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Studies on Simultaneous Effluent Evaporation and Water Recovery System

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Abstract: - Leather tanning industry uses large quantity of water for processing which results in copious quantity of liquid effluent. Disposal of tannery effluent has become a major environmental concern. A new technique has been developed to augment the water evaporation rate from the tannery effluent (soak liquor) and to recover fresh water. In this work, water in the tannery effluent (soak liquor) is evaporated using a spray tower and fresh water is recovered using a vapour compression refrigeration system (VCR). In the spray tower simultaneous heat and mass transfer takes place between the soak liquor and air which results in the evaporation of water from the soak liquor and humidification of air. Condensation of water vapour from the humidified air using VCR system yields fresh water. Experimental analysis has been carried out to find the effect of operational parameters like heat supplied to the soak liquor, heat removed from the humidified air, relative humidity of inlet air and the soak liquor flow rate on the evaporation rate and the amount of fresh water collected.

Key-Words: - Soak liquor; Spray tower; Heat and mass transfer; Evaporation; Condensation; Fresh water

1 Introduction

Leather processing is an important activity in many countries. Leather tanning industry is classified as one of the most red polluting industries [1]. The waste water let out after washing the hides consisting of 2-4% sodium chloride, traces of calcium chloride along with bio-particles like blood, flesh, skin and other suspended particles is termed as 'soak liquor'. It is highly polluting as it produces large amount of organic and chemical pollutants. Nearly 30-40 litres of water is required to process per kg of hide and globally 300-500 billion litres of effluent (soak liquor) is disposed every day from the tanneries. These effluent when disposed untreated causes damage to the environment by polluting the land, water bodies etc., as the major constituent is sodium chloride salt. At present the effluents are evaporated in shallow natural evaporation ponds by keeping it over a long period of time.The evaporation rate is about 4 litres/m^2/day. Large area is required as the rate of evaporation is less and it is also polluting the nearby lands.This has given rise to major problems like the treatment of such large quantity of effluent, requirement of huge area for treatment and availability of water for processing.

It is becoming increasingly difficult for tanning industries to meet the present regulations concerning effluent disposal and their survival is at stake. Also nowadays the availability of land in urban and semi-urban areas is becoming more costly.The above problems in present effluent treatment has created an urge to develop some new techniques to increase the evaporation rate with less area.

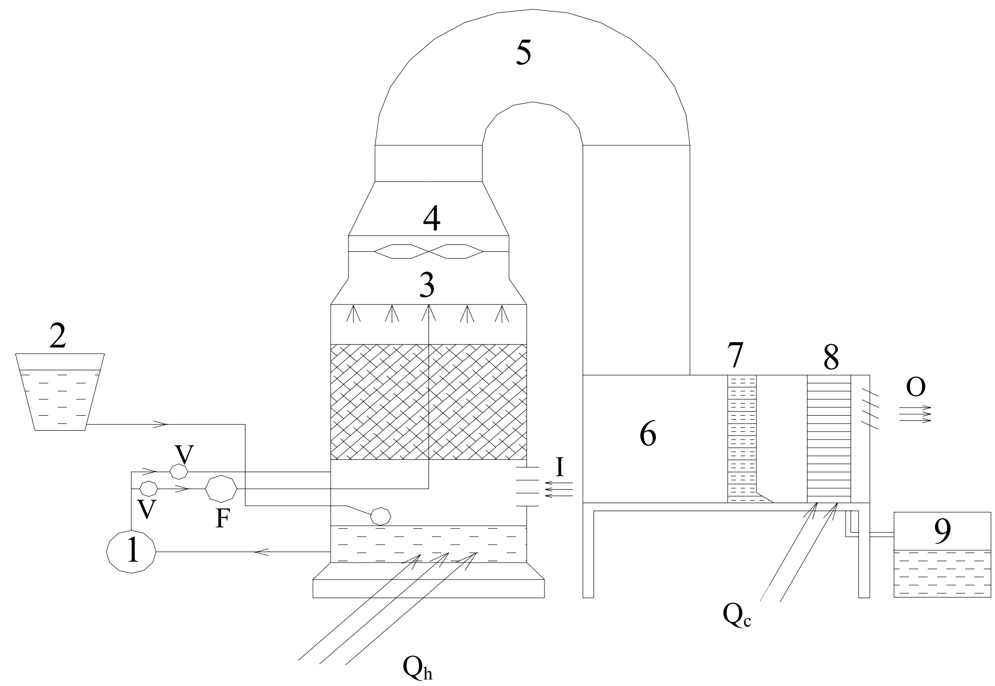
Lot of techniques are being found out to augment the evaporation rate [2,3]. One of the techniques is by increasing the contact area between the effluent and air [4,5]. Another method of increasing the evaporation rate is by increasing the temperature difference between effluent and air which is a driving potential for evaporation [3,6,7,8]. Simultaneous increase in contact area and temperature difference can be achieved by using a spray tower and VCR system [9].

