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Investigation of forced circulation crystallizer performance as major unit in factories of production of NaCl

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ABSTRACT

This work represents the performance of a forced circulation crystallizer (FCC) equipped with a condenser as main stage of in many industrial processes. The purpose of this paper is gathering fresh water and also liquor from brackish water. So a blender is constructed before crystallizer to concentrate the saline water to about 30 wt% as a suited feed for a FCC. The effect of cooling water flow rate of FCC on quality of effluent liquor from FCC is studied in this paper. The evaporation rate from FCC is obtained 0.085 kg/min at 85.8 C boiling temperature of liquor. At this temperature the highest amount of white crystal is produced. Experiments show the produced crystal is in size range of (675- 795 μm). Minimum amount of energy consumption by heat exchanger is 6.4 kW. h. which is obtained at 6.3 kg of the product. Also, experimental results show the relation between the cooling water flow rates, amount of feed, vaporization rate, distilled water and pH as graphs.

KEYWORDS

Liquor;
Forced circulation crystallizer;
Salt crystal;
Energy consumption.

INTRODUCTION

Evaporation is a process used to concentrate a solution of nonvolatile solute and a volatile solvent which in many cases is water[1]. A portion of the solvent is vaporized to produce a concentrated solution, slurry or thick, viscous liquid[2]. Evaporators are used for this purpose. Evaporators are used to separate materials based on differences in their boiling temperatures[3]. Either the vapor or the concentrate stream, or both, may be the desired product. Its purpose is to concentrate nonvolatile solutes such as organic compounds, inorganic salts, acids or bases. Typical solutes include phosphoric acid, caustic soda, sodium chloride, sodium sulfate, gelatin, syrups and urea[4]. Evaporation is conducted by vaporizing a portion of the solvent to produce a concentrated solution or thick liquor. Evaporation is different from distillation in that there is no attempt to separate the vapors into individual components[5]. Evaporation differs from drying in the sense that the residue is a liquid - sometimes a highly viscous one - rather than a solid[6]. Another difference is that, in evaporation the vapor is usually a single component, and even when the vapor is a mixture, no attempt is made in the evaporation step to separate vapors into individual components[7]. Evaporation differs from crystallization in that emphasis is placed on concentrating a solution rather than forming and building crystals[8]. Evaporators are categorized in three sections; a). Short tube vertical evaporator (Calandria evaporator), b).

Rising film (Climbing film) evaporator or vertical tube evaporator, c). Falling film evaporator and d). Forced circulation tubular evaporator. The liquid in a forced circulation evaporator is pumped using a motor through the tubes to minimize tube scaling or salting when precipitates are formed during evaporation[9]. Forced circulation evaporators are used in mining industry, and used to evaporate corrosive or highly viscous solutions. Forced circulation evaporators are efficient in transferring heat from steam to liquid, maintaining continuous liquid flow, low amount of salting, scaling and fouling[9]. These types of evaporators are used for the separation of sodium chloride, sodium sulphate, urea, ammonium sulphate, magnesium chloride, citric acid and caustic potash.

Published papers from 1986 to 1995 focused on the technical feasibility of forced crystallizers[10]. During 1995 to 2000 the researches have been focused on development of forced crystallizers. Since 2000, the published papers have been investigated the operating conditions which improved the thermodynamic efficiency and economics in order to make it more cost effective and competitive with other concentrating techniques such as heating desalination ponds, concentrating channels[10].

Totally, the crystallization is occurred when the saturated solution is changed to its supersaturated and this process can be achieved by solution evaporating.

This technique is an environmental friendly and cost saving process competitive with other concentrating techniques[10]. Therefore, the most industrial crystallizers are of the evaporative type and these types are used for more than 50% of the sodium chloride crystals production in the world. Since the most common evaporative type is the forced circulation (FC) model is selected for this study. Today's the studies regarding the performance of FCC are essential to evaluate the operating parameters of the FCC[10].

Published papers about the crystallization process on stream liquor from blender are rare, also.

The several effective parameters in performance of FCC are evaluated in this experimental work. So, the effect of the variation of flow rate of cooling water in condenser of FCC on quality properties of produced salt crystals such as size distribution and color are surveyed. Also, the level of energy consumption in each experiment is evaluated and the optimum value is introduced. A typical schematic of forced circulation crystallizer is shown in Figure 1.

