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ANALYSING THE EFFECT OF FOULING ON A CROSS FLOW MICRO HEAT EXCHANGER

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ABSTRACT
Heat exchangers as a heat transfer device have gained wide applications across different levels of domestic and industrial set-ups. The fouling formation in heat transfer equipment is the complex process, which is determined by the physical properties of the heat carrier, material of the unit and hydraulic characteristics of the flow. The mathematical model based on the asymptotic behaviour of water fouling is examined. The objective of this project is to study the effect of fouling on a cross flow heat exchanger. A theoretical approach showing the effect of fouling has been developed. This approach is based on the basic fouling deposition. The outer and inner rate of fouling relationship was shown. The rate of fouling was kept constant at 0.0007 to 0.00009 and its result is shown. As it can be observed the heat transfer coefficient has affected the heat exchanger adversely. The developed model can be used as a very useful tool in the design and operation of the heat transfer equipment by controlling the parameters affecting fouling processes. The heat transfer coefficient of the inlet diameter is calculated as 4.99*10^5 WM^2/K and the outlet diameter heat transfer is 1.76 WM^2/K. The fouling formation in heat transfer equipment is the complex process and this process determines the heat transfer coefficient and the mass flow rate of the shell and tube.

1.0 INTRODCUTION
The dynamics of heat exchangers can be described by physical laws concerning mass, energy and momentum. By using those laws the heat exchanger can be modelled with physical equations that depend on the mass flows, inlet and outlet temperatures of the fluids that go through the heat exchangers. It is also possible to model other factors that can influence the effectiveness of the heat exchanger, for example heat transfer to or from the surroundings and also the rate of fouling (Gudmundsson et al., 2011).
Heat exchangers (HEs) are devices used in both industrial and domestic applications that involve energy (heat) transfer fluids. Generally, heat exchangers are classified as counter-flow, cross-flow and parallel flow with their operating conditions categorized as steady state operation and dynamic operation (Gudmundsson et al., 2011). In steady state operations, the mass flow and temperatures do not change with time like they will do in dynamic operations (Yunus and Afshin, 2015).
Often there is accumulation of deposits on the heat transfer surfaces of a cross flow heat exchangers while in service. As the deposits accumulate leading to increased fouling, the efficiency of the heat exchangers reduces, making it important to understand the condition of the heat exchangers while in use. The accumulation of these unwanted materials on the heat exchangers surface in such a way that it affects its heat transfer efficiency is called fouling.
Based on the prevalence of fouling and its attendant challenges in cross flow heat exchangers, modern heat exchangers are generally designed to tolerate slight fouling (Gudmundsson et al., 2011). Moreover, there are different types of fouling mechanisms that can either occur individually or simultaneously. The most common as described by Epstein (1999) are the Scaling/Precipitation, Particulate/Sedimentation, Corrosion, Chemical, Freezing and Biological fouling.

Scaling fouling otherwise known as precipitation or crystalline fouling is the commonest type of fouling and is often as a result of reverse solubility salts like calcium carbonate ($CaCO_3$) typically found in water. The solubility of this salts decline as the temperature increases and hence forms deposits on the surface of the heat exchangers.

It is difficult to remove scale fouling via mechanical means, and as a result, the use of chemical cleaning methods may be required. Particulate fouling on the other hand, is the accumulation of particles, on a heat transfer surface, that forms an insulating layer, and reduces the rate of heat transfer leading to operations failure (Abd-Elhady et al., 2007).

When certain particles like sand, dirt or rust in the fluid settle and accumulate on the surface of the heat transfer equipment, sedimentation occurs. As noted in scale fouling, the intricacy of the cross flow heat exchangers design and their nature may make mechanical removal of the deposits to be very tough. Corrosion fouling results from a chemical reaction involving the surface material of the heat exchangers.

Fouling is common for chemically sensitive materials when the fluid is heated to temperatures near its decomposition (degradation) temperature (Epstein, 1999; Kazi et al. (2009). Coking of hydrocarbon material on the heat transfer surface is also a common chemical fouling problem. Whereas, freezing fouling occurs when a portion of the hot stream is cooled to near the freezing point of one of its components, biological fouling occurs when biological organisms grow on heat transfer surfaces (Kazi et al., 2009).

