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INVESTIGATION OF THERMAL PERFORMANCES OF THE PLATE TYPE HEAT EXCHANGER OF THE BAEC 3 MW TRIGA MK-II RESEARCH REACTOR

M. S. Islam, M.M. Uddin, A. Haque, M. A. Salam, M. M. Haque and M.A. Zulquarnain

Reactor Operation and Maintenance Unit (ROMU) Atomic Energy Research Establishment, Savar, Dhaka
Email: romu@dhaka.net

ABSTRACT

Plate type heat exchanger offers very good heat transfer characteristics in single-phase flow rather than shell and tube one. Part of the reason is the small hydraulic diameters, typically being less than 5 mm. Other advantages of plate type heat exchangers are the extremely compact design and the efficient use of the construction material. In spite of their good heat transfer performances, it is necessary to evaluate the performances of the plate type heat exchanger under the operating conditions. The purpose of this article is to investigate the operational performances of the 4 MW plate type heat exchanger having 151 plates after its 6 years operation which is connected with the cooling systems of the reactor. It has been found that secondary water properties such as EC, TDS, and receptivity play an important role over the thermal performances of the plate type heat exchanger. From the performance analysis, it is clear that performance of the heat exchanger has been degraded gradually due to the secondary raw water chemistry, environmental dirts and algae and bacterial growth. The operating and design thermal efficiencies have differed significantly for the last six years and is found to be about 45 % and 67 %, respectively. The operating performance of the plate type heat exchanger can be restored at the expected level by ensuring proper maintenance as well as preventive maintenance works to be done on secondary water system.

Keywords: Single-phase flow, Small hydraulic diameter, Operational thermal performances, Preventive maintenance work

1. INTRODUCTION

The 3 MW TRIGA MK-II research reactor of Bangladesh Atomic Energy Commission has been operating since September 14, 1986. The primary and secondary cooling system had been incorporated by shell & tube type heat exchanger. The shell and tube type heat exchanger lost its efficiency due to scale formation in the shell side (secondary coolant side). As mechanical cleaning was not possible in the shell side that is why chemical cleaning/wash was performed to recovery the lost efficiency of the shell and tube type heat exchanger but the result was not satisfactory. With this degraded operational performances of the shell and tube type heat exchanger, it was very difficult to operate the reactor at 3 MW (thermal) power level during worst weather conditions. As a consequence, a new plate type heat exchanger was installed by replacing the existing shell and tube heat exchanger. After installing the plate type heat exchanger, the BAEC 3 MW TRIGA MK-II research reactor was operated smoothly for three years. But for the last few years it is observed that heat exchanger primary inlet temperature rises abnormally and also the pressure drop of the coolant in the secondary side of the heat exchanger increases abruptly. This increasing temperature and pressure drop give the confirmation that heat exchanger mini-channels of the secondary side are being blocked. So this article includes the present performance of the heat exchanger and the factors that are responsible for the blockage of the heat exchanger and some recommendations which implementation is necessary to sustain the smooth operation of the reactor. This article describes the following:

Performance evaluation of the plate type heat exchanger

i. Factors affecting the performance of the plate type heat exchanger
ii. Methods applied for improving the performance of the plate type heat exchanger

2. GEOMETRY OF THE PLATE TYPE HEAT EXCHANGER

The plate type heat exchanger of BAEC 3 MW TRIGA MK-II research reactor is originated from Alfa LAVAL, USA. The technical specifications of the plate type heat exchanger are given in Table 1. In plate type heat exchanger, heat is transferred from one medium to another through the metal plates, which have been pressed, into a special pattern. The general design of plate type heat exchangers allows for an almost infinite number of combinations of geometric parameters for the plate pattern, port design, flow paths etc. In the following, only the most common geometry's will be covered (1).