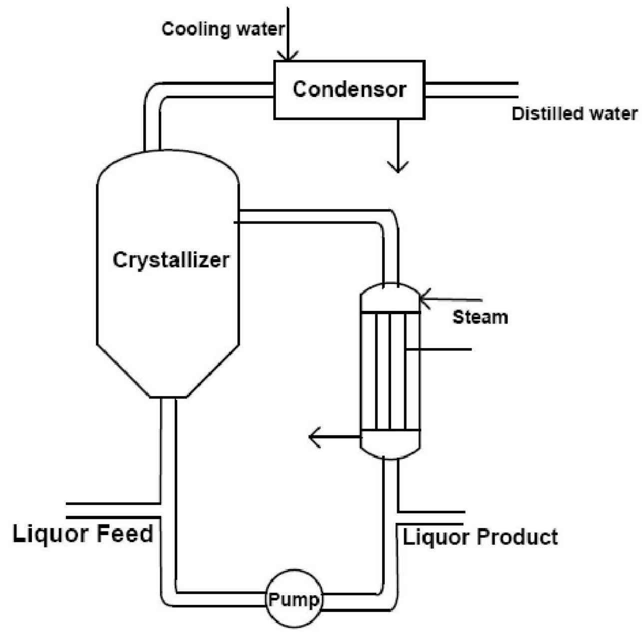

Figure 1 : A schematic of proposed FCC

MATERIALS AND METHODS

Experimental set up

The crystallizer is made of stainless steel and it's insulated to conserve the energy and thermometers record temperatures of suction and discharge lines of centrifugal pump, liquor of crystallizer and exit line of heat exchanger. A glass gauge demonstrates the level of liquor in crystallizer and a pressure gauge monitored the operating pressure and provides safety. Two electrical coils are used in heat exchanger as energy supplier and temperature can be set in different values. A condenser is situated on top of crystallizer to condense effluent vapors. The process of crystallization is used basically to separate minerals from their water solution, as the solution reaches saturation state. Crystallization is one of the pristine unit processes.

Methods

When the salinity percentage of brackish water in blender reaches to 20%, the brine is drained and blender is refilled with salt and water. Effluent liquor from blender as feed of crystallizer is pumped to heat exchanger and crystallizer, consequently. The circulation of liquor is done from the bottom of the crystallizer through the tubes of the vertical heat exchanger and then is heated and back into the crystallizer where evaporation occurs. Slurry is pumped through the tubes to decrease tube scaling or salting in a FCC when precipitates are formed during evaporation. Ultimately, the process of crystallization is used basically to separate minerals from their water solution, as the solution reaches saturation state. Crystallization is one of the pristine unit processes.

RESULTS AND DISCUSSION

Forced circulating crystallizer is one of the energy consuming equipments which are more applicable in industries. The amount and size of produced crystals, the amount of required energy and the amount of cooling water flow rate are important in determination of the process qualification. The amount of feed flow rate, operating pressure, operating temperature and the value of boiling point inside the crystallizer are considered as effective parameters on the process qualification. Studying the performance of the crystallizer is advantageous in finding the optimum operating conditions and predicting the process behavior. In this section the experimental results of the study are presented. The initial concentration of salt in feed is 0.3 kg/kg.

Cooling water flow rate of condenser

Constant amount of feed, 50 kg/hr at 27.11 C is used to investigate the amount of cooling water for the condenser. An optional double pipe concurrent condenser is set to cool the exit steam from the top of the crystallizer. Water flows in the outer pipe of the condenser as a cooling fluid at 17 C. The vapor condensation phenomena, decreases the pressure inside the crystallizer and also decreases the boiling point of liquor. So, the flow rate of cooling water affects the amount of crystal growth. Figure 2 shows the relation between these two parameters. The fraction of the amount of cooling water flow rate to the amount of crystals is between 2.3 to 3.1, approximately.

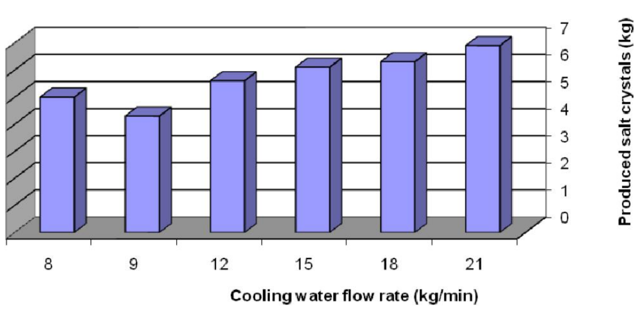

Figure 2 : The amount of produced salt versus the amount of cooling water

On the other hand, the condensate can be considered as the distilled water. In Figure 3 the amounts of produced distilled water versus the cooling water flow rate is shown. The increase in the amount of cooling water in the condenser about 13 kg/min increases the amount of condensate from 15 kg to 24.8 kg and produces the higher amount of distilled water. The required amount of cooling water due to the amount of feed can be known according to the experimental results shown in Figure 4. This is applicable in designing and performance evaluation of a crystallizer.