This work aims to develop a system which requires less floor area, increase the evaporation rate and to recover the fresh water from the water evaporated from the effluent. The system works on the principle of simultaneous heat and mass transfer that takes place between the soak liquor and air in the spray tower leading to evaporation of water in soak liquor. Studies are carried out to utilize the heat rejected from the condenser of the VCR system to increase the temperature of the soak liquor. The hot soak liquor can be sprayed in the enclosed chamber to enhance the contact area between the soak liquor and air. Thus, both the process will contribute for increase in the evaporation rate compared to the conventional method. Moreover in present situation there is more scarcity for the availability of water. It will be useful if we recover fresh water from the above evaporation process. Efforts are made to recover the fresh water from the above evaporation process using the cooling load available in the evaporator of the VCR system [10].

2 Description of the System

Figure 1 shows the schematic arrangement of the effluent evaporation and water recovery system. The main components of the setup comprise of spray tower, duct arrangement, condensing chamber, vapour compression refrigeration system and pipe arrangement for soak liquor flow. The spray tower is of cylindrical structure made of fibre reinforced plastic in order to prevent corrosion. At the bottom of the tower it has a sump for collecting soak liquor. Piping is provided from the sump to the heat exchanger for heating the soak liquor.At the center of the tower it has packing for about half of its height which is made up of corrugated sheets of polyvinyl chloride arranged in European cross flute type. The packing increases the contact area between the soak liquor and air and also the residence time of soak liquor, hence enhancing heat and mass transfer [11,12,13].The corrugated arrangement will improve turbulence in air flow. It has a surface to volume ratio 190 m^2/m^3. Nozzles are provided at the top of the tower to spray the soak liquor as fine droplets.

Opening for air entry is provided at the lower circumference of the tower. An induced draught fan made of FRP blades is provided at the top of the tower which will induce the flow of air. Soak liquor pump is used to pressurize the liquor and is sprayed in the spray tower through PVC pipe and nozzles. Suitable bypass arrangements are provided for soak liquor flow in order to vary the flow rate of soak liquor to the tower. A makeup soak liquor tank is connected to the sump of the tower through float controlled valve. This valve will maintain constant level in the sump to compensate the loss of water in soak liquor due to evaporation.



1. Soak liquor pump
2. Makeup soak liquor tank
3. Spray tower
4. Induced draught fan
5. Duct
6. Condensing chamber
7. Droplet filter
8. Heat exchanger
9. Fresh water tank
F. Flow meter
I. Inlet air
O. Outlet air
Q_h. Heating load
Q_c. Cooling load
V. Valves

Fig. 1, Schematic diagram of simultaneous effluent evaporation and water recovery system

The exit of the tower is connected to the duct arrangement for air flow. The duct is connected to the condensing chamber through the droplet filter which separates the water particles carried away by air from the tower. The duct and the condensing chamber are made up of galvanized iron sheet of 0.5 mm thick. The whole condensing chamber is insulated with thermorexin insulating material which has a thermal conductivity of 0.035 $W.m^{-1}.K^{-1}$ in order to prevent heat gain from the ambient. A heat exchanger is placed in the condensing chamber to which the cooling load from the evaporator of the VCR system is transferred. Piping is provided at the bottom of the chamber where the fresh water is collected in a tank. Opening is provided at the end of the condensing chamber for the exit of air.

The vapour compression refrigeration system comprises of semi-hermetic compressor, shell and tube water cooled condenser, shell and coil type evaporator and an expansion device. The refrigerant used is R134a which is a chlorine free HFC refrigerant [14,15].The refrigerant has zero ozone depletion potential and a global warming potential of 1300 [16]. Two heat exchangers are used, one placed in the condensing chamber which removes heat from the hot air to the evaporator and another connected to the sump of the tower to reject heat from the condenser to the soak liquor. Here water is used as a secondary fluid to transfer thermal load from the evaporator and condenser of the vapour compression refrigeration system. Suitable bypass arrangements are provided for the flow of water in order to vary the flow rate and carry out the parametric study.

