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Performance Investigation of Plate Type Heat Exchanger (A Case Study)

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Abstract:
Heat exchanger is a thermodynamic system which is most commonly used in the process industry for exchanging heat energy between the fluids. flowing in the same or opposite direction. It is desired that effectiveness of heat exchanger should remain as large as possible. Heat exchanger's performance may be improved by the addition of fins or corrugations. These investigations include design of plate type heat exchanger, heat transfer enhancement, flow phenomenon and cleanliness factor. In process plants, this type of heat exchange is generally used for recovering heat content of exhaust steam. However, with the flow of fluid for a long period, fouling occurs on the plate surface. Therefore, it is required to investigate the effect of fouling, wherever the heat exchanger is installed. An extensive experimental investigation has been carried out under clean and dirty condition of the said plate type heat exchanger. Heat transfer and flow data were collected in experiment. From collected data heat transfer rate, overall heat transfer coefficient, fouling factor and cleanliness factor were evaluated. Based upon the cleanliness factor data, next date of cleanliness for plate type heat exchanger was predicted. It is felt that the outcome of the present research work may be quite useful for efficient operation of plate type heat exchanger installed in Process plants.
***Key Words**: Plate type heat exchanger, Fouling factor, Cleanliness factor*

NOMENCLATURE

A Cross sectional area, m^2
b Mean flow channel gap, m
C_p Specific heat of water, KJ/kg K
CF Cleanliness factor
FF Fouling factor, m^2 K/W
$\dot{m}$ Mass flow rate, kg/s
Q Heat transfer rate, kJ/s
r_a Aspect ratio, dimensionless
T Temperature, °C
w Width of flow channel, m
β Chevron angle, degree
λ Corrugation pitch, m

I. INTRODUCTION

Heat exchanger is one of the most commonly used equipment in process industry. The function of a heat exchanger is to exchange heat energy between the flowing fluids in the same or opposite direction. It is desired that the effectiveness of a heat exchanger should remain as large as possible. Plate type heat exchanger (PHE) was first commercially introduced in 1920's in order to meet hygienic demands of dairy industry (Seligman, 1963 and Carlson, 1992), while some patents existed as early as in 1870's in Germany (Clark, 1974). Design of this type of plate heat exchanger reached maturity in 1960's with development of more effective plate geometries, assembly and improved gasket material and range of possible applications has widened considerably (Kakac and Liu, 2002). PHE's are now a day widely used in a broad range of heating and cooling applications in food processing, chemical reaction processes, petroleum, pulp and paper, as well as in many water chilling applications. Some basic features of plate type heat exchanger include high efficiency and compactness, high flexibility for desired load and pressure drop, easy cleaning and cost competitiveness. Before 1990's such applications were mostly in fields of concentrating liquid food and drying of chemicals. Applications in refrigeration systems were rare, mainly because of concerns over refrigerant leakage and also because of pressure limits required, especially for condensation applications. In the last two decades with the introduction of semi welded and brazed plate type heat exchanger, this type of exchange has been increasingly used in refrigeration systems, for domestic heat pumps for large ammonia installations for water chilling. Heat exchangers, including plate type heat exchanger and other types, are designed and employed according to two criteria i.e. heat transfer and pressure drop. Based on fouling mechanism, it is shown that a satisfactory prediction of the fouling behavior of heat exchangers is not yet possible. This contribution presents a physical model for description of fouling, caused by sedimentation and crystallization. In order to verify theoretical considerations, experiments were carried out on a test rig, which could also be used for field experiments (Bohnet et al., 1987). Fouling and to a lesser extent corrosion and their minimization are key priorities during life of many heat exchangers. Particularly those in process industry duties and these aspects should never be neglected during life of heat exchanger (Hesselgreaves and Reay, 2001). Performance of heat exchangers degrades with time due to fouling or deposition of material on heat transfer surfaces. The fouling of critical heat exchangers in manufacturing plants results in a significant cost impact in terms of production losses, energy efficiency and maintenance costs. While most plants monitor their exchangers to some degree ability to effect real and sustainable improvements requires four components i.e. real time monitoring advance warning mechanism, ability to diagnose cause of fouling, ability to treat cause in order to slow or reverse degradation(Prasad et al., 2005). The rate of fouling is highly dependent on properties of crude blends being processed as well as operating temperature and flow conditions. A predictive model using statistical methods was developed which can predict rate of fouling and decrease in heat transfer efficiency in a heat exchanger (Radhakrishnan et al., 2007). This makes it possible to evaluate fouling induced reduction in recovering an energy flow. The crucial assumption is that measurements of mass flow rate and inlet and outlet temperature and chemical composition are available for each process stream, method of identification of influence of fouling on heat recovery in a heat exchanger network. The method is based on mathematical models, enabling the interpretation of industrial measurements of operating parameters of the heat exchange network. (Markowski et al., 2013). Fouling experiments including particulate fouling tests and composite particulate and precipitation fouling tests have been performed. The tests are primarily focused on effects of concentration and average velocity. Scanning electron microscope (SEM) was used to investigate microscopic structures of composite fouling. Heat transfer coefficients and friction factors have been obtained in clean tests. The plate heat exchanger with largest d_e and height to pitch ratio shows best anti fouling performance (Zhang et al., 2013).

