A STUDY ON THE CHARACTERISTIC OF FOULING FACTOR OF A LABORATORY SCALE SHELL AND TUBE HEAT EXCHANGER

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Abstract - **Heat exchangers have been commonly used in industrial processes such as thermal power plant, chemical process, air conditioner device, refrigerator, even in some bigger energy processes like oil and gas. The performance of a heat exchanger is not permanently the same during daily and even annually uses whereas one of the most common causes is the fouling factor. In this research, the performance of a laboratory scale heat exchanger was observed by the inlet and outlet temperature of hot oil and cold water fluids based on characteristic of fouling factor. The flow rates were kept constant at 0.72 m^3/hour for shell and 0.468 m^3/hour for tube. The observation time was at 06.00 am, 12.00 am, 18.00 pm, 24.00 pm every day for six respective days. The result shows that ΔT_m changes irregularly during the observation while the fouling factor increases regularly and decreases significantly by the end of the observation.**

Keywords: Heat exchanger, fouling factor, shell and tube, characteristic.

I. INTRODUCTION

The designed heat exchanger of this first year is going to be operated for 23 days with no stop and the data of measurement is then taken. An analysis is then conducted based on the obtained data to study the performance characteristic of the designed heat exchanger.

II. EXPERIMENTAL METHOD

Method we use in this research is by analyzing the planned specification of heat exchanger design, the designed specification calculation so the proper specification can be obtained in numbers and transformed into a laboratory scale heat exchanger. The flowchart of this research is as follows.
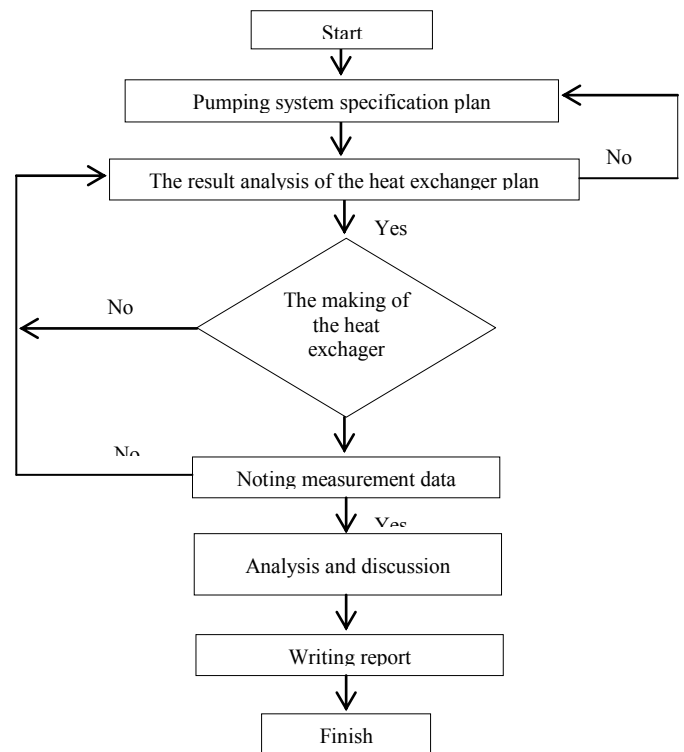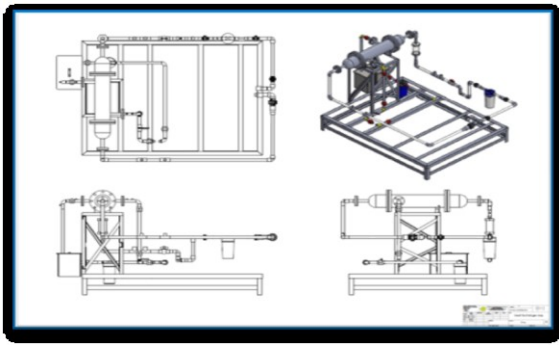

Picture 1. Flowchart of research activities

III. DISCUSSION

In this research, determining the heat exchanger design specification was firstly conducted before calculation analysis of the laboratory scale shell and tube heat exchanger.
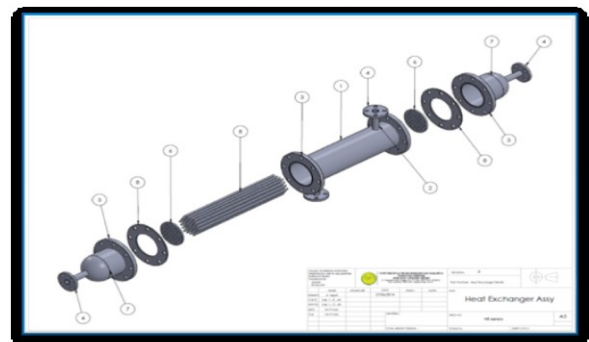
Picture 2. Heat exchanger assembly