3 Experimentation

3.1 Clarification of the Soak Liquor

The soak liquor let out from the tanneries consist of dissolved salt and suspended particle like dust, skin , blood, flesh etc., Hence the soak liquor clarification has to be done which is a pretreatment process to remove suspended particles to get near pure soak liquor [17]. The soak liquor is clarified in a test apparatus by adding 100 ppm of poly aluminum chloride and 200 ppm of alum. This mixture is stirred continuously for about 30 minutes in the clarifier. The clarified liquor is allowed to settle down for 3 hours so that dust and other suspended particles collect at the bottom. After filtering, almost pure soak liquor is collected from the top portion. The soak liquor thus obtained contained about 2.9% salt concentration.

3.2 Experimental Procedure

Soak liquor filled in the sump of the tower is pumped to the heat exchanger where the heat is transferred to the soak liquor from the condenser of the VCR system and its temperature is augmented. The heated soak liquor is sprayed in the tower through nozzles. It travels through the packing material as a thin film and collects in the sump of the tower. Air is drawn in through the circumference of the tower by induced draught fan. Soak liquor and air flow in the counter flow direction inside the tower. Simultaneous heat and mass transfer take place between the soak liquor and air. The driving potential for this process is the temperature difference and vapour fraction difference between the soak liquor and air [18,19,20]. This will result in the evaporation of the water in the soak liquor and the air will get humidified. The loss in water content is compensated by supplying water from the makeup tank so that constant concentration level is maintained to carry out experimentation. For real applications the soak liquor is added from the makeup tank and the liquor is re-circulated in the system till its concentration reaches about 20 %, i.e., near the crystallization region.Then the liquor is taken into small shallow solar pans for further evaporation and recovery of salt.

The soak liquor falling in the sump of the tower gets cooled as the heat is carried away by the air which can be heated again as mentioned above. The humidified air leaving the tower is allowed to flow through the duct arrangement to the insulated condensing chamber. The droplet particle carried over by the air is separated by the filter and the air is allowed to flow through the heat exchanger. The chilled water from the evaporator of the VCR system is circulated in the heat exchanger whose temperature is maintained below the dew point temperature of the humidified air. Condensation of the humidified air takes place and fresh water is collected in the fresh water collecting tank. The chilled air leaving the exit of the condensing chamber can be used for air conditioning applications.

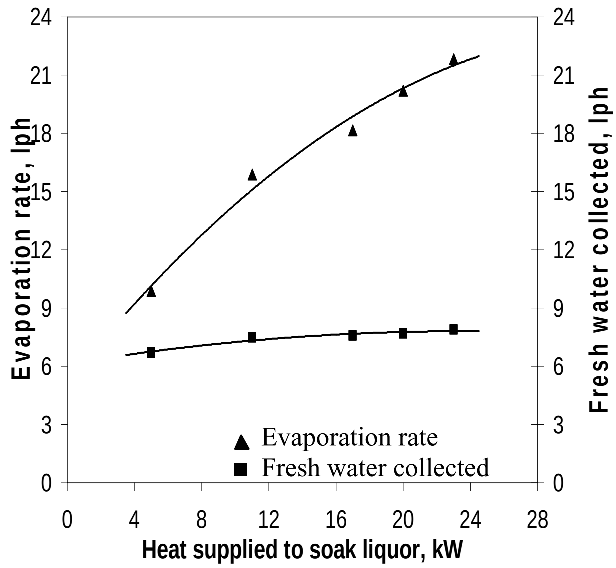
3.3 Instrumentation and Measurements

Experimentation is carried out at Chennai, India(Latitude of 13^{o}N). Experiments are carried out in the months of November to February. The experimental setup is at ground level which is at an elevation of 6m above mean sea level (MSL). Parametric studies are carried out to find the effect of heat supplied to the soak liquor, heat removed from the humidified air, relative humidity of inlet air and soak liquor flow rate on the evaporation rate and fresh water collected. The heat supplied to the soak liquor is varied by varying the flow rate of hot water to the heat exchanger.Apart from the above additional heaters are placed in the spray tower sump to carryout the parametric study.The heat removed from the air is varied by varying the chilled water flow rate to the condensing chamber. Experimentation is carried out at different days and different hour of the day to find out the effect of relative humidity.

