

## RESEARCH ARTICLE

## Experimental study of Triple Effect Forced Circulation Evaporator at Perundurai Common Effluent Treatment Plant

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### Abstract

Disposal of saline effluent from textile industries is an increasing problem worldwide since the dyeing process involves usage of more inorganic salts. Evaporation and cooling is the common technique used to extract available salts and reusable water. Pre-treatment, multiple effect falling and forced circulation evaporators is the major steps of one option to provide the purposes of zero discharge desalination process for textile waste water. Reverse osmosis (RO) reject is conveyed to forced circulation evaporator after increasing the concentration in multiple effects falling film evaporator (MEE) in order to separate salt and reusable water. This study presents the optimization of operating parameters such as residence time, flow rate of cooling water, occupied capacity of crystallizer (third effect), color and size distribution of salt crystals, amount of water separated, amount of salt separated, steam and energy consumption of triple effect forced circulation evaporator for the effective separation of salt and water.

**Keywords:** Thermal desalination, forced circulation evaporator, multiple effect evaporator, forced circulation crystallizer.

### Introduction

India is the second largest export of cotton yarn and there are about 10,000 garment manufacturers and 2200 bleaching and dyeing industries in India. Majority are concentrated at Erode and Tirupur district of Tamil Nadu, Surat in Gujarat and Ludhiana in Punjab. Erode and Tirupur districts at least have 50% of dyeing and bleaching industries where in 30% industries are attached to Common Effluent Treatment Plant (CETP).

Dyeing is a combined process of bleaching and coloring, which generates voluminous quantities of wastewaters and in turn causes environmental degradation. These effluents consist of high Total Dissolved Solids (TDS), chloride, sulphate, hardness and carcinogenic dye ingredients. The untreated textile wastewater can cause rapid depletion of dissolved oxygen if it is directly discharged into the surface water sources due to its high BOD value. The effluents with high levels of BOD and COD values are highly toxic to biological life. The quality of such effluent can be analyzed by their physico-chemical and biological analysis. Monitoring of the environmental parameters of the effluent would allow having, at any time, a precise idea on performance evaluation of ETP and if necessary, appropriate measures may be undertaken to prevent adverse impact on environment. The obtained results were very much useful in identification and rectification of operational and maintenance problems and it can be also utilized to establish methods for improved textile industry and plant waste minimization strategies.

Water treatment is a very important step to change these conditions and to achieve a sustainable situation. Indian government has an awareness of this and limits for water effluent quality exist. Unfortunately, this regulation is not closely supervised and a lot of places do not follow the regulation. In newly developed industrial areas, advanced wastewater treatment is used for textile effluent, as the one such place is SIPCOT in Perundurai. Each industry bears the responsibility for dealing with the effluent water from their processing. Therefore, 14 textile units together formed PCETP. Each of the units has different shares in the treatment plant and consequently they are allowed for different maximum flows that they can discharge to the treatment plant. The treatment plant only handles industrial effluent from those 14 textile industries. PCETP can operate 3600 m<sup>3</sup>/d wash water and 450 m<sup>3</sup>/d dye bath.

Evaporation is an operation used to remove a liquid from solution, suspension or emulsion by boiling off some of the liquid. It is thus a thermal separation or thermal concentration process. We define the evaporation as one that starts with a liquid product and ends up with more concentrated one (Kim, 2011). Forced circulation evaporation is used if boiling of the product on the heating surfaces is to be avoided due to the fouling characteristics of the product, or to avoid crystallization. The circulation liquid is heated when it flow through the heat exchanger and then partially evaporated when the pressure is reduced in the separator, cooling the liquid to the boiling temperature corresponding to this pressure.