The plate pattern of this heat exchanger is chevron, or "herringbone" shaped as shown in Fig.1. Normally, each plate has identical pattern but every second plate is rotated 180^0 so that the pattern of adjacent plates points in opposite directions. The shape and size of the corrugations determine the geometry of the unit cell within the structure. The corrugation is usually close to sinusoidal and can be identified by the following parameters:

i. The chevron angle
ii. The pressing depth
iii. The corrugation pitch
iv. The radius of curvature at the tips of the corrugations

Of these, most plate heat exchangers on the market have similar pressing depths and corrugation pitch, while the chevron angles vary depending on the application. The chevron angle is quite important for heat transfer and pressure drop, both increasing with increasing angle (2). When a package of plates are pressed together, the holes at the corners form continuous tunnels or manifolds, leading the media (which participate in the heat transfer process) from the inlets into the plate pack, where they are distributed in the narrow passages between the plates. This type of heat exchanger design is shown in Fig. 1. Because of the gasket arrangement on the plates, and the placing of "A" & "B" plates alternately, the two liquids enter alternate passages, e.g. the warm liquid between even number passages, and cold liquid between odd number passages. Thus the media are separated by a thin metal wall. In most cases the liquids flow in opposite directions. During the passage through the equipment, the warmer medium will give some of its heat energy to the thin wall, which instantly looses it again to the colder medium on the other side. The warmer medium drops in temperature while the colder one is heated up. Finally, the media are led into similar hole-tunnels at the other end of the plates and discharged from the heat exchanger (3). One passage carries colder fluid and the adjacent passage contains hotter fluid. It should be mentioned that the directions of the hotter and colder fluids are counter currents.

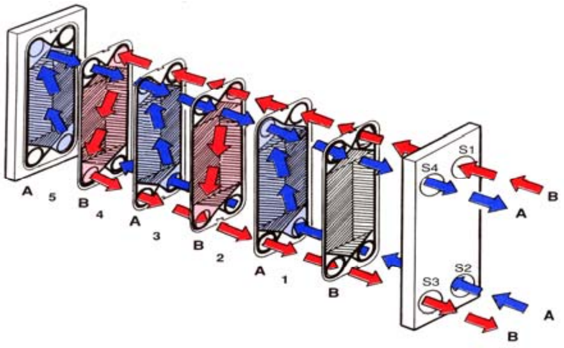

Fig 1: Geometry of the plate type heat exchanger

3. PERFORMANCES OF PLATE TYPE HEAT EXCHANGER

3.1 Pressure Drop Characteristics

Heat exchanger inlet and outlet pressure differences for primary and secondary side reveal an important phenomena about the operating condition of the plate type heat exchanger. Figure 2 represents the pressure drop vs. Time graph of the plate type heat exchanger of BAEC 3MW TRIGA Mk-II research reactor for the last six years operation. From the pressure versus time graph it is observed that the pressure drop for secondary side increases with the time. From Fig.2 it is also seen that present operating pressure drop in the secondary side is almost 108 kPa whereas the recommended operating pressure is 62 kPa. The large difference between operating and recommended pressure is an indication that the heat exchanger-mini channels of the secondary sides are being blocked due to dirts, mud, and algae-bacterial growth. That is why the pressure drop in the secondary side of the heat exchanger increased for the last six years. From the graph it is also observed that pressure drop in the primary side is almost constant for the whole operating period. The reason is that the water quality of the primary side is strictly maintained.

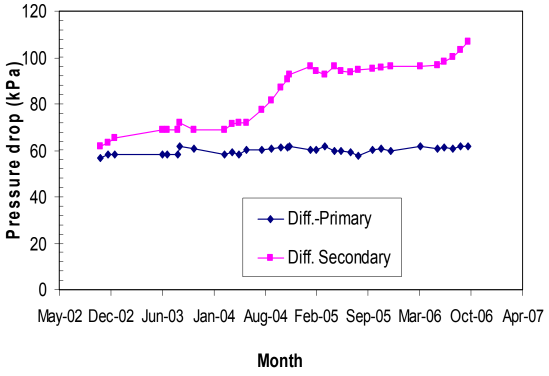

Fig. 2 Pressure differences vs Time

3.2 Heat Transfer Characteristics

Heat exchanger inlet and outlet temperature differences in the primary and secondary side also reveal an important indication of the heat exchanger performance whether there is fouling due to scale

