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RESEARCH ARTICLE

DESIGN SENSITIVITY ANALYSIS OF EVAPORATOR USING CHEMCAD

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ABSTRACT

CHEMCAD can perform complex design sensitivity analysis in short time, record and recall information with consistency and speed. One of the important process activities in chemical engineering is the concentration of the liquor in an evaporator. Parameters that determine the performance of a calandria evaporator are outlet concentration of liquor and steam economy. These parameters are studied by performing variations in designing parameters of the calandria evaporator using CHEMCAD. The simulation is performed by changing designing parameters such as number of tubes, inner diameter of tubes and length of tubes. All these simulations are carried out at different feed temperatures. Design sensitivity studies can be used to identify the role of important design parameters and to propose an optimal setup also. This paper presents a systematic approach for design sensitivity analysis of calandria evaporator by changing design parameters. An increase in the outlet concentration of liquor and steam economy of evaporator with the rise in number of tubes, inner diameter of tubes and length of tube has been observed. These two parameters also increase with increase in feed temperature.

INTRODUCTION

Use of computer-aided design (CAD) does not change the nature of the design process but as the name states it aids the product designer. Softwares providing such facilities include Aspen HYSYS, CHEMCAD, Aspen Plus, HTRI Xchanger Suite etc (Bilalis, 2000). CHEMCAD is a powerful and effective software tool for chemical process simulation. It uses an integrated module called CC-THERM for the designing of heat exchangers (Chemstations, Inc., 2007). Evaporators are integral part of a number of process industries. Evaporators are kind of heat transfer equipments where the transfer mechanism is controlled by natural convection or forced convection. Calandria evaporator consists of short tube bundle enclosed in a cylindrical shell, which is called as calandria. A solution containing a desired product is circulated through tubes inside the evaporator and it is heated by a heat source like steam which is fed to the calandria (Coulson and Richardson, 1999). Design sensitivity analysis is used to obtain the sensitivity of various aspects of a design model with respect to changes in design parameters in order to facilitate structural modifications (Kaya *et al.*, 2015). This paper presents a systematic approach for design sensitivity analysis of calandria evaporator by changing design parameters for different feed temperature. Basically, calandria evaporator is fed with 5000 kg/h NaOH solution containing 10% solute by weight. The feed at 313K is to be concentrated to NaOH solution containing 40% by weight of the solute under an absolute pressure of 101.325 kPa. Steam is available at pressure of 303.975 kPa (saturation temperature of 407K) and the overall heat transfer coefficient is 1750 W/(m^2 K) (Gavhane, 2011). In this work, the variation in the outlet concentration of liquor and steam economy of evaporator is investigated with respect to changing parameters such as number of tubes, inner diameter and length of tubes.

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Procedure

A simulation of the calandria evaporator was performed in CHEMCAD according to the specifications mentioned in Table 1. On the CHEMCAD user interface, a flow sheet was generated using the HTXR heat exchanger (calandria evaporator) as shown in Figure 1. Sodium hydroxide slurry has to be concentrated in the calandria evaporator. However, slurry flows through the tubes and steam through calandria. For the rigorous simulation, CC-THERM is called up at "Sizing: Heat Exchangers". The calandria evaporator is specified with different parameters in the setting windows as mentioned in the above table. Thus, a simulation is run for calandria evaporator data. Simulations for variations in the values of calandria evaporator specifications were then performed and the results were compared with the basic simulation. The variation included change in number of tubes as 182,192, 202, 212, inner diameter of tubes as 0.043m, 0.044m, 0.045m, 0.046m, 0.047m and length of tubes as 1.5m, 1.48m, 1.52m, 1.54m. And all these variation studied at different feed temperatures as 298K, 303K, 313K, 323K, 333K. Every specification was changed for above values keeping the others constant.

Table 1: Geometric data of the calandria evaporator

Specifications	Value
Design	TEMA R
Material	Carbon Steel
Tube Outer Diameter	0.05 m
Tube Wall Thickness	0.002 m
Tube Length	1.5 m
Tube Pattern	Triangle (30°)
Tube Pitch	0.063 m
Shell Diameter	1.15 m
Tube and Shell Fouling	0.000176 m^2K/W
All Nozzle Diameter	0.1 m
Shell to Outer Tube Limit Clearance	0.07m