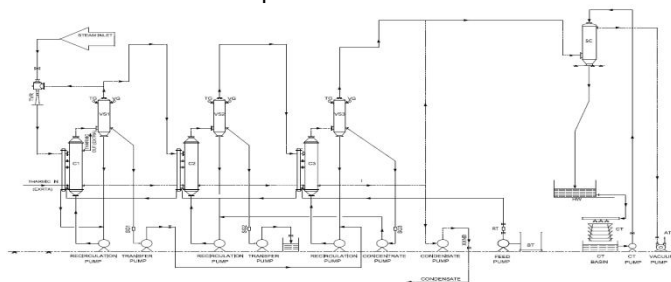
Forced circulation evaporators normally used for liquid which prone to fouling, scaling, and crystallizing or those which are inversely soluble or while concentrating thermally degradable materials. According to PCETP, different serial units such as pretreatment units, multiple effects falling film and forced circulation has been in operation to separate salt and reusable water. Feed supply of five effect falling film evaporators is the exit stream from pretreatment unit and feed source of three effect forced circulation evaporator is the concentrate of five effect falling film evaporator. This crystallizer is one stage of the zero discharge desalination processes. The authors focus on the crystallizing section. Since forced circulation evaporators are optimally suited as crystallizing evaporators for saline solutions this type is considered (Farahbod *et al.*, 2012). As in this type of crystallizer the temperature of heat exchanger, flow rate of cooling water, vessel design, vaporization rate and residence time can have a major impact on the size distribution and the amount of crystals produced so, this study has perused on major principles in performance of three effect forced circulation evaporator supposed to salt and water separation.

### Materials and methods

**Experimental procedure:** The whole evaporator plant (MEFCE) is constructed of stainless steel to prevent corrosion from high concentrated sodium chloride in high temperature. Of course the setup is insulated to conserve energy. By means of thermocouple we shall record temperatures of important parts such as on suction line of centrifugal pump, entrance line to heat exchanger (calendria), crystallizer (last effect) and on exit line of heat exchanger (calendria). A glass gauge illustrates the level of liquor in the crystallizer (last effect) and a pressure gauge is provided on top of the crystallizer (last effect) to monitor the vapor pressure and provide safety. Steam is provided to the first calendria. The steam and feed is entered on the basis of feed forward sequence. A surface condenser is situated on top of the crystallizer (last effect) and vapor condenses through it by cooling water circulation from cooling tower.

**General procedure:** Slurry from falling film evaporator is stored in balance tank and pumped to the crystallizer (first effect) through the tubes of the first calendria, where heat is added. The vapor from first effect is separated and sends to the second effect in order boil the effluent and so as to third effect. The liquor in a forced circulation evaporator is pumped through the tubes of three effects to decrease tube scaling or salting when precipitates are formed during evaporation. Three circulation pumps keep the crystal slurry in homogeneous suspension throughout the cycle and heat exchanger is located on the discharge side of the circulating pump. The heated liquid then flows into the vapor space, where flash evaporation occurs, giving some super saturation.

Fig. 1. Schematic diagram of triple effect forced circulation evaporator in PCETP.



The vapor leaving from the last effect is condensed in the condenser and the supersaturated liquid flows down the down flow tube and then up through the bed of fluidized and agitated crystals, which are growing in size. The leaving saturated liquid will be transferred to second and third effect by means of transfer pump, finally goes back as a recycle stream to the heater, where it is joined by the entering fluid. The larger crystals (salts) settle out and with mother liquid are withdrawn as product from the last effect crystallizer. Figure 1 shows sketch of triple effect forced circulation evaporator in PCETP. Sufficient slurry height (submergence) is maintained in the main body of the crystallizer and at the top of the heat exchanger to prevent local boiling on the tube surface. This is necessary to preclude salt precipitation on the tangential inlet and tubes so a high circulation rate is provided for adequate tube velocity to achieve good heat transfer.

**Feed characteristics:** Table 1 shows the average chemical analysis of reject from five effect falling film evaporators which is fed to triple effect forced circulation evaporator during the desalination process.

Table 1. Average chemical analysis of forced circulation feed waste water.

Content	Composition
TDS	125000 ppm
Total hardness (TH)	400 mg/L
pH	10-11
Specific gravity (S.G) @ 50c	1.07

### Results and discussion

In this experimental study, the cooling water flow rate, residence time and occupied volume percentage of the crystallizer are investigated as major independent variables on crystallization performance and the effect of these parameters is discussed in the following parts.

**Variation of cooling water flow rate and its effects:** The effect of cooling water flow rate in the surface condenser which is situated at the top of crystallizer of last effect on the amount, color and size distribution of the produced salt crystals was investigated by changing the flow rate of cooling water from 135 to 270 kg/h. Also the effect of the parameter on the rate of energy consumption was studied.

Fig. 2. Variation of the amount of salt separated with cooling water flow rate.