Temperature, humidity and flow rate measurements are made for soak liquor, air and secondary fluid at several places of interest. Liquor temperature, water temperature and dry bulb temperature of air is measured by using thermocouples. Copper-constantan thermocouples (T type), insulated with teflon, are used which has a range of -100 to150 °C and an accuracy of ±0.1°C. They are connected to a Hewlett Packard data acquisition system, which gives digital reading of all temperatures. Ball valves are used to control the flow rate of liquor and is measured with a turbine type flow meter and a stopwatch. It has a measuring range of 0 to 20 $m^3 h^{-1}$ and an accuracy of ±0.001 m^3h^{-1}. Air velocity at various locations are measured with a vane type digital anemometer which has a range of 0 to 10 m s^{-1} with accuracy of ±0.1 m s^{-1}. Relative humidity of the air is measured with a digital RH meter (Humiread). RH meter has a range of 0 to100% and accuracy of ±0.1 %. Evaporation rate is measured from the volume of make up water drawn from the tank over specified time. Flow rate of secondary fluid, water is measured with rotameter having a range of 0 to 5000 lph with accuracy of ± 100 lph. A micromanometer is used to measure the air pressure drop in the tower. All measuring instruments are calibrated with standards before carrying out experimentation.

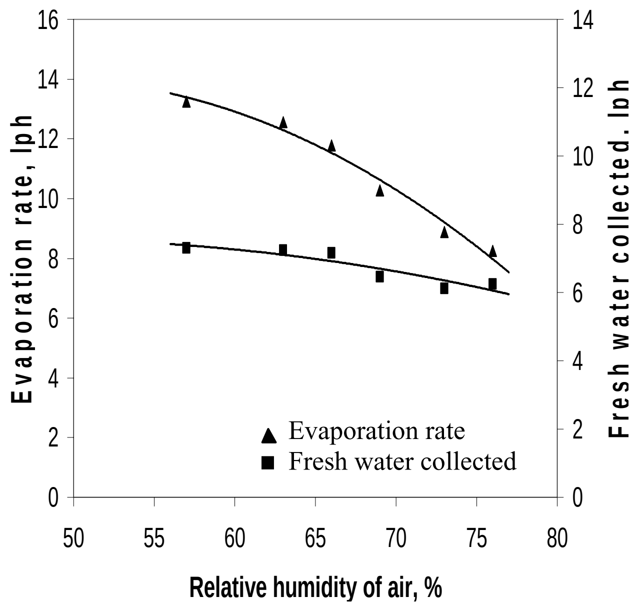
4 Results and Discussion

Figure 2 shows the variation in the evaporation rate and fresh water collected with the heat supplied to the soak liquor. There is a sharp increase in the evaporation rate when the heat load is increased. The increase in heat load will augment the temperature of the soak liquor which is sprayed in the tower. The temperature difference potential between the soak liquor and the air increases which is a driving potential for heat and mass transfer between the soak liquor and air and hence the evaporation rate. There is a small variation in the



Salt concentration 2.9 % Relative humidity 67 %
Mass flow rate 4.12 $kg.s^{-1}$ of soak liquor Cooling load Q_c 6 kW

Fig.2, Effect of heat supplied on the evaporation rate and the fresh water collected



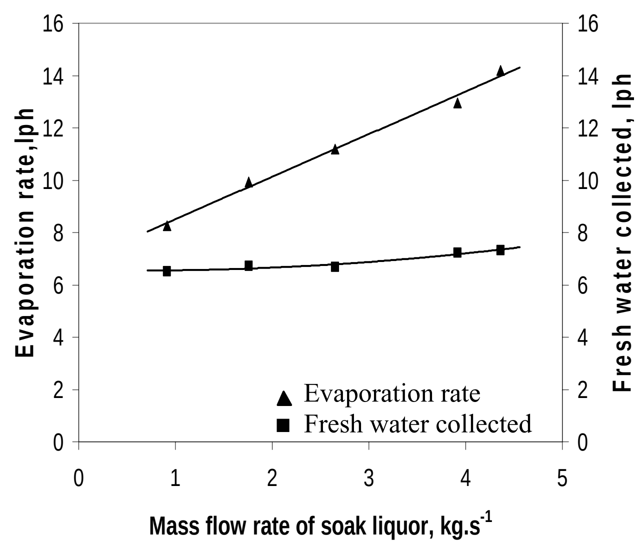
Salt concentration 2.9 % Heating load Q_h 8.65 kW
Mass flow rate 3.81 $kg.s^{-1}$ of soak liquor Cooling load Q_c 6 kW

Fig.3, Effect of relative humidity of inlet air on the evaporation rate and the fresh water collected.

fresh water collected with respect to the heat load. This is contributed by the increase in the evaporation rate of soak liquor because of which there is a change in the state of air at the exit of the tower.