In purpose of experimental investigation in this paper, overall heat transfer coefficient and fouling factor are calculated for plate type heat exchanger. According cleanliness factor has been evaluated for predicting the next date of cleanliness based upon the findings reported by Prasad et al. (2005).

II. EXPERIMENTAL SET-UP

Experimental set-up consistst a plate type heat exchanger, insulated hot water storage tank, control valves, condensate steam bucket valve, pump, filter and appropriate instrumentation for collecting the data.

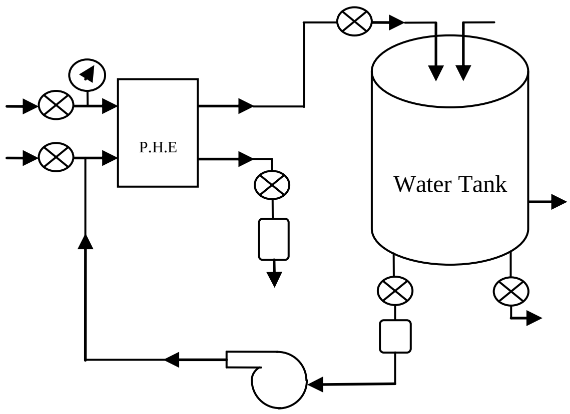

Fig.1: Schematic of experimental set-up.

The corrugated type stainless steel plates of the plate type heat exchanger allow the flow of steam water through V-shape channels in a counter flow manner. The plates remain sealed with gasket in order to prevent water and steam leakage. The hot water from a plate type heat exchanger was supplied to the insulated tank through a pipeline. The storage tank was provided with a thermocouple for measuring temperature of hot water in the tank. A Variac is provided in order to control power supply to the centrifugal pump. Stainless steel made pipeline was used to make a supply of steam and water throughout the system. It was properly insulated in order to minimize the heat loss. Data was required for temperature measurement at inlet/outlet port of water and steam, mass flow rate of water and pressure of steam in plate type heat exchanger.

III. DATA POCESSING

Heat transfer rate, Overall heat transfer coefficient, Fouling factor, Cleanliness factor of plate type heat exchanger during clean and dirty condition was calculated by using the following equation:

$$U = \frac{Q}{A\Delta T_{LMTD}} \quad (1)$$

$$FF = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}} \quad (2)$$

$$CF = \frac{U_{dirty}}{U_{clean}} \quad (3)$$

Next date of cleaning for plate type heat exchanger was predicted based upon the threshold limit cleanliness factor (CF) reported by Prasad et al. (2005).

IV. RESULTS AND DISCUSSION

Results obtained w.r.t. heat transfer rate (Q), overall heat transfer coefficient (U), fouling factor (FF) and cleanliness factor (CF) under the said experimental investigation have been presented.

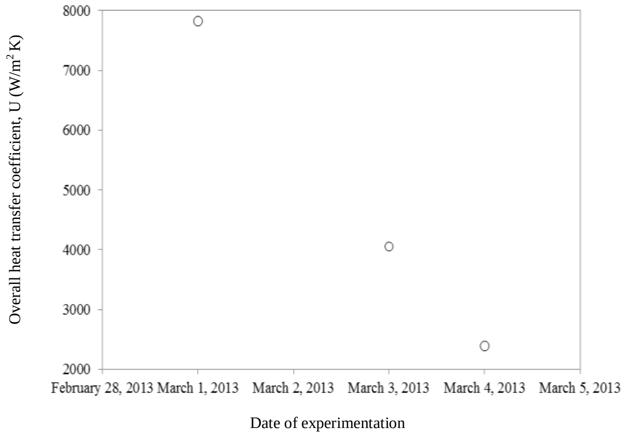

Fig. 2: Variation of overall heat transfer coefficient (U) with use of PHE.

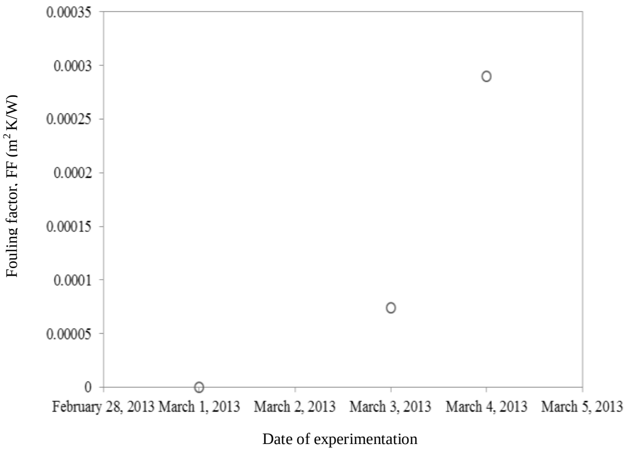

Fig. 3: Variation of fouling factor (FF) with use of PHE.