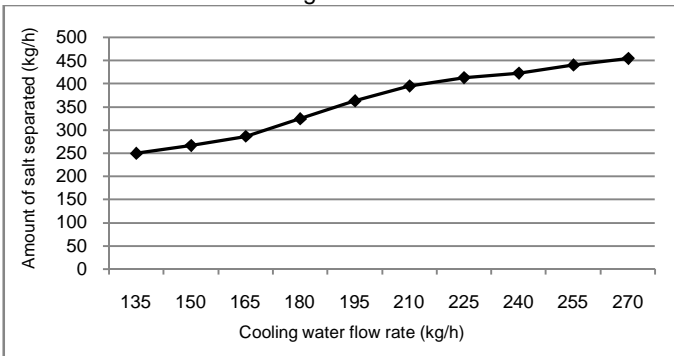


Fig. 6. pH and S.G of slurry versus cooling water flow rate.

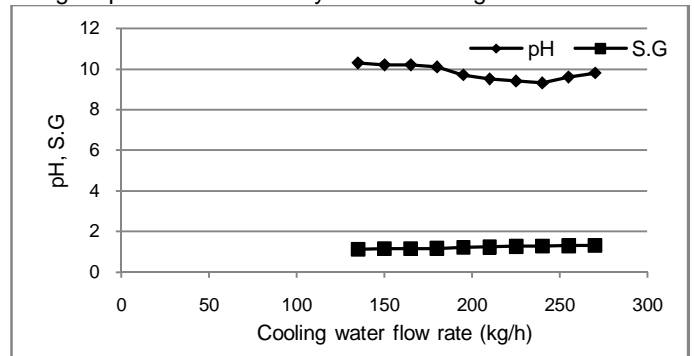


Fig. 3. Variation of the average size of salt crystal with cooling water flow rate.

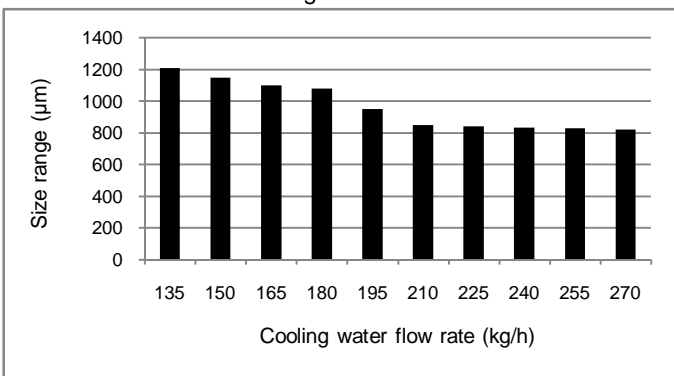


Fig. 7. TDS of slurry versus cooling water flow rate.

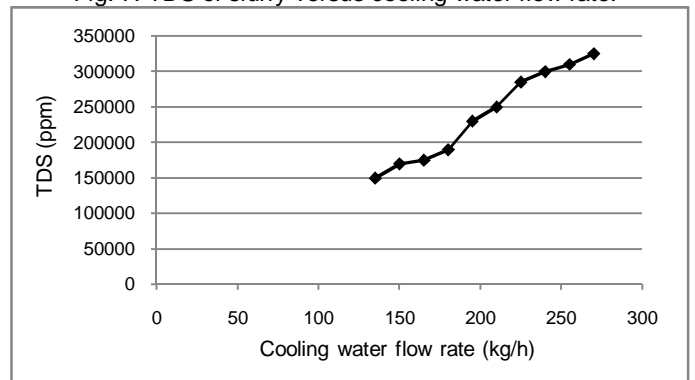


Fig. 4. Variation of temperature of solution in crystallizer with cooling water flow rate.

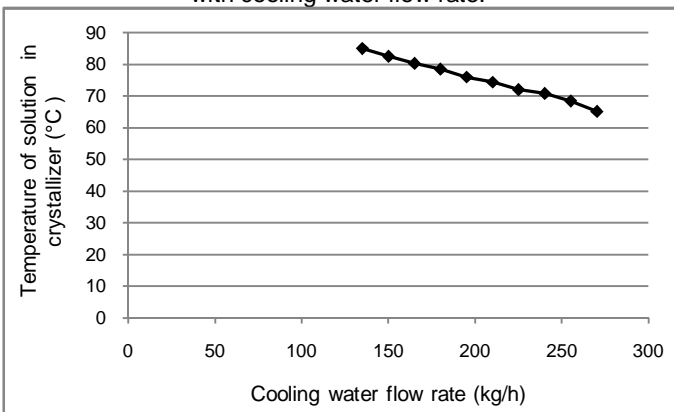


Fig. 8. Condensate water versus cooling water flow rate.