One major issue about fouling is the fact that it has a chronic operational effect that is considered the major unsolved problem in heat transfer technology (Costa et al., 2011). Fouling rate, defined as the difference between the material deposition and removal rates on the heat transfer surfaces (Morimoto et al., 2011), is an important phenomenon that has capacity to determine the performance of a heat exchangers.

As deposits accumulate on the heat transfer area, the resistance to heat transfer increases and the effectiveness of the heat exchangers diminishes. The cost of fouling is connected to energy wastage and associated downtime cost implication. This invariably is due to the period of heat exchangers cleaning and additionally due to reduced product quality. There are many ways to detect fouling. However, many of the classical methods require the process to be operating in a steady state condition or to be stopped (Gudmundsson et al., 2011).

This study is aimed at investigating the effectiveness of a cross flow micro heat exchanger due to fouling which significantly influence the overall design of a cross flow micro heat exchanger may be determine. The amount of material employed for construction as well as performance between cleaning schedules. Consequently, to reduce the enormous economic loss as it directly impacts the initial cost, operating cost and heat exchanger performance.

2.0 MATERIALS AND METHOD

When fouling accumulate in a heat exchanger the resistance to heat transfer increases, which decreases the heat transfer coefficient U. it can be quite hard to detect changes in heat transfer coefficient with frequent mass flow changes (Yunus and Roberth, 2005).

2.1 Fouling Effect on Heat Transfer

It is important to know the difference between a clean surface U_c and a fouled one U_f . U_f can be related to the clean surface as U_c while U is the overall heat transfer coefficient.

$$\frac{1}{u} = \frac{T_w - T_b}{Q}$$

$$\frac{1}{U_f} = \frac{1}{h_h} + \frac{\delta}{KA} + \frac{1}{h_c A} \qquad 3.1$$

Where R_f is the total fouling resistance which is given as stated by (Kaka, 2002).

$$U_c = \frac{A_o}{(A_i * h_i)} + \frac{1}{h_o + A_o} * \frac{\log\left(\frac{d_o}{d_i}\right)}{(2 * pi * K * L)}$$

$$R_f = \frac{1}{U_c} - \frac{1}{U_{(t)}}$$

$$R_f = \frac{\ln\left(\frac{d_f}{d_c}\right)}{2\pi K_f L} \quad 3.2$$

The heat transfer under fouling condition can be expressed as

$$U_f = \frac{1}{\frac{A_i}{A_i h_i} + \frac{A_o \ln\left(\frac{d_o}{d_1}\right)}{2\pi KL} + R_{fo} + R_{fi}(i)\frac{A_o}{A_i} + \frac{1}{h_o}} \quad 3.3$$

2.2 Fouling Effect on Pressure Drop

Fouling adds an extra layer to the heat exchanger, changing the original geometry of the pipes. In a tubular heat exchanger, a fouling layer roughness the surface, decreases the inside diameter and increases the outside diameter of the tubes. The frictional pressure drop in the tube for a single phase flow can be calculate by:

$$\mathbf{\Delta P = 4ƒ\left(\frac{L}{d_i}\right)\frac{\rho U_m^2}{2}} \quad 3.4$$

Where ƒ is the fanning friction factor, L indicates the tube's length, d_i is the inner diameter and U_m is the fluid velocity.

2.3 Heat transfer coefficient

The convective heat transfer coefficient, h can be calculated from:

$$h = \frac{N_u * k}{d} \quad 3.5$$

Where, Nu is the Nusselt number and d is the subchannel height. The heat transfer coefficient is developed by using Nusselt number as follows:

$$N_u = 0.332 * Re^{1/2} * Pr^{1/3} \quad 3.6$$

Where, Re is the Reynolds number and Pr is the Prandtl number and lz is length of airstream of the plates. Reynolds number of a flow is calculated as:

$$Re = \frac{u * d}{v} \quad 3.7$$

Where, u is the velocity of the fluid and ν is the kinematic viscosity (m^2/s). This also can be interpreted as ratio of the inertia and viscous forces. Prandtl number is calculated as:

$$Pr = \frac{v}{\alpha} \quad 3.8$$

Where, α is the thermal diffusivity.

