Fin Efficiency of Spiral Finned Crystallizer for Progressive Freeze Concentration System

Shafirah Samsuri  
Faculty of Chemical Engineering  
Universiti Teknologi Malaysia  
Skudai, Johor  
shafirahsamsuri@gmail.com

Mazura Jusoh  
Faculty of Chemical Engineering  
Universiti Teknologi Malaysia  
Skudai, Johor  
mazura@cheme.utm.my

Abstract—Progressive freeze concentration (PFC) has been proven to be a viable technology for concentration of liquid solution. In this study, fin efficiency of spiral finned crystallizer for PFC system is investigated. Spiral fin has been evaluated as a potential additional surface in the crystallizer for progressive freeze concentration. The addition of spiral fin was introduced in order to further improve the productivity of the ice crystal. The result shows that the value of fin efficiency is 0.98 which is nearly equal to 1. This value indicates that the introduction of fin is appropriate. Moreover, the result indicates that the size of fin is also suitable for the crystallizer. The attachment of the spiral fin to the crystallizer can give advantages to the process especially for high productivity of product.

Keywords—Freeze concentration, progressive freeze concentration, fin efficiency, design, crystallizer.

I. INTRODUCTION

Concentration process basically consists of water removal to reduce weight and volume of solution products. It is mainly carried out by using evaporation, reverse osmosis (RO) and freeze concentration (FC). Evaporation uses large amount of energy to supply heat for vaporization of water especially for low concentration solution and not suitable to concentrate solution with volatile organic compound. RO uses least amount of energy because it involves no phase changes. However, clogging of membrane can easily occur and this requires high cost for membrane replacement and osmotic pressure needed. The FC process is a great alternative to evaporation and RO for concentration of many liquid foods.

During FC process, liquid becomes more viscous when its temperature gets lower, and ice crystal will form when the liquid starts to freeze [1]. It offers some advantages in product quality, aroma retention and product yields. Product quality is usually high since low temperatures are used to produce ice crystals, which later can be removed. However, very expensive initial investment still limits its use in many potential applications. So far, the only method used for FC is by suspension freeze concentration (SFC). In SFC, small ice crystals are formed and removed from mother solution. In contrast to SFC, another method which is progressive freeze concentration (PFC) has been investigated in which only a single ice crystal is formed in the system as a layer or block on the cooling surface. This makes separation between ice crystal and concentrated solution becomes much easier than SFC. In addition, the system becomes simpler and cheaper comparatively [2]. Illustration of ice crystal formation in SFC and PFC is shown in Figure 1.

In the development of PFC, many processes and systems have been studied and designed. Many efforts have been established to improve the PFC system where it is proven that it can be used for concentration of fruit juices, wastewater, pharmaceutical and sea water. However, some of the existing PFC system have some weaknesses such as low productivity of the product [3], consists of many equipments [4] and had too long of process time [5]. Although PFC is shown to be effective for the production of high quality of the products, its productivity is still lower than SFC. All of this encouraged the researchers to find a good method for obtaining higher quality of ice crystal with higher productivity. As an alternative to these problems particularly to the low

![Figure 1. Illustration of (a) suspension freeze concentration (b) progressive freeze concentration](image-url)
productivity problem, a new spiral finned crystallizer has been built for the PFC system, in which the ice crystal grows on the inside wall of the crystallizer.

To build a new design in the PFC system, effective heat transfer should be emphasized since the heat transfer plays an important role in the production of ice crystal. Thus, the efficiency of the PFC system will be high. Heat is transferred from one solution to another solution through a wall. The rate of heat flow is directly proportional to the difference of temperature between the two solutions and to the product of overall heat transfer coefficient and the contact surface area for heat transfer. The temperature is changing because of the heat transfer from the hot solution to the cold solution. The temperature of the solution changes more rapidly at high heat transfer rate compared to low rate of heat transfer.

Besides the temperature difference, surface area also affects the rate of heat transfer. The surface area can be added by the addition of fin [6]. Fin is used as an extended surface to improve the heat transfer performance. Moreover, increasing surface area for heat transfer will reduce the resistance. Although the theory and practice of fin has been widely studied by many researchers for different applications of heat exchangers, the efficiency of fin in the crystallizer has not been studied.

The principal aim of this paper is to discuss the fabrication of the spiral finned crystallizer for the PFC system. Then, the newly fabricated spiral finned crystallizer was evaluated in terms of fin efficiency.

II. METHODOLOGY

A. Equipments

According to literature, several considerations need to be used in order to design a new crystallizer. Construction material, surface area, solution movement, sampling accessibility and temperature profiling are the important factors to certify that the crystallizer works well [7]. Suitable and exact selection, sizing and placing of these factors onto the new crystallizer must be performed in order to get the best performance.

The new crystallizer named as spiral finned crystallizer is equipped with spiral fin and covered with cooling jacket. Cylindrical shape was chosen for this new crystallizer. Stainless steel was chosen as the construction material for the new crystallizer and cooling jacket because it has high resistance towards corrosion by some compositions in the solution [8]. Its thermal conductivity is also suitable as a material that would be involved in heat transfer. Moreover, many researchers have used stainless steel for the fabrication of their PFC system such as [3], [9], [10], [5], [11], [12] and [13].