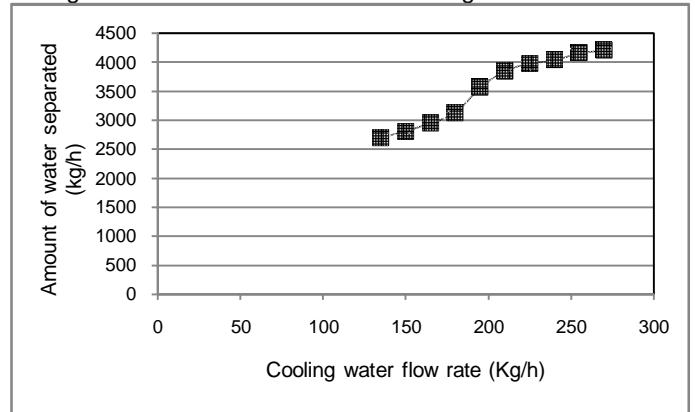


Fig. 5. Energy consumption versus cooling water flow rate.

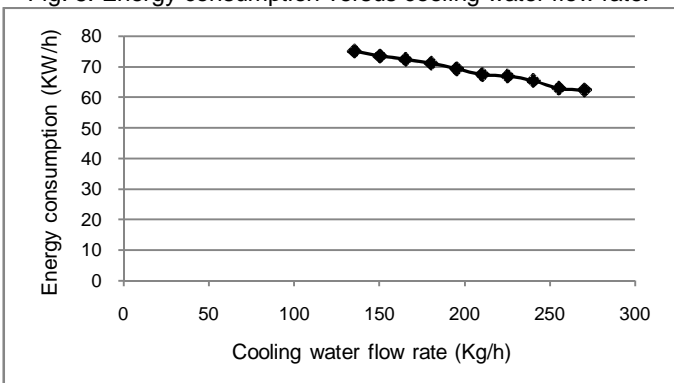


Figure 2 shows the amount of separated salt crystals and average size range of salt crystals with cooling water flow rate. Coarse salt crystals (1200 µ) are produced with decreasing of cooling water flow rate (Fig. 3). So the rate of salt production obtained with 210 kg/h of cooling water flow rate during 3 h is much more compared with other cooling water flow rates. If cooling water flow rate decreases the top region of solution in the main body of the crystallizer (last effect) will be occupied by vapor and then saturation temperature of the brine increases. Consequently, temperature of heat exchanger must be set on higher values to provide proper temperature for vaporization.

According to Figure 2 the amount of salt produced with increasing of cooling water flow rate. So the rate of salt production obtained with 210 kg/h of cooling water flow rate during 3 h is much more compared with other cooling water flow rates. Figure 3 shows the amounts of produced salt crystals and size range of salt crystals with cooling water flow rate. According to Figure 3, coarse salt crystals (700–830 μm) are produced with increasing of cooling water flow rate. If cooling water flow rate decreases the top region of solution in the main body of the crystallizer will be occupied by vapor and then saturation temperature of the brine increases. Consequently, temperature of heat exchanger must be set on higher values to provide proper temperature for vaporization. Figure 4 and 5 shows the effect of variation of cooling water flow rate and inside temperature of crystallizer (third effect) on energy consumption. Figure 6 and 7 shows the pH value of feed and Total Dissolved Solids versus cooling water flow rates. Figure 8 shows the production rates of condensate water in different flow rates of cooling water. As it is seen, the amount of produced condensate water is proportional to cooling water flow rate.

**Variation of residence time and its effects:** The effect of residence time variation on the operating parameters such as quality and quantity of separated salt crystals, energy consumption, pH, concentration and density of produced slurry and amount of condensate water separated was studied. As shown in Fig. 9, the amount of produced distilled water increases with increasing of feed residence time (1-5 h).

Fig. 9. Variation of condensate water with residence time.

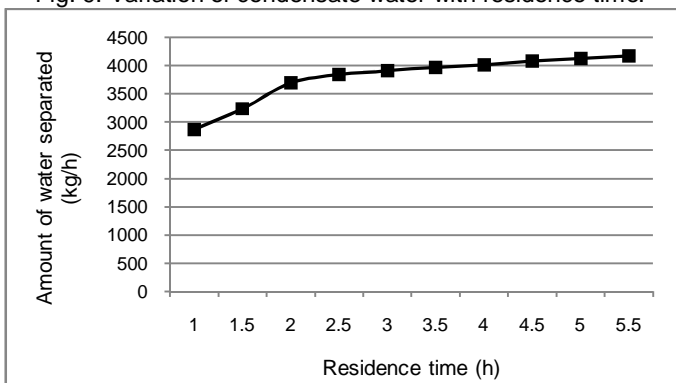


Fig. 10. Consumption of energy versus residence time.