2.4 Effectiveness of Heat Exchanger

The concept of effectiveness is applied to the heat transfer process in a heat exchanger. The effectiveness of the cross flow heat exchanger is defined as:

$$E = \frac{\text{actual Heat transfer}}{\text{maximum possible Heat transfer}}$$

$$E = \frac{\dot{m}_H C_p (T_{hi} - T_{ho})}{\dot{m}_c C_p (T_{hi} - T_{ci})} \quad 3.9$$

$$E = 1 - \exp\{H_c^{-1} * NTU^{0.22}[\exp(H_c^{-1} * NTU^{0.78}) - 1]\} \quad 3.10$$

3.0 RESULTS AND DISCUSSION

Case Study

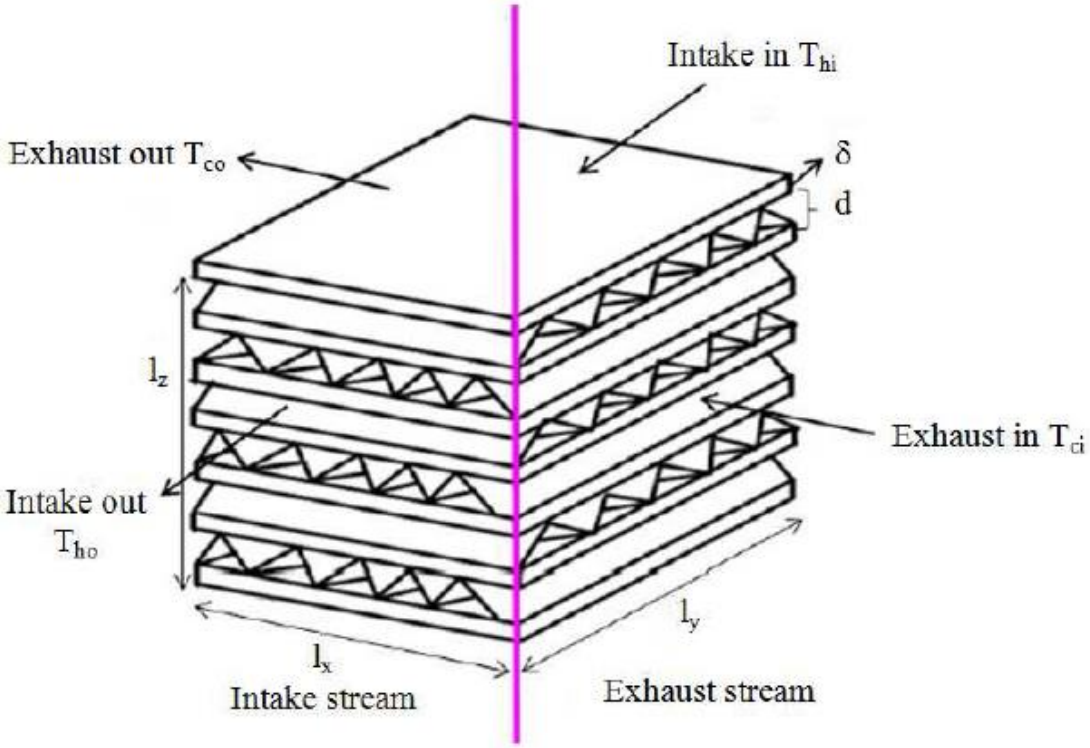

Fig.4.1. Physical model of cross-flow heat exchanger

The analytical technique developed in this work, was geared to stimulating the rate of fouling on a cross flow heat exchanger. The heated element under various flow conditions is considered. The heat exchanger uses stream water to cool hot water and it's in constant operation while the flow condition is fixed at 10 kg/s. Since the primary resistance to heat transfer is in the air layer, the heat exchanger rate of fouling was analysed by bonding the heat exchanger to a heated copper block and measuring the stream water flow rate, pressure drop, heat input to the metal, and inlet and exit temperatures.

The pressure drop of the water was extremely high due to the relatively small area that the air had to pass through to reach the shell side compared to the open cross sectional area. In order to analyse the cross flow heat exchanger which its input parameter is shown in APP A, performance criteria were established.

The goal of this heat exchanger is to dissipate heat to the sea water to prevent overheating. For a given set of design constraints (i.e. pressure drop of each fluid and difference in inlet temperature between the two fluids) a well-designed cross flow heat exchanger provides a high rate of heat transfer/frontal area of the heat exchanger. Other measures of design performance include weight, size, noise, and filtering requirements. The goal described in this chapter is to design a heat HE to analyse its rate of fouling. Other performance parameters include rates of heat transfer/mass and heat transfer/volume. Noise and filtering requirements are also mentioned as possible performance parameters. Noise calculations were not performed.