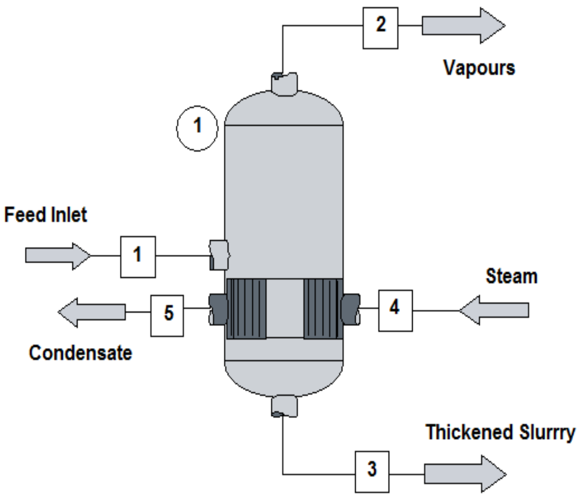

Figure 1. Schematic for Calandria Evaporator

The outlet concentration of liquor is given in terms of percentage of NaOH in the thickened slurry coming out of the evaporator. Steam economy of evaporator is the ratio of amount of water evaporated to the amount of steam fed to the evaporator. However, at different temperature of feed graphs are plotted with variations in number of tubes, inner diameter of tubes and length of tubes. Differences in the values of outlet concentration of liquor and steam economy of evaporator were studied and graphs were plotted.

RESULTS AND DISCUSSION

Effect of Number of Tubes

Figure 2 and Figure 3 depicts the outlet concentration of liquor and steam economy, respectively, against number of tubes at constant inner diameter of tubes of 0.046m and length of tube of 1.5m. Curves for different values of feed temperatures are 298K, 303K, 313K, 323K, 333K are plotted. It was observed that as the number of tubes increases at different feed temperatures, the outlet concentration of liquor and steam economy increases rapidly. The increase in number of tubes increases the available surface area for heat transfer. As a result, more heat will be transferred from the steam to the liquor through the tubes. Thus, as the temperature of liquor increases, the evaporation of water increases which results in increasing concentration of the liquor as well as steam economy. The more the feed temperature, the less will be the difference between the boiling point of feed and it's temperature. So, the heat required will be less to take the feed to its boiling point at higher feed temperatures. Therefore, with increase in feed temperature, outlet concentration of the liquor and steam economy increases.

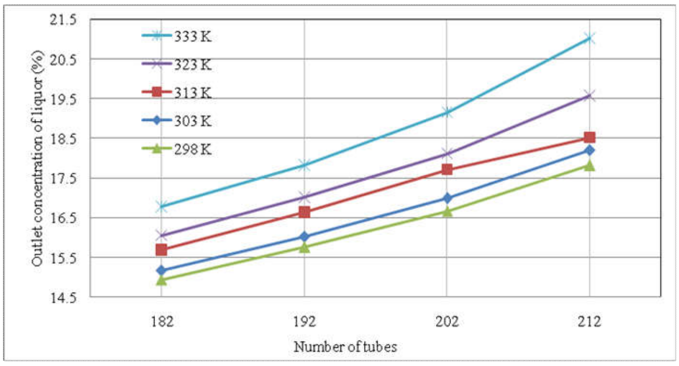

Figure 2. Outlet concentration vs number of tubes at different feed temperature

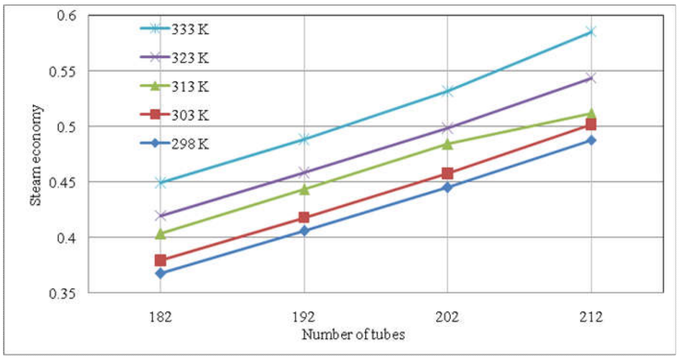

Figure 3. Steam economy vs number of tubes at different feed temperature

Effect of Inner Diameter of Tube

Figure 4 and Figure 5 represents the outlet concentration of liquor and steam economy, respectively, against inner diameter of tube at constant length of tube of 1.5m and number of tube of 192 tubes. Outer diameter of tube is also kept constant at 0.05m. Curves for different values of feed temperatures are 298K, 303K, 313K, 323K, 333K are plotted. It was observed that as the inner diameter of tube increases at different feed temperatures, the outlet concentration of liquor and the steam economy increases. The increase in inner diameter of tube at constant outer diameter of tube decreases the thickness of tube, reducing resistance to the heat transfer. So, the increase in heat of the liquor will obviously increase the liquor temperature. As the temperature of liquor increases, the evaporation of water increases that result in increase in the concentration of the liquor and steam economy also. The more the feed temperature, the less will be the difference between the boiling point of feed and it's temperature. So, the heat required will be less to take the feed to its boiling point at higher feed temperatures. Therefore, with increase in feed temperature, outlet concentration of the liquor and steam economy increases.