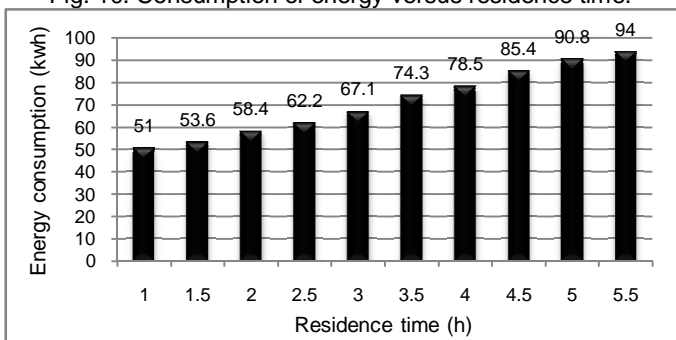


Fig. 11. Amount of salt separated with increasing residence time.

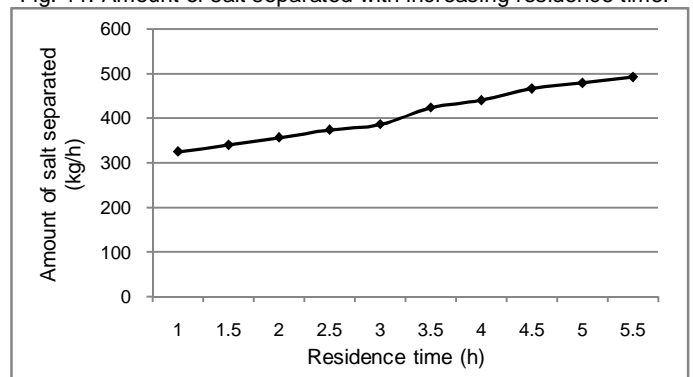


Fig. 12. Average size range versus residence time.

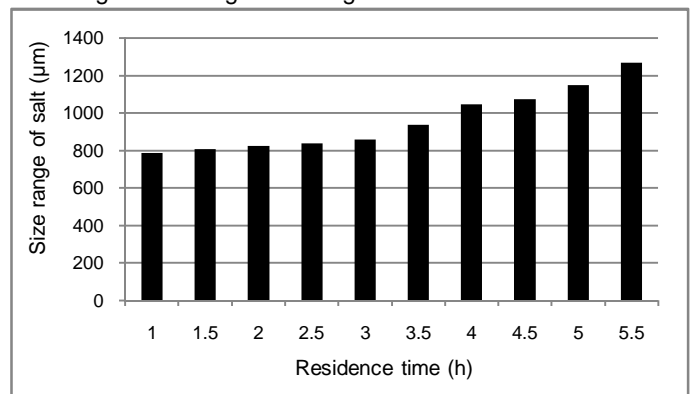


Fig. 13. density of slurry versus residence time.

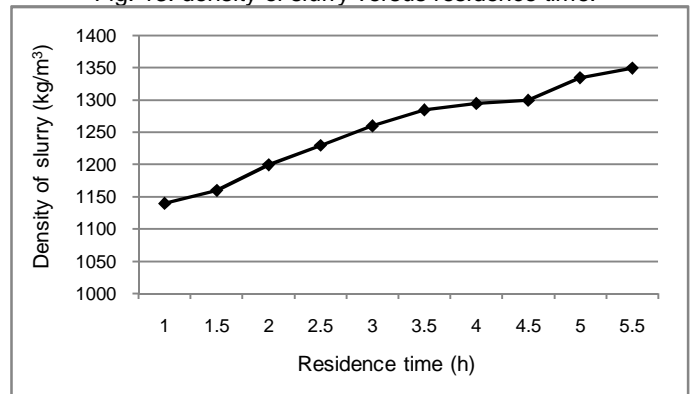


Figure 10 shows that amount of energy consumption versus residence time for different occupied volumes and this obtained 70% total volume of the crystallizer is the best value. Figure 11 shows that residence time increases the amount and size range of produced salt crystals. Size of crystals is enhanced by more circulation and also more vaporization rate because an increase in salt concentration resulted in an overall increase in crystal sizes. The effect of residence time on density of produced slurry is shown in Figure 13. Figure 12 shows that residence time increases the amount and average size range of produced salt crystals (Hash and Okorafor, 2008). Size of crystals is enhanced by more circulation and also more vaporization rate because an increase in salt concentration resulted in an overall increase in crystal sizes.