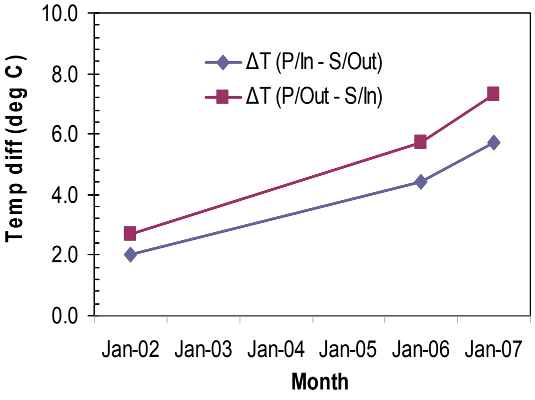

Fig 3: Temperature difference vs Time

Figure 3 represents the temperature analysis of the primary and secondary side of the plate type heat exchanger. From Fig. 3 it is clear that inlet and outlet temperature difference in the primary and secondary side of the heat exchanger increases with time. This indication plays an important role to analyze the present heat transfer situation. It is also clear that heat transfer from primary side to secondary side decreases as the secondary side mini-channels experiences blockage due to dirt things and algae-bacterial growth as a result primary side temperature differences also increases gradually. It is moreover clear that increasing trend of temperature difference for secondary and primary side is almost same.

Table 1: Specifications of the plate type heat exchanger installed in the BAEC 3MW TRIGA Mk-II Research Reactor

Parameters	Unit	Hot Side (Primary)	Cold Side (Secondary)
Fluid		Hot Water	Cold Water
Volume Flow Rate	Lit/min	13230	12474
Inlet Temperature	^{0}C	45.56	33.33
Outlet Temperature	^{0}C	37.78	41.56
Pressure Drop	kPa	68.3	62
Heat Exchanged	kW	7089	
L.M.T.D	^{0}C	7.6	
Heat Transfer Area	m^2	274.16	
Relative directions of fluids		Counter-current	
Number of Plates		151	
Number of passes		1	
Plate Material		AISI 304	
Overall Length ×Width ×Height	m	2.18 × 1.16 × 2.87	
Liquid Volume	m^3	0.47	0.47
Design Pressure	kPa	690	690
Test Pressure	kPa	897	897
Design Temperature	^{0}C	87.76	87.76

3.3 Comparison of Design and Operational Thermal Efficiency of the Heat exchanger

The heat exchanger design and operational thermal efficiency has been calculated using two different methods as effectiveness (ε) - NTU and LMTD (4). The effectiveness of a heat exchanger is defined as:

$$\varepsilon = \frac{Q_{act}}{Q_{max}} \qquad (1)$$

In the LMTD method, the rate of heat transfer is determined from

$$\dot{Q} = UA\,\Delta T_{LMTD} \qquad (2)$$

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \qquad (3)$$

Both the methods have shown the similar results. From the calculation, it has been found that present operational thermal efficiency is 45.35 % whereas design thermal efficiency is 67.40 %. The difference of the operational and design thermal efficiency is around 22 % which indicates the present worst performance of the heat exchanger.

4. FACTORS AFFECTING THE PERFORMANCE OF THE PLATE TYPE HEAT EXCHANGER

(l) Equations are preferably typed using Word The following parameters affect the heat transfer efficiency of the heat exchanger. These are as follows:

a. Electrical Conductivity (EC)
b. Total Dissolved Solids (TDS)
c. Algae and Bacterial growth

a. Electrical Conductivity (EC)

EC is a very important parameter for heat exchanger longevity. From the operating data, it is seen that the EC increases with the operating hours.

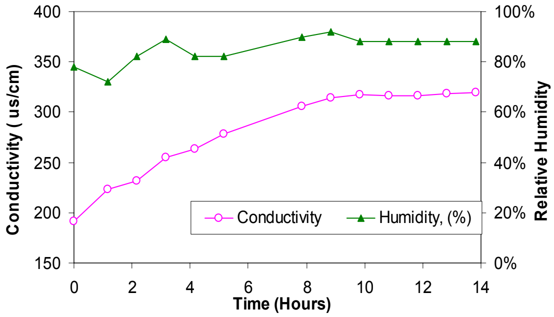

Fig 4: Conductivity Vs Time

In our heat exchanger, EC always maintained within the limit recommended by the supplier [Sorrento Electronics Inc. (SEI), USA] by maintaining two cycles of concentration (5). From Fig. 4 of EC versus time of continuous operation (forty-eight hours operation) at full power (3MW thermal), it is seen that EC increases accordingly with the operating hours and reached at the saturation level (double of the make-up water EC) approximately after 10 hours continuous operation. This two-cycles of concentration of EC is maintained by maintaining fifteen gallon per minute (GPM) of bleed-off from the cooling tower sump.