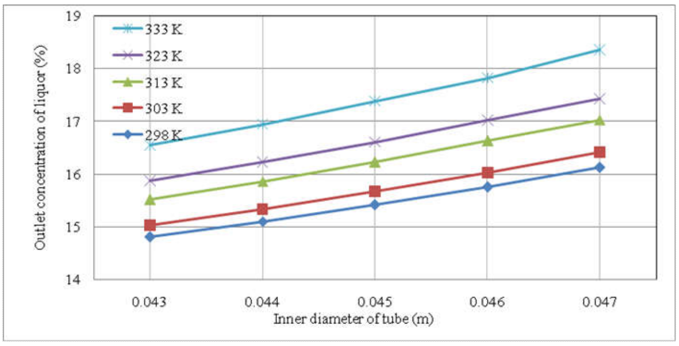

Figure 4. Outlet concentration vs inner diameter of tube at different feed temperature

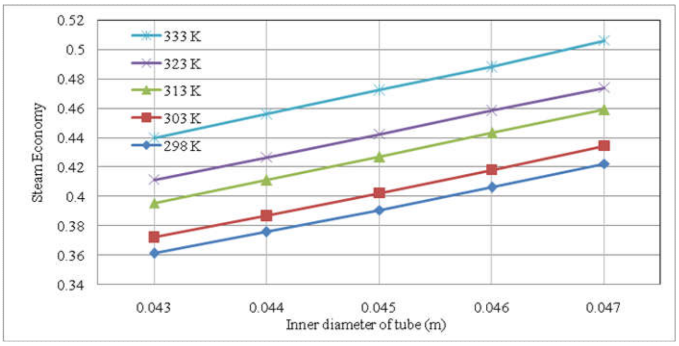

Figure 5. Steam economy vs inner diameter of tube at different feed temperature

Effect of Length of Tube

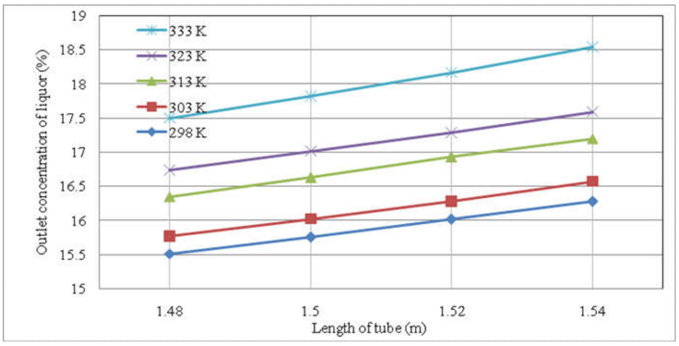

Figure 6. Outlet concentration vs length of tube at different feed temperature

Figure 6 and 7 shows the outlet concentration of liqu ******* steam economy respectively, against length of tube at constant inner diameter of tubes of 0.046m and 192 tubes. Curves for different values of feed temperatures are 298K, 303K, 313K, 323K, 333K are plotted. It was observed that as the length of tube at different feed temperature increases, the outlet concentration of liquor and the steam economy increases. The increase in length of tube increases the available surface area for heat transfer. As a result, more heat will be transferred from the steam to the liquor through the tube.

As the temperature of liquor increases, the evaporation of water increases giving an increased concentration of the liquor and steam economy also increases. The more the feed temperature, the less will be the temperature difference between it and the boiling point. So, the heat required will be less to take the feed to its boiling point at higher feed temperatures. Thus, outlet concentration of liquor and steam economy increases with increases in feed temperature.

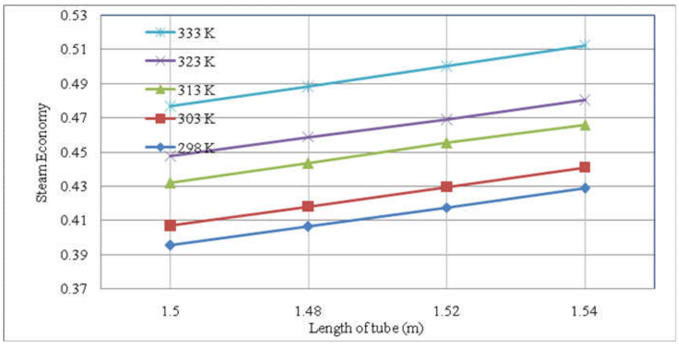

Figure 7. Steam economy vs length of tube at different feed temperature

Conclusion

Simulation for a calandria evaporator was carried out and evaluated using the CHEMCAD software. For changing design parameters (number of tubes, inner diameter of tubes and length of tubes at different feed temperature), a design sensitivity analysis is done for investigating the influence of outlet concentration of liquor and steam economy. It was observed that the outlet concentration of liquor and steam economy of evaporator increases with increase in number of tubes, inner diameter of tubes and length of tube. As the feed temperature increases for each change in design parameters, the outlet concentration of liquor and steam economy of evaporator also goes on increasing.

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