Also, the amount of produced crystals increases if vaporization process prolongs. So, optimized results of energy consumption and amount of produced salt are in 3 h as residence time compared with 2 h and 4 h. The effect of residence time on density of produced slurry is shown in Fig. 13.

**Variation occupied volume percentage of crystallizer and its effects:** Cooling water flow rate in condenser and residence time of feed in crystallizer (last effect) are extremely important in crystallization process. The occupied volume percentage of the crystallizer is another major parameter which affects the amount of produced salt crystals, growth of crystalline and empty space of crystallizer, Fig. 14 shows the amount of energy consumption for different occupied volumes and Fig. 15 shows the residence time variation for different occupied volumes and obtained 70% total volume of the crystallizer is the best value.

### Conclusion

Since forced circulation evaporators are optimally suited as crystallizing evaporators for treating the textile waste water comprising of sodium chloride salt this type is considered (Farahbod *et al.*, 2012). So, in this performance analysis, major variables in performance of triple effect forced circulation evaporator supposed to salt and water separation are investigated. Results show that residence time of 3 h is the best duration for this experiment because the crystal growth is in the suitable range (740-860  $\mu\text{m}$ ) and also the maximum rate of salt separated and minimum energy consumption about 67.5 kWh are obtained. Comparing with literature, industrial salt crystals such as fine grade salt and coarse grade are usually in the size range of 0.08 mm and 0.08-2 mm respectively. So, obtained size distribution of crystals in this study is good enough.

Another major parameter is cooling water flow rate in the condenser and according to the experimental results the optimum value is 210 kg/h. With this flow rate of cooling water the energy consumption is less and the amount of separated salt is remarkable compared with the other flow rates. Dimensions of the main body and occupied volume space affect the size of salt crystals and also the rate of vaporization, so different occupied volume percentages are studied. Minimum entrainment and also reasonable salt production are obtained when the occupied capacity of crystallizer is 70%.

Fig. 14. Amount of energy consumption versus volume %.

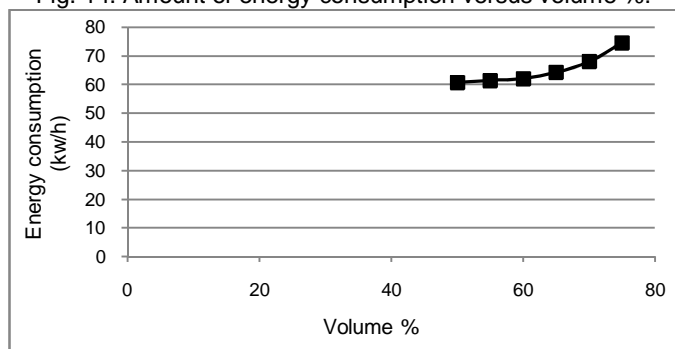
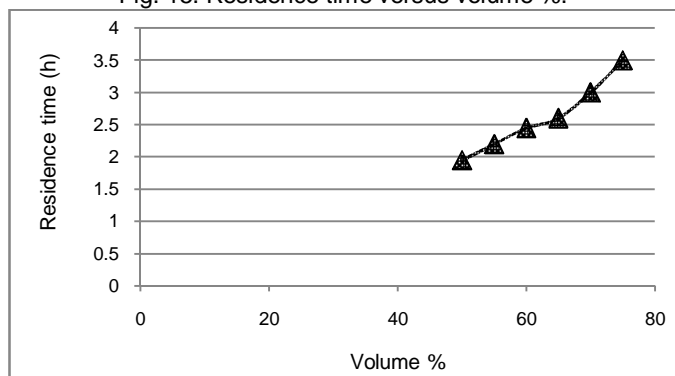


Fig. 15. Residence time versus volume %.



### Acknowledgements

Author deeply thank the plant manager of PCETP, Mr. T. Ravi Kannan for providing the opportunity to explore the plant. Author express his sincere thanks to Dr. K. Saravanan, Prof. and Head, Dept. of Chemical Engg., Kongu Engineering College, Perundurai and also thank co-author of this study Mr. A.S. Periasamy Manikandan for his impeccable support through out the study.

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