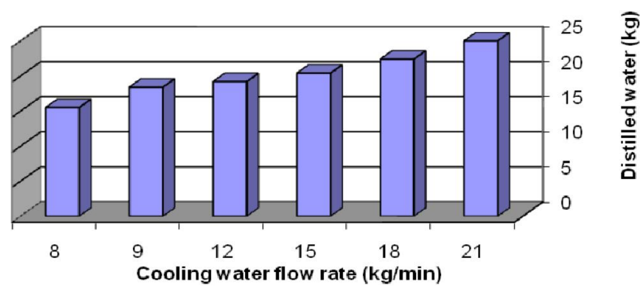

Figure 3 : The amount of distilled water versus the amount of cooling water

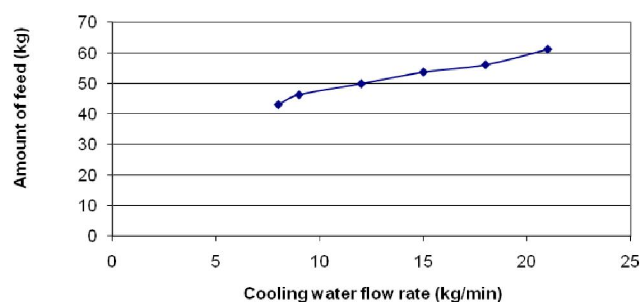

Figure 4 : Relation between the amount of feed and the amount of cooling water

Feed temperature

The amount of required energy to make the liquor to be saturated is dependant on the feed temperature. The lowest amount of consumed energy is obtained at 26.7 C according to the experiments according to Figure 5. pH of the produced liquor doesn't change roughly comparing with the pH of the feed liquor. However, changing temperature changes the pH according to Figure 6. At the proper 26.7 C of feed temperature the pH value is 10.5 and 11 for the feed and the product liquor, respectively.

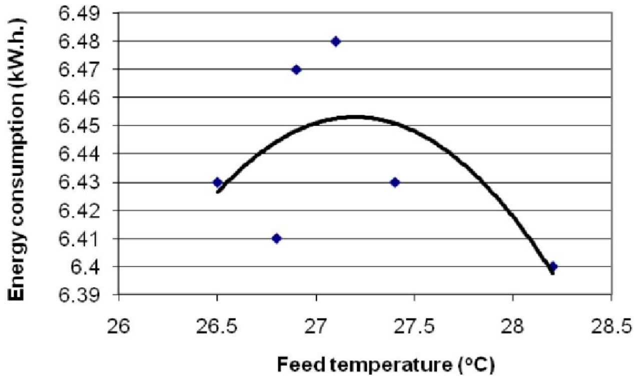

Figure 5 : The amount of energy consumption versus feed temperature

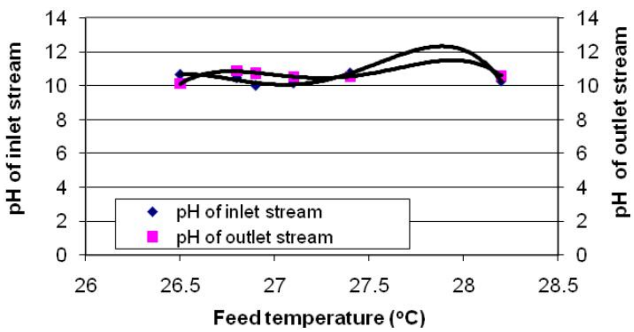

Figure 6 : pH values of feed and product versus feed temperature

Boiling temperature

The effect of boiling temperature on the rate of vaporization is shown in Figure 7. With the constant amount of feed the higher boiling temperature, produces lower amount of vapor at each minute. Also, the cream crystal is produced at temperatures higher than 89.2 C and the lower quality is gained. The best mode of production is at 85.5 C which with lower boiling temperature, higher vaporization rate and white crystal is produced.

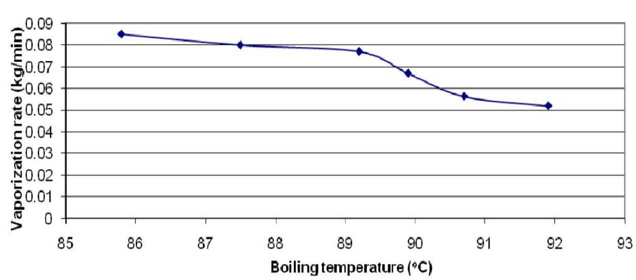

Figure 7 : The rate of vapor versus boiling temperature

Operating pressure

Decreasing the operating pressure inside the crystallizer, reduces the water vapor partial pressure above the liquor and helps the faster vaporization at lower temperature. So, the lower amount of energy is required in heat exchanger to boil up the recycled liqour. Vaccum pump is used to decrease the inside pressure of the vessel due to the stability of vessel. The relation between the operating pressure and the amount of energy consumption is shown in Figure 8. The minimum amount of energy consumed in the heat exchanger is 6.3 kW.h. at 66 kPa operating pressure.