3.1 Effect of fouling on the Outer Diameter

Fouling factor measures the thermal resistance introduced in heat exchanger by fouling. It is the reciprocal of the heat transfer coefficient of the dirt formed in the heat exchange process. The higher the fouling factor, the lower the overall heat transfer coefficient of the heat exchanger. There are many problems that confront the heat exchangers but the major cause of reduction in heat exchanger performance is the effect of fouling.

Whatever the cause or exact nature of the deposit, additional resistances to heat transfer is introduced and the operational capability of the heat exchanger is correspondingly reduced. In many cases, the deposit is heavy enough to significantly interfere with the fluid flow and increase the pressure drop required to maintain the flow rate through the exchanger. Figure 4.1and 4.2 shows the plot of overall heat transfer coefficient against fouling resistance of the outer surface for a square and triangular pitch type. From this figure, it was observed that as the fouling resistance is increasing as the heat transfer coefficient reduces, the overall heat transfer coefficient is decreasing with an increasing rate of fouling. Equation 3.10 was used to show the effect of fouling on overall heat coefficient of the outer surface diameter and the inner surface fouling was kept constant at this value 0.00009, 0.0002425, 0.000395, 0.0005475, 0.0007.

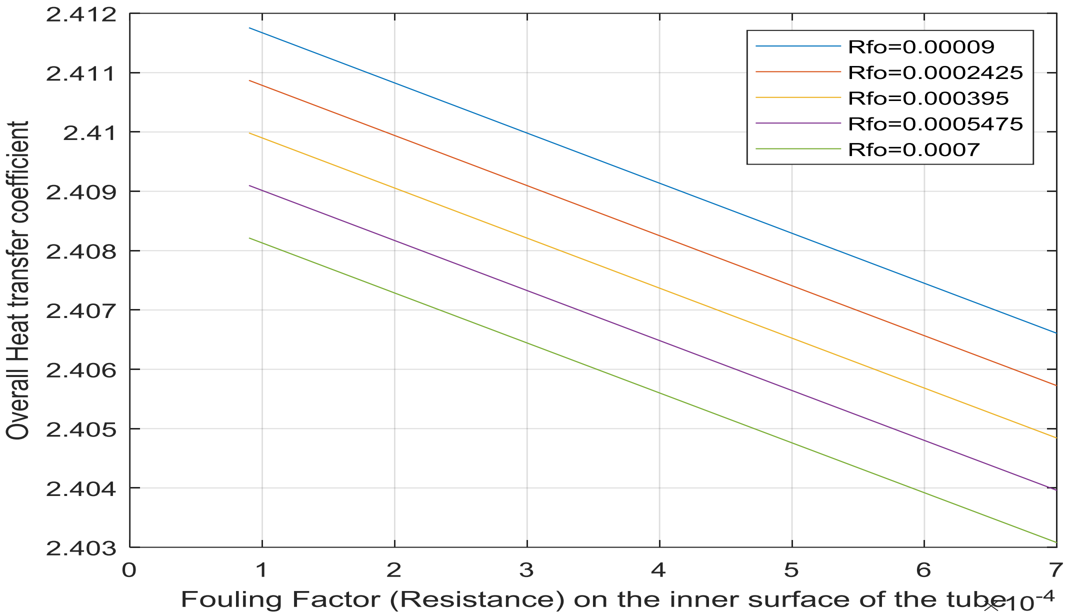

Fig 4.1 Overall heat transfer against fouling for the square pitch

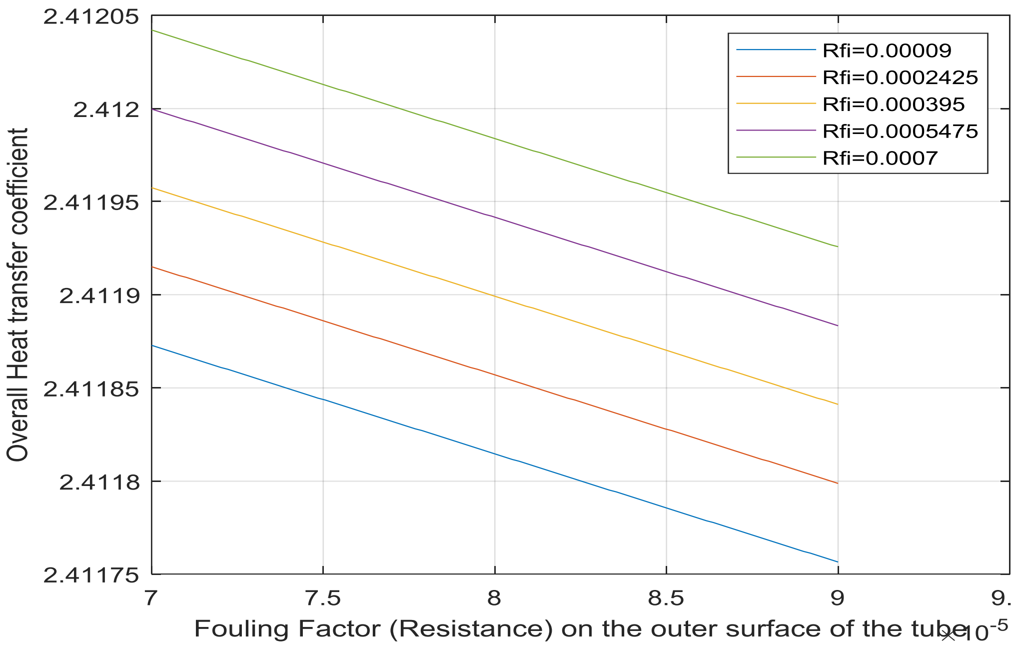

Fig 4.2 Overall heat transfer against fouling for the triangular pitch

3.2 Effect of fouling on the Inner Diameter

The mean heat transfer coefficient was deduced using Equation 3.12 to 3.15. The Nusselt numbers were evaluated with the equation 3.13 using the mean heat transfer coefficients obtained. The slopes of the fluids were observed to increase in successive rate of fouling of the outer diameter. This development increased the heat transfer coefficient downstream of the inner diameter. The empirical equations used to analyse this project observed that to calculate and show the relationship between the rate of fouling and heat transfer coefficient the outer diameter fouling will be kept constant. It also observed that the heat transfer coefficient decreased as fouling factor diminishes. Figure 4.3 and 4.4 shows the plot of overall heat transfer coefficient against fouling resistance of the outer surface for a square and triangular pitch type. The heat transfer coefficient increases as the rate of fouling of the outer diameter changes from 0.0007 to 0.00009.