It is to be mentioned that EC is measured from cooling tower sump water. From Fig.4 it is moreover clear that relative humidity has small effect on the operating hours and after certain hours operation relative humidity goes to constant value. It is to be mentioned that EC has a strong effect on humidity. As the humidity decreases, evaporation loss of the cooling tower sump water increases. Consequently EC of the secondary water increases. The reason is that if the evaporation loss is higher, total dissolved solids increases in the cooling tower. So EC of the cooling tower water ultimately increases.

b. Total Dissolved Solids [TDS]

TDS is also important parameter for heat exchanger performance. Dirt from the environment and other solids come from the secondary water due to the evaporation loss of the cooling tower ultimately affects the heat exchanger performance. These solids enhance the EC of the cooling tower water and also make blockage in the mini channels of the heat exchanger. Thus the heat exchanger performance degraded day by day.

c. Algae and Bacterial Growth

Algae and Bacterial growth have bad impact on heat exchanger normal operation. As secondary side of the heat exchanger is connected with the cooling tower which is open to the atmosphere, algae and bacterial growth enhanced and made blockage in the mini channels of the heat exchanger. Thus passages of the heat exchanger reduced and ultimately flow of the heat exchanger reduced. And finally heat exchanger lost its efficiency.

5. METHODS APPLIED FOR IMPROVING THE PERFORMANCE OF THE PLATE TYPE HEAT EXCHANGER

To improve the heat exchanger performance two methods were applied. These are as follows:

a. Maintaining Two-Cycles of concentration
b. Injection of Bacticide, CTB-54 and Sl-20,000 chemicals to improve the water quality

a. Maintaining Two Cycles of Concentration

The EC of the secondary water of the plate type heat exchanger is always kept under the two times value of the existing EC in the make-up water of the cooling tower. For this reason, fifteen GPM bleed-off water is maintained through cooling tower. Thus way EC never goes beyond the two times value of the EC. If the EC value does not cross the two times value of the make up water, the heat exchanger performance will never be interrupted. This method was recommended by SEI, USA (1, 5).

b. Injection of Bacticide, CTB-54 and Sl-20,000 Chemicals to Improve The Water Quality

The cooling tower water is stagnant for maximum times of a week. In an account, we can say that per week the reactor operated at 3 MW for only twenty five hours. During this time the cooling tower water are in flowing condition. So rest of the time the cooling tower water and heat exchanger water are not agitated. During this time algae and bacterial growth accelerated and suffocate the passage of the heat exchanger. To prevent this, bacticide are injected in the cooling tower water once in a week. From our experience, it is seen that after injecting the bacticide, the EC of the cooling tower water increases rapidly. Then CTB-54 and SL-20000 are injected in the cooling tower water to reduce the EC of the water (1, 5).

6. CONCLUSION

The heat exchanger is the vital part of the cooling system of the TRIGA research rector. The difference between the resigned and operational thermal efficiencies has been found about 22%. The differences are due to changes the water properties with respect to operational hour of the reactor and the factors that are responsible to interrupt the secondary water quality. It is necessary to minimize the differences between the two. The increasing tendency of the pressure drop is due to several reasons identified in the paper. Early mitigation of the increasing tendency of the pressure drop is needed to maintain the normal operation of the reactor. There are no maintenance activities performed after installation of the plate type heat exchanger for about six years. It is necessary to clean the heat exchanger in order to keep controlling pressure drop and temperature difference with in the design value limit. Proper maintenance of the heat exchanger could substantially improve the thermal performances over it and will protect any untoward situation in the primary and secondary cooling systems.

7. FURTHER RECOMMENDATION

From this paper it has been observed that the heat exchanger performances degraded a lot for the last 6 years although two preventive maintenance method i.e. two cycles of concentration and chemical injection method to the secondary water continued time to time to restore the normal operating performance of the heat exchanger. It has been experienced that this two preventive action cannot restore the heat exchanger normal performance. That’s why presently it is recommended to disassemble the heat exchanger and then dipped the heat exchanger plates with sulfamic acids for several hours and finally clean the plates with brush and high jet of water. It is to be mentioned that present heat exchanger is glue type which is not convenient to disassemble and mechanical wash. For that reason, our future recommendation is to install clip type heat exchanger which is very much easier for proper maintenance.

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