According to Miyawaki et al. [14], the productivity can be easily increased simply by increasing the contact surface area between solution and coolant. The heat transfer will be enhanced with the increase of contact surface area. By generating this idea, the spiral fin was built in this crystallizer for the purpose of making bigger contact surface area. Figure 2 shows the schematic diagram of the spiral finned crystallizer. Generally, this crystallizer is in a cylindrical shape and is attached with rectangular shaped fin. Fins are positioned at the inner wall of the crystallizer in a spiral form.

The apparatus is composed of straight cylindrical vessel with 8 cm in diameter and 30 cm long, spiral fin with 2 cm height, 2 cm width and 201.06 cm long, cooling jacket with 2 cm width and inlet and outlet streams for solution and coolant. By addition of the spiral fin, surface area is increased to 107.73%. This value was obtained by comparing the surface area between spiral finned crystallizer and cylindrical crystallizer without fin.

Cooling jacket covers the crystallizer for cooling purpose. Coolant will be circulated around the cooling jacket by using a peristaltic pump (757300-55, Masterflex, USA). In order to minimize heat transfer from the environment, the crystallizer is insulated by polyurethane foam. Polyurethane foam gives minimization of heat loss due to its low thermal conductivity value, high strength to weight ratio and low cost of material.

The thermocouples are engaged at the crystallizer for temperature profiling purpose. The thermocouples are connected to PicoLog (USB TC-08, UK) data acquisition software which is plugged to a computer. The temperatures were displayed through a connected computer.

B. Fin Efficiency Calculations

In order to determine whether the fin is created efficiently or not for the crystallizer, calculation of fin efficiency was carried out. According to Geankoplis (2003), fin efficiency can be calculated through equations 1 and 2 and the graph in Figure 3.

\[
L_c = L + t/2
\]  

\[
L_c = (h/kt)^{1/2}
\]

III. RESULT AND DISCUSSION

The issue to be discussed is of great importance because of the need to increase the heat transfer from solution to the coolant. In this paper, the surface area has been highlighted for the increment of heat transfer. This surface area is the area
where heat is being transferred. For instance, the size of the window at home affects the heat transfer through the window. More heat will be lost through a larger window than through a smaller window with the same material, insulation and thickness. Larger area has more particles working to conduct heat. Thus, heat transfer is directly proportional to the surface area of which the heat is conducted.

For the purpose of increasing the surface area, spiral fin was introduced in the crystallizer. This surface area is the area of contact surface between solution and coolant. With the help of stainless steel as a material of the construction in the crystallizer, the contact surface area can really affect the heat transfer. One of the methods to increase the contact surface area is by adding the fin to the system as an extended surface. Currently, finned walls are employed in heat exchange devices for the increment of heat transfer rates [16]. In order to evaluate the performance of fin for the crystallizer, fin efficiency was determined.

The spiral fin is made of stainless steel (k = 17 W/m.K). The length of the fin is 2 cm and the thickness is also 2 cm. The ethylene glycol has a convective coefficient of W/m².K. A close-up of the spiral fin with the dimension is shown in Figure 4. Calculation of the fin efficiency is as follows:

\[ L = 2 \text{ cm}, \ t = 2 \text{ cm}, \ h = 0.43 \text{ W/m}^2\text{K}, \ k = 17 \text{ W/m.K} \]

\[ L_f = L + t/2 = 0.02 + 0.02/2 = 0.03 \text{ m} \]

\[ L_c(h/kt)^{1/2} = 0.03(0.43/(17)(0.02))^{1/2} = 0.034 \]

Using figure 3a, \( \eta_f = 0.98 \).

According to the calculated value of the \( \eta_f \), this value is approaching 1 which indicates that its efficiency is near to 100% efficiency. The value of \( \eta_f \) is satisfactory and spiral fin can be applied in this crystallizer. This value also shows that the spiral fin is suitable enough to be attached in the crystallizer. Its dimension is also correct and has a good ratio between thickness and length.

Referring to the excellent value of \( \eta_f \), this shows that fin plays a role in the PFC system to enhance its performance. Adding spiral fin to the crystallizer in the PFC system increase the surface area and can sometimes be an economical solution to heat transfer problems. Spiral fin appears as an interesting way to improve heat transfer in PFC process especially to overcome productivity limitations.

It can be a possible solution for productivity enhancement in PFC system. The idea of the attachment of the spiral fin to the crystallizer is a novel idea that can be applied to the other heat exchange equipments.

IV. CONCLUSION

The fin efficiency of spiral finned crystallizer is calculated and analyzed in this work. It was found that the fin efficiency is high at 0.98. The addition of spiral fin to the crystallizer can increase the efficiency of heat transfer and this increase will provide significant advantages in terms of the productivity of the product. This work shows that the spiral fin is significant enough to be attached in the crystallizer for PFC system.

ACKNOWLEDGMENT

This work is supported by the Government of Malaysia and Universiti Teknologi Malaysia.

REFERENCES