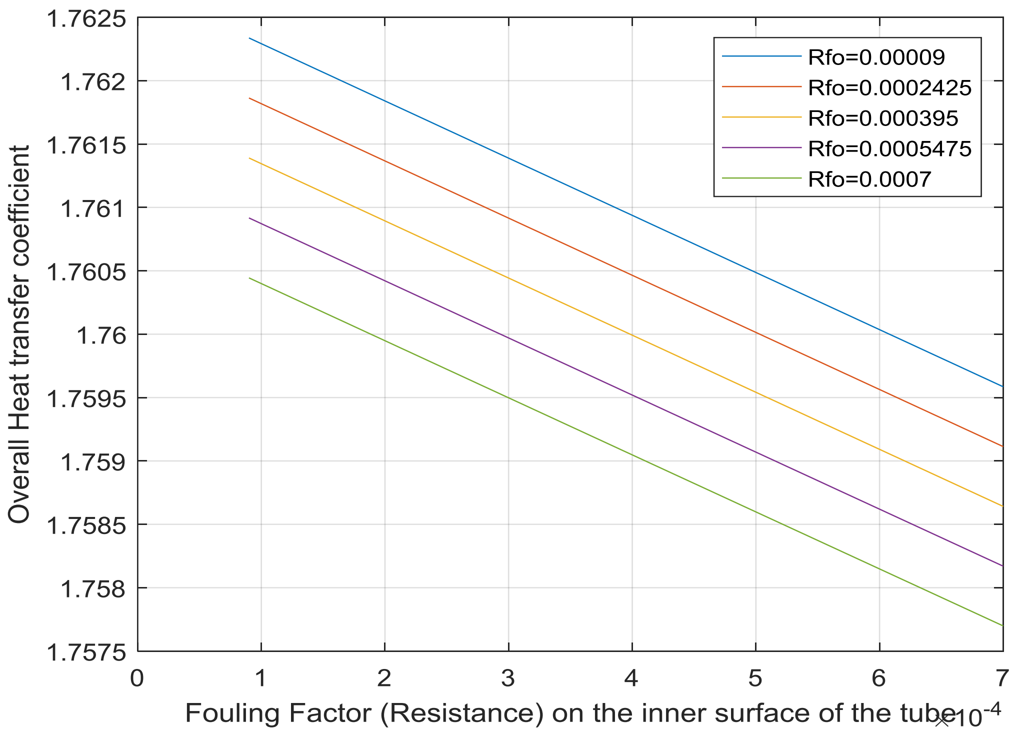

Fig 4.3 Overall heat transfer against fouling for the square pitch

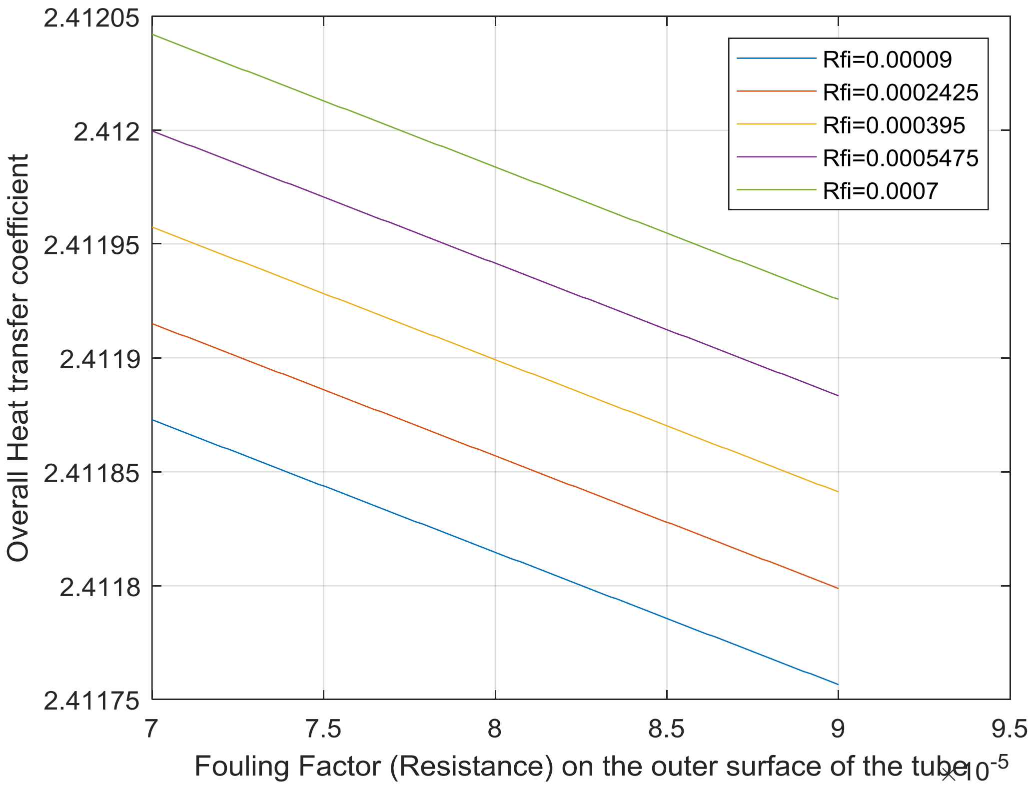

Fig 4.4 Overall heat transfer against fouling for the triangular pitch

4.0 CONCLUSION

Cross flow heat exchangers was analysed to efficiently transfer heat between a stream water and hot water. The optimum design of heat exchangers under a set of design constraints was determined. Additionally, Matlab software was used to accurately model the heat transfer.

This project has analyzed the effect of fouling on the overall performance of a heat exchanger. The heat exchanger considered was a water cooler that uses stream water as its coolant. The results obtained for the water cooler show that on average, the deviation of the overall heat transfer coefficient, heat duty, and effectiveness has been fully analysed. The results also revealed that fouling factor increases steadily over years. Fouling adversely affected the performance parameters of the heat exchangers such as: overall heat transfer coefficient, effectiveness, heat duty etc. As a result, the entire system performance was affected.

Successful analysis of the rate of fouling on a cross flow heat exchangers under modest design constraints has been achieved. For the heat exchanger alignment, and bonding, fabricating the heat exchanger out of a material with better thermal properties will be recommended for construction. Methods of fabrication such as ceramic molding and metal injection molding should be explored since they are potentially inexpensive and rapid means of producing very high performance micro heat exchangers. This project therefore also recommended that the periodic maintenance of the water cooler should be carried out after every 30 days of operation in other to reduce fouling.

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