Picture 3. The unit of heat exchanger system

Tabel 1. Designed specification of shell and tube heat exchanger

Designed Specification of HE	Unit
Tube diameter	OD = 0,0127 mm
Length of tube	0,6 m
Are of Heat Exchanger	0,88 m^2
Shell incoming fluid mass flow rate (mh)	0,075 kg/s
Tube incoming fluid mass flow rate (mc)	0,122 kg/s
Tube incoming cold fluid temperature (Tci)	27°C/ 300 K
Tube outgoing cold fluid temperature (Tco)	37°C / 310 K
Shell incoming hot fluid temperature (Thi)	47 ^{O}C / 320 K
Thermal load (Q)	5100 Watt
Overall heat transfer coefficient (U)	900 W/m^{2}K
Heat exchanger effectiveness	61 %.

IV. RESULT ANALYSIS

The result analysis is based on 23 months of experiment data. The 23 months here is a scaled time of 23 days wherein one day is scaled to be equal to one month. This scaling method is considered to be important in order to have a longer simulation period of the heat exchanger experiment and give a better chance to observe the performance characteristic.

Calculation of heat flow rate absorbed by the cooling water which can be done by using the equation below,

$$Qc = mc\ cst \times Cpc \times (Tco-Tci) \qquad (1)$$

Calculation of heat flow rate released by the hot fluid,

$$Qh = mh\ cst \times Cph \times (Thi - Tho) \qquad (2)$$

Calculation of Log mean temperature difference of both fluids,

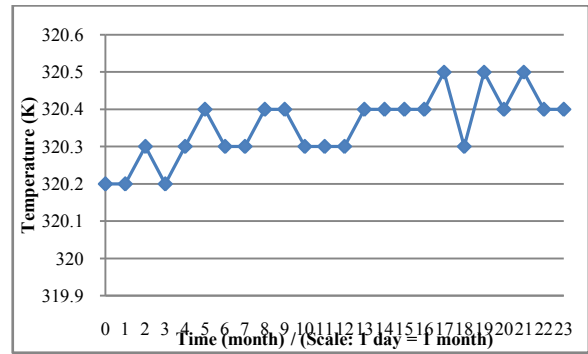$$\Delta Tm = \left(\frac{\Delta T1 - \Delta T2}{\ln (\Delta T1/ \Delta T2)}\right) \qquad (3)$$

Calculation of overall heat transfer coefficient (U),
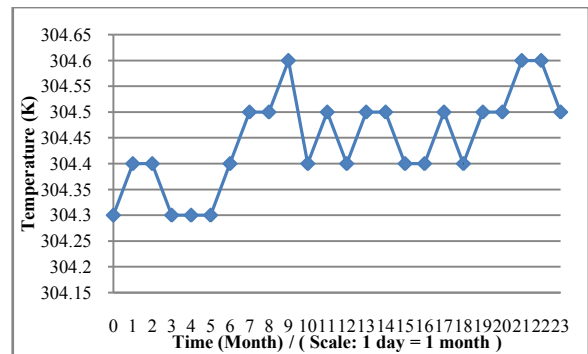
$$U = \frac{Qcst}{Acst\ .\ \Delta Tm} \qquad (4)$$

Calculation of fouling factor during operation which can be done by using the equation below,

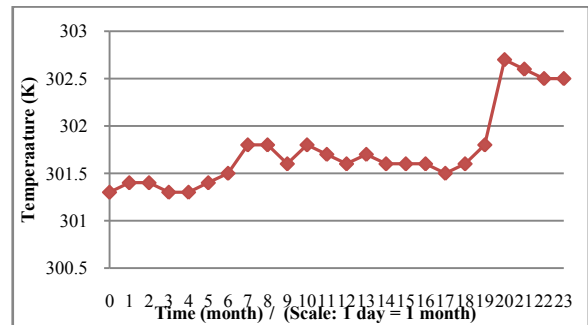$$\Sigma Rf = \frac{1}{Uf} - \frac{1}{Uc\ cst} \qquad (5)$$