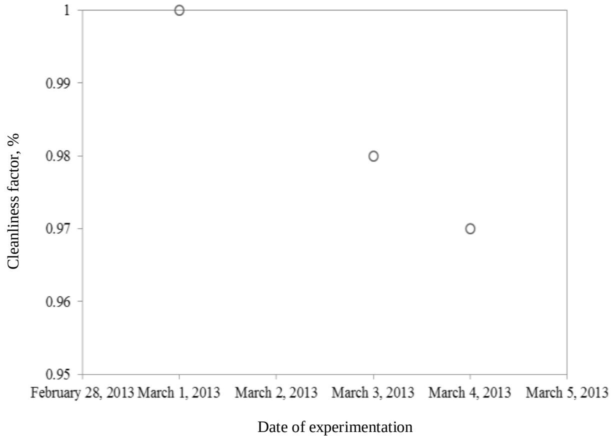

Fig. 4: Variation of cleanliness factor (CF) with use of PHE.

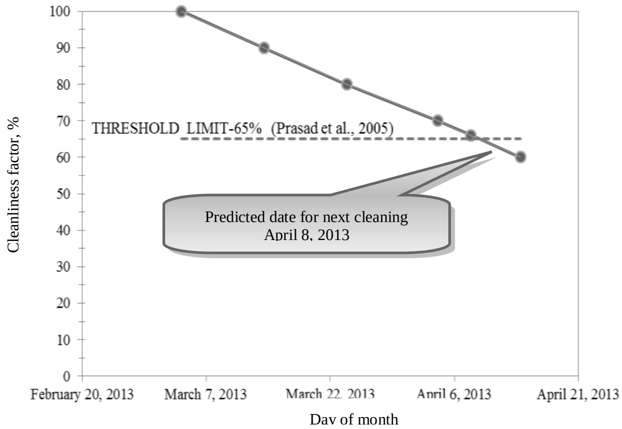

Fig. 5: Prediction of next date of cleaning for plate type heat exchanger.

Next date of cleaning for plate type heat exchanger was predicted by using variations of cleanliness factor (CF) from clean to dirty condition. Based upon the experimental data available in first set of experiment for cleanliness factor, number of days has been predicted for cleanliness factor of 0.65 as reported by Prasad et al. (2005).

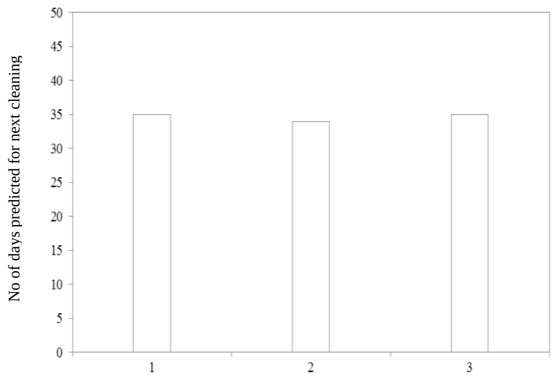

Fig. 6: Comparison of number of days predicted for next cleaning of plate type heat exchanger.

Number of days for next cleaning have been found in first, second and third set of experiment as 35,34 and 35 respectively. It can be noted that during three sets of experiments, the number of predicted days almost remained the same for the next cleaning of plate type heat exchanger.

V. CONCLUSIONS

This study investigated the performance of a plate type heat exchanger. Based on a case study, the following conclusions were deduced:

- Heat transfer rate decreased monotonously with use of heat exchanger i.e. from clean to dirty condition. Heat transfer rate may have decreased due of thermal resistance created by fouling on surface of plate type heat exchanger.
- Overall heat transfer coefficient decreased with use of heat exchanger i.e. from clean to dirty condition. Fouling on the surface of plate type heat exchanger may be responsible for decreasing overall heat transfer coefficient from clean to dirty condition.
- Fouling factor increased monotonously with use of heat exchanger i.e. from clean to dirty condition. Increase in fouling factor from clean to dirty condition is due to decrease in overall heat transfer coefficient from clean to dirty condition.
- Cleanliness factor decreased monotonously with use of heat exchanger i.e. from clean to dirty condition. Decrease in cleanliness factor is due to decrease in overall heat transfer coefficient from clean to dirty condition.
- Based upon the experimental data available in first set of experiment for cleanliness factor, number of days has been predicted for cleanliness factor of 0.65 as reported by Prasad et al. (2005) almost remain the same for next cleaning of plate type heat exchanger.

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