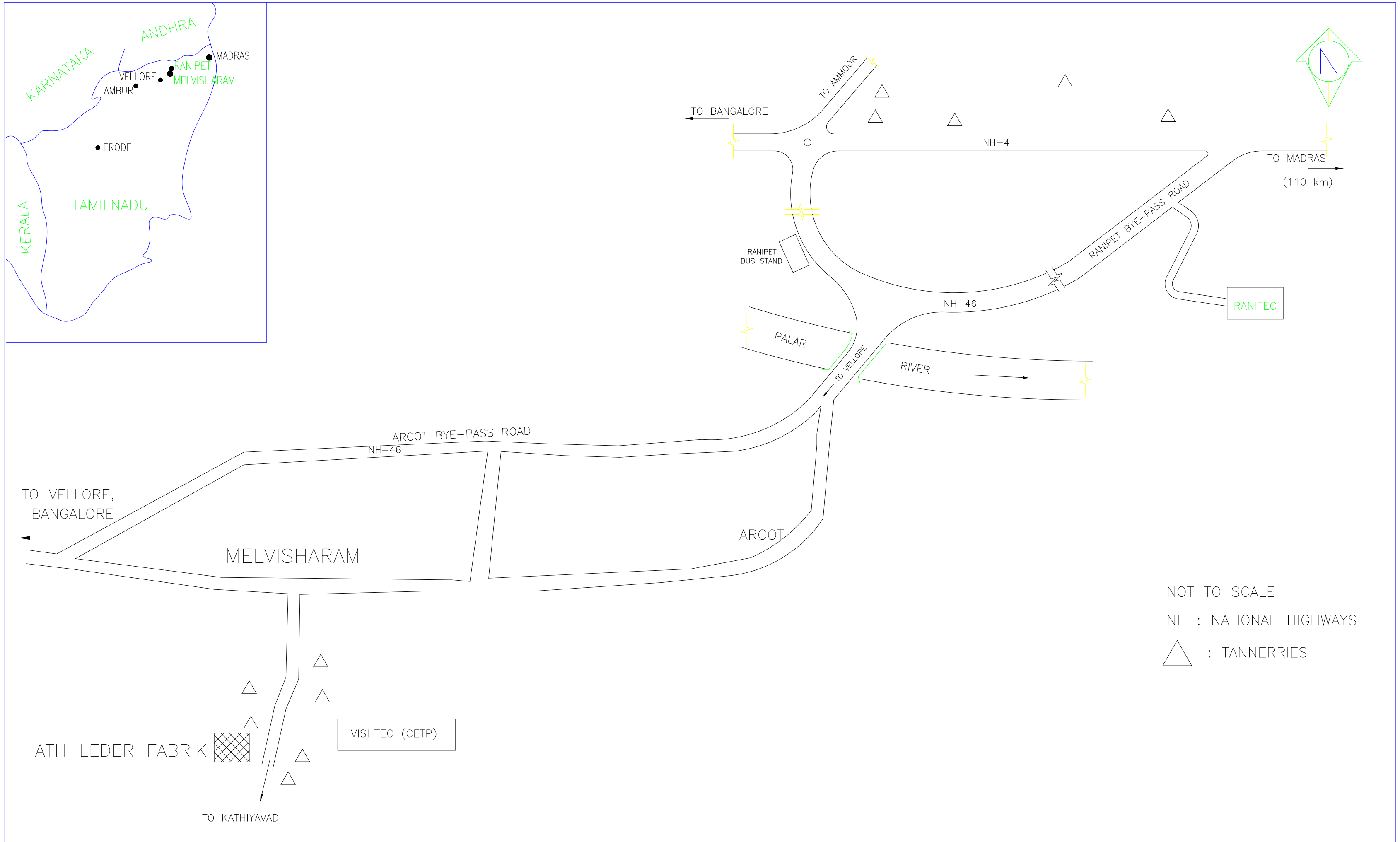
2.2 Capital cost - Equipment

Cost of equipment	458,600
Depreciation @ 12.5%	57,325

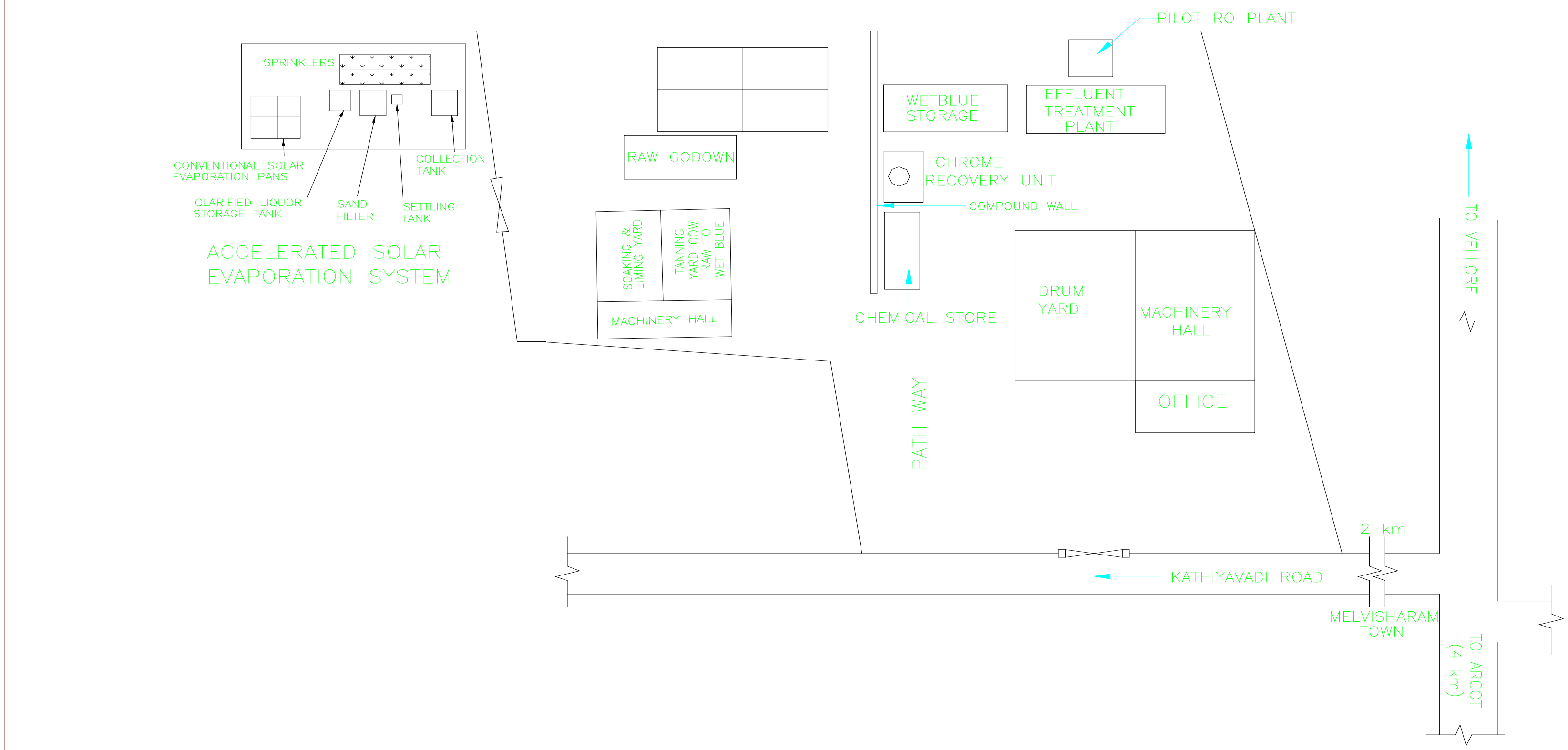
Total cost of depreciation/year	80,280
Cost of depreciation per day (INR.80,280 ÷ 365 days) (Continuous operation)	220/day

2.3 OPERATIONAL COST PER DAY

Electricity (50 kWh @ Rs.3.50/kWh)	175	
Labour (INR.2000 x 150% x 12 months ÷ 300 days)/2	60	
Chemicals	5	
Total operational cost/day		**240**
Operational cost/m^3 effluent evaporated (INR.240 ÷ 5 m^3)		48/m^3 or US$ 1.03/m^3
Total cost (capital + operational)/m^3 (INR. 220 + INR. 240 = INR. 460 ÷ 5 m^3)		92/m^3 or US $ 1.97/m^3



ANNEX 4: LOCATION OF ATH LEDER FABRIK, MELVISHARAM



ANNEX 5: LOCATION OF ACCELERATED SYSTEM AT ATH LEDER FABRIK

Annex 6: Operational data of the simplified version of the accelerated evaporation system at ATH Leder Fabrik, Melvisharam