Figure 3 shows the effect of relative humidity of the inlet air on the evaporation rate and fresh water collected. As the relative humidity of air at the inlet increases, evaporation rate of soak liquor decreases. As the relative humidity increases, the partial pressure of water vapour in air and hence the specific humidity increase. This reduces the partial pressure difference between soak liquor interface and air resulting in reduced mass transfer rate. Hence the evaporation rate of soak liquor reduces with increase in relative humidity. The decrease in the evaporation rate has an impact in the amount of fresh water collected as the exit air conditions leaving the tower vary.

The variation in the evaporation rate and fresh water collected with the mass flow rate of soak liquor is presented in Fig. 4. The evaporation rate of soak liquor is directly proportional to the contact area between the soak liquor and air. As the mass flow rate of soak liquor increases, the exposure rate of the soak liquor to the air increases resulting in increased heat and mass transfer.This results in the increased evaporation rate. The amount of fresh water collected does not have much variation as that

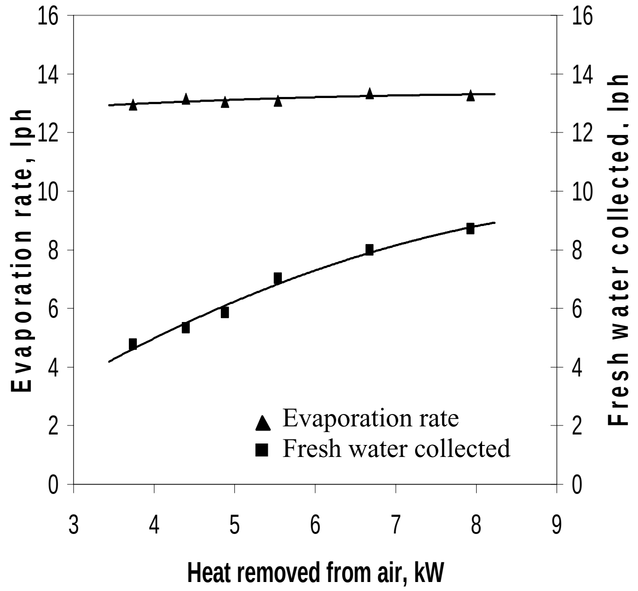


Salt concentration 2.9 % Heating load Q_h 8.65 kW
Relative humidity 62 % Cooling load Q_c 6 kW

Fig.4, Effect of mass flow rate on the evaporation rate and the fresh water collected.

of evaporation rate, since it is more dependent on the condition of exit air and the heat removed from air.

Figure 5 depicts the variation of amount of fresh water collected with the heat removed from the air. The amount of fresh water collected increases sharply with the increase in the heat removed from the humidified air leaving tower. As the heat removal rate increases, more moisture will condense from the humidified air which results to increase in fresh water collection rate.The evaporation rate of the soak liquor almost remains constant as the increase in the heat removal rate not having much impact on the heat and mass transfer between the soak liquor and air.



Salt concentration 2.9 % Heating load Q_h 8.65 kW
Mass flowrate 3.894 $kg.s^{-1}$ Relative humidity 57 %
of soak liquor

Fig.5, Effect of heat removal on the evaporation rate and amount of fresh water collected.

5 Conclusions

A laboratory scale model has been developed to augment the evaporation rate of water from the tannery effluent (soak liquor) and to recover fresh water.Experimental studies has been carried out to understand the effect of various operational parameters on the performance of the system. Evaporation rate increases steeply with the heat supplied and mass flow rate of soak liquor. The fresh water collection rate increases extensively with the heat removed from the air and sparingly with the heat supplied to soak liquor and mass flow rate of soak liquor. The evaporation rate and fresh water collection decreases with the increase in the relative humidity. The fresh water obtained can be used for hide processing and other applications. Moreover the chilled air that is available at the exit of the condensing chamber can be used for airconditioning applications. It has been found that the evaporation rate has been increased almost twice when compared to that of the conventional method with less floor area. Moreover fresh water is recovered from the soak liquor which can eliminate the water scarcity to some extent.

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