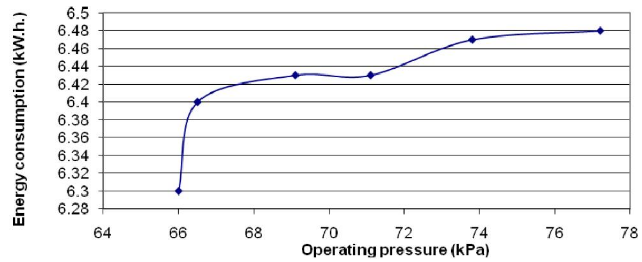

Figure 8 : Heat exchanger required energy versus operating pressure

Size and amount of produced crystal

The size of produced crystal is important in determination of the production quality. At the proper 85.5 C which produces white crystal the size of crystal is in range of 675- 795 micrometer. Figure shows the effect of boiling temperature on the size range of produced crystal. At this proper range, the highest amount of crystal is produced. The relation between the size and the boiling temperature is obtained in Figure 9.

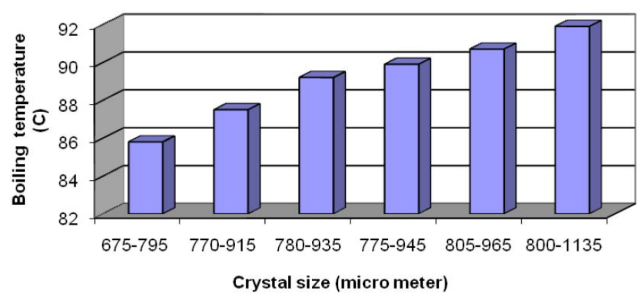

Figure 9 : Boiling temperature versus crystal size

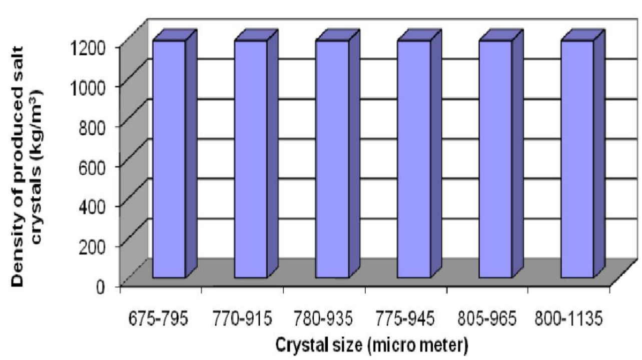

Figure 10 : Density of salt crystal versus crystal size

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Although the value of density of produced crystal doesn't change with the range of crystal size. This is indicated in Figure 10.

Figure 11, shows the dependency of the produced salt crystals on the amount of energy consumption by the heat exchanger.

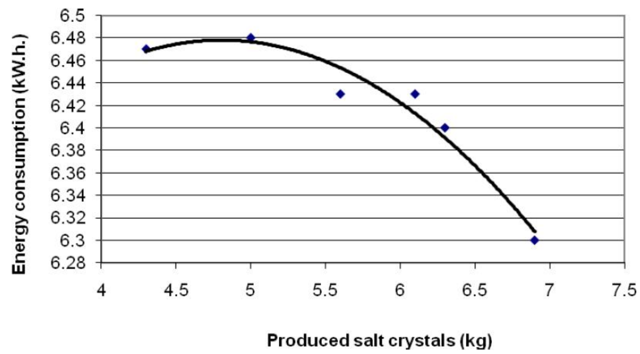

Figure 11 : Energy consumption related to the amount of product

CONCLUSIONS

In this study, the operating parameter which is important in one forced circulating crystallizer which is equipped with a condenser is considered. Results are applicable as rules of key in designing and optimization purposes. Relations between the amount of feed, amount of cooling water, amount of produced crystal, vaporization rate, distilled water, crystal size, operating pressure, operating temperature and the amount of energy consumption in the heat exchanger are investigated experimentally and reported as graphs. According to the surveys, white salt crystals with size growth of (675-795) is produced at operating temperature of 85.8 C when the vaporization rate is 0.085 kg/min. The lowest value of consumed energy is obtained 6.4 kW.h. when 6.3 kg salt is produced.

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