February & March 2001

Date	At 0830 hours		At 0830 hours (Next day)		Volume reduced in 24 hours, l	Salt balance				Avg. flow, l	Spillage, l	Actual evaporation, l
	Volume, l	TDS, mg/l	Volume, l	TDS, mg/l		TDS input, kg	TDS output, kg	Difference, kg	Difference, %			
1	2	3	4	5	6	7	8	9	10	11 [(2+4)/2]	11 x 10	13 (6-12)
05/02/01	20000	21375	11000	27127	9000	427.5	298.4	-129	-30.20	15500	4681	4319
06/02/01	20000	20700	11500	26345	8500	414.0	303.0	-111	-26.82	15750	4224	4276
07/02/01	20000	21544	11500	27909	8500	430.9	321.0	-110	-25.51	15750	4018	4482
08/02/01	20000	21450	11000	28300	9000	429.0	311.3	-118	-27.44	15500	4253	4747
09/02/01	20000	19430	12000	24906	8000	388.6	298.9	-90	-23.09	16000	3694	4306
10/02/01	20000	24950	11000	31500	9000	499.0	346.5	-153	-30.56	15500	4737	4263
11/02/01	11000	31500	6000	40590	5000	346.5	243.5	-103	-29.71	8500	2526	2474
12/02/01	20000	25755	11000	30295	9000	515.1	333.2	-182	-35.30	15500	5472	3528
13/02/01	11000	30295	6000	41220	5000	333.2	247.3	-86	-25.78	8500	2192	2808
14/02/01	20000	28170	11000	37370	9000	563.4	411.1	-152	-27.04	15500	4191	4809
15/02/01	11000	37370	6000	43100	5000	411.1	258.6	-152	-37.09	8500	3153	1847
16/02/01	20000	28350	11000	36720	9000	567.0	403.9	-163	-28.76	15500	4458	4542
17/02/01	11000	36720	7000	42865	4000	403.9	300.1	-104	-25.71	9000	2314	1686
19/02/01	20000	24716	11000	37200	9000	494.3	409.2	-85	-17.22	15500	2669	6331
20/02/01	11000	37200	5500	43101	5500	409.2	237.1	-172	-42.07	8250	3471	2029
21/02/01	20000	35242	12000	42700	8000	704.8	512.4	-192	-27.30	16000	4368	3632
22/02/01	12000	42700	6000	49920	6000	512.4	299.5	-213	-41.55	9000	3739	2261
23/02/01	20000	26900	12500	38420	7500	538.0	480.3	-58	-10.73	16250	1744	5756
24/02/01	12500	38420	7000	52250	5500	480.3	365.8	-115	-23.84	9750	2325	3175
26/02/01	20000	28240	14000	38320	6000	564.8	536.5	-28	-5.01	17000	852	5148
27/02/01	14000	38320	9000	44096	5000	536.5	396.9	-140	-26.02	11500	2993	2007
28/02/01	20000	27312	14000	37512	6000	546.2	525.2	-21	-3.86	17000	656	5344
01/03/01	14000	37512	8000	51191	6000	525.2	409.5	-116	-22.02	11000	2422	3578
02/03/01	20000	28150	14000	45942	6000*	563.0	643.2	80	14*			
03/03/01	14000	45942	9000	53240	5000	643.2	479.2	-164	-25.50	11500	2933	2067

04/03/01	9000	53240	6000	62442	3000	479.2	374.7	-105	-21.81	7500	1636	1364
05/03/01	20000	29720	14000	47340	6000*	594.4	662.8	68	12*			
06/03/01	14000	47340	8500	68520	5500	662.8	582.4	-80	-12.12	11250	1364	4136
07/03/01	8500	68520	5500	83882	3000	582.4	461.4	-121	-20.79	7000	1455	1545
08/03/01	20000	27855	14000	37275	6000	557.1	521.9	-35	-6.33	17000	1076	4924
09/03/01	14000	37275	8000	54674	6000	521.9	437.4	-84	-16.18	11000	1780	4220
10/03/01	8000	54674	4500	82490	3500	437.4	371.2	-66	-15.13	6250	946	2554
12/03/01	20000	26880	12500	38386	7500	537.6	479.8	-58	-10.75	16250	1746	5754
13/03/01	12500	38386	6000	51360	6500	479.8	308.2	-172	-35.78	9250	3309	3191
14/03/01	20000	25380	11000	36930	9000	507.6	406.2	-101	-19.97	15500	3095	5905
15/03/01	11000	36390	5500	54580	5500	400.3	300.2	-100	-25.01	8250	2063	3437
17/03/01	17000	30380	11000	46260	6000	516.5	508.9	-8	-1.47	14000	206	5794
18/03/01	11000	46260	4000	64240	7000	508.9	257.0	-252	-49.50	7500	3713	3287
19/03/01	20000	34080	13000	54320	7000*	681.6	706.2	25	4*			
20/03/01	13000	54320	7500	71200	5500	706.2	534.0	-172	-24.38	10250	2499	3001
21/03/01	20000	39615	12000	52000	8000	792.3	624.0	-168	-21.24	16000	3399	4601
22/03/01	12000	52000	6500	64516	5500	624.0	419.4	-205	-32.80	9250	3034	2466
24/03/01	17500	50372	8500	62948	9000	881.5	535.1	-346	-39.30	13000	5109	3891
25/03/01	8500	62948	3500	99620	5000	535.1	348.7	-186	-34.84	6000	2090	2910
26/03/01	20000	45364	12500	54378	7500	907.3	679.7	-228	-25.08	16250	4076	3424
27/03/01	12500	54378	3500	96318	9000	679.7	337.1	-343	-50.40	8000	4032	4968
28/03/01	20000	43812	14000	63720	6000*	876.2	892.1	16	2*			
29/03/01	14000	63720	4500	89320	9500	892.1	401.9	-490	-54.94	9250	5082	4418
31/03/01	14500	62890	8000	88720	6500	911.9	709.8	-202	-22.17	11250	2494	4006
				Average	6700						2940	3760
* Faulty data											**Average actual volume of liquor evaporated, l**	**3760**
							Average rate of evaporation, mm/d					**15.0**

Annex 7

Calculation of operational cost – Simplified version of the plant in ATH, Melvisharam

1. Basis

Handling capacity/day	20000 l	
Average volume evaporated/day/sprinkler section	3760 l	
Average volume evaporated/day in 4 sprinkler section	15040 l	
Average volume evaporated/day in conventional pan	4960 l	
Area occupied by a sprinkler section	31m x 7.5m	= 232.5 m^2
Channel and reservoirs (shared by 4 sprinkler sections)	31 x 1.3 = 40.3 ÷ 4	= 10.1 m^2
		242.6 m^2
		Say 250 m^2

2. Cost of treatment

2.1 Capital cost – Civil work (adequate for 4 sprinkler sections)

	Amount in INR.
Civil work – tanks, sumps etc.	525,000
Civil work – conventional pans of area 1102 m^2 @ INR. 1100/m^2	1,212,200
Sub total	**1,737,200**
Depreciation @ 5%	86,860

2.2 Capital cost - Equipment (adequate for 4 sprinkler sections)

Pipes, fittings, pumps, valves, etc.		
a. Pipes, etc. (4 x Rs. 84650)	INR. 338,600	
b. Pumps	INR. 126,500	
c. Valves	INR. 33,000	498,100
Depreciation @ 12.5% p.a.		62,262
Total depreciation		149,122
Cost of depreciation per day (INR. 149,122 ÷ 365 days) (Continuous operation)		408/day

2.3 Operational cost per day

Electricity (2.25 kW x 2 nos. x 24 hrs. @ INR.3.50)	378.00	
Labour (INR.2000 x 150% x 12 months ÷ 300 days)	120.00	
Chemicals	22.00	
Total operational cost/day		**520**
Operational cost/m^3 evaporated (INR.520 ÷ 20 m^3)		26/m^3 or US$ 0.56/m^3
Total cost (capital +operational)/m^3 (INR.408 + INR.520 = INR.928 ÷ 20 m^3)		46.40/m^3 or US $ 0.99/m^3 say US$ 1/m^3

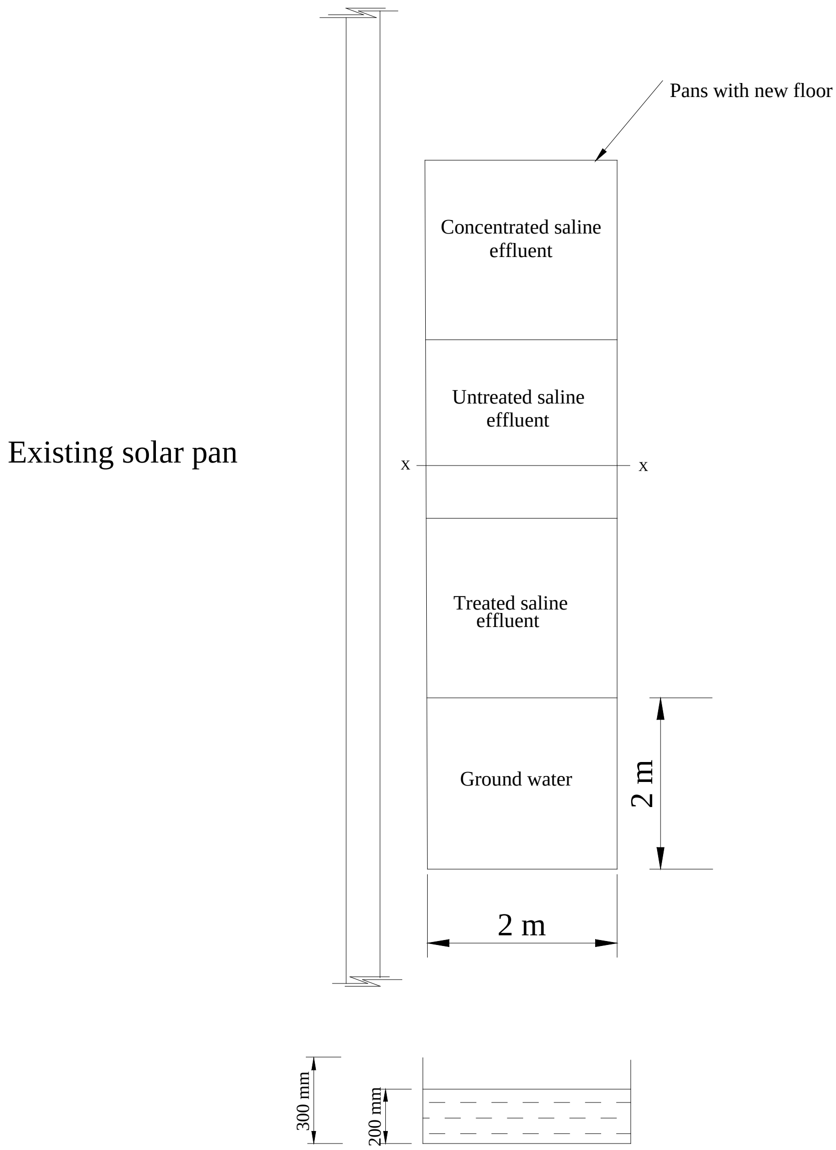
Annex 8: Experiments on solar evaporation in plastic trays

Date	Ground Water			Saline effluent						Ambient air temp., ^{o}C
				Untreated (raw)			Treated			
	Scale reading, mm		Evapn. in mm	Scale reading, mm		Evapn. in mm	Scale reading, mm		Evapn. in mm	
	Initial	Final		Initial	Final		Initial	Final		
13-14/2/01	196	203	7	46	53	7	56	63	7	
14-15/2/01	203	210	7	53	60	7	63	70	7	
15-16/2/01	210	218	8	60	67	7	70	78	8	
16-17/2/01	218	225	7	67	74	7	78	85	7	
17-18/2/01	225	232	7	74	81	7	85	93	8	33.2
18-19/2/01	232	239	7	81	88	7	93	100	7	34
19-20/2/01	239	246	7	88	95	7	100	107	7	37.7
20-21/2/01	246	253	7	95	102	7	107	114	7	34.5
21-22/2/01	253	261	8	102	109	7	114	121	7	32.6
22-23/2/01	261	268	7	109	116	7	121	128	7	34.9
23-24/2/01	268	276	8	116	121	5	128	134	6	34.6
24-25/2/01	276	283	7	121	126	5	134	140	6	37.8
25-26/2/01	283	291	8	126	129	3	140	144	4	37.5
26-27/2/01	291	298	7	129	130	1	144	147	3	35.9
27-28/2/01	298	305	7	130	132	2	147	150	3	36.3
28/2-1/3/01	305	313	8	132	133	1	150	153	3	37.1
1-2/3/01	Dried completely			133	135	2	153	156	3	
2-3/2/01				135	136	1	156	159	3	36.7
3-4/3/01				136	138	2	159	162	3	35.9
4-5/3/01				138	139	1	Dried completely			37.3
5-8/3/01				139	144	5				35.5
8-9/3/01				144	145	1				36.2
9-10/3/01				145	147	2				33.3
10-11/3/01				147	148	1				34.5
Total			117			102			106	
No. of days taken for evaporation			17			> 26			23	
Average rate of evaporation, mm/d			**6.9**			**< 3.9**			**4.6**	

Note: On 5 March 2001 (20th day), the untreated saline liquor reached a slurry-like state.

Annex 9: Experiments on evaporation of liquors in solar pans

Arrangment of pans



Cross sectional view at XX

Experiments on solar evaporation of saline effluent in conventional pans in SSC, Ambur

Section 3: Cycle-3

Date	Ground water			Untreated (raw) saline effluent			Treated saline effluent			Concentrated saline effluent			Ambient temp. ^0C			Relative humidity, %		
	Column height, mm		TDS, mg/l	Column height, mm		TDS, mg/l	Column height, mm		TDS, mg/l	Column height, mm		TDS, mg/l						
	At 0830 h	Difference		At 0830 h	Difference		At 0830 h	Difference		At 0830 h	Differ-ence		Min.	Max.	Avg.	Min.	Max.	Avg.
11/06/01	200		5636	200		78812	200		79140				28.9	34.8	32	43	59	51
12/06/01	193	7	5842	193	7	81964	193	7	82325				29	33.8	31	43	59	51
13/06/01	185	8	6126	186	7	85106	185	8	86089				28	33.6	31	43	61	52
14/06/01	178	7	6463	179	7	88422	178	7	89321				29.1	32.5	31	44	60	52
15/06/01	171	7	6631	172	7	92107	171	7	93107				29.6	31.9	31	45	60	53
16/06/01	164	7	6911	166	6	95418	164	7	97025	200		224812	30.6	35.6	33	36	51	44
17/06/01	156	8	7298	158	8	100483	156	8	102056	194	6	232595	30.4	36.6	34	35	51	43
18/06/01	148	8	7669	151	7	105081	148	8	107712	186	8	243228	31.1	36.9	34	35	51	43
19/06/01	140	8	8106	143	8	111044	140	8	113851	178	8	254010	31	36.8	34	36	52	44
20/06/01	128	12	8911	136	7	116528	129	11	124418	169	9	265792	30.9	36.2	34	37	52	45
21/06/01	119	9	9553	128	8	124230	120	9	133004	161	8	279374	31	35.6	33	38	53	46
22/06/01	111	8	10236	121	7	131261	113	7	141133	154	7	291709	30.8	33.8	32	41	56	49
23/06/01	103	8	11040	115	6	138084	106	7	150708	147	7	305858	31.4	37.1	34	36	50	43
24/06/01	96	7	11832	109	6	145438	99	7	161349	141	6	318177	31.4	36.1	34	37	49	43
25/06/01	88	8	12916	103	6	158715	92	7	173746	135	6	332701	31.8	36.5	34	35	48	42
26/06/01	80	8	14242	96	7	165642	84	8	190067	127	8	Salt	31.5	36.3	34	35	50	43
27/06/01	72	8	15861	89	7	178659	77	7	207785	119	8		31.4	36.7	34	35	49	42
28/06/01	64	8	17881	82	7	194183	70	7	228786	110	9		30.8	35.1	33	36	49	43
29/06/01	56	8	20432	76	6	209221	63	7	254253	101	9		30	33.3	32	42	53	48

30/06/01	48	8	23906	71	5	223472	57	6	280858	93	8		30.3	33.5	32	42	53	48
01/07/01	40	8	28791	66	5	241347	51	6	314598	85	8		30.2	33.9	32	41	53	47
02/07/01	33	7	35056	62	4	255928	45	6	Salt	77	8		30.9	33.3	32	40	54	47
03/07/01	26	7	44553	58	4	273869	40	5		dried completely			30.5	36.3	33	37	52	45
04/07/01	18	7	64741	55	3	288172	35	5					29.9	34.3	32	40	51	46
05/07/01	10	8		53	2		30	5					29.8	34	32	41	56	49
06/07/01	Completely dried			51	2		dried completely						29.9	32.7	31	45	54	50
07/07/01				49	2								30.3	35	33	41	53	47
08/07/01				Reached slurry-like state									30.4	35	33	40	52	46

Average rate of evaporation, mm/d

Ground water (26 days)	**7.88**	Dried completely
Untreated saline effluent (>27 days)	**<5.81**	Not dried completely but reached a slurry-like state
Treated saline effluent (25 days)	**7.08**	Dried completely

Concentrated saline effluent (17 days)	**7.69**	-	The higher evaporation rate than the treated saline effluent may due to the removal salt crystals from the surface of the liquor. A thin layer of salt deposits on the surface of the liquor which retards the further evaporation. This layer of salt needs to be removed manually from time to time. Hence the evaporation rate seems higher than the chemically treated saline effluent though the TDS concentration is low in chemically treated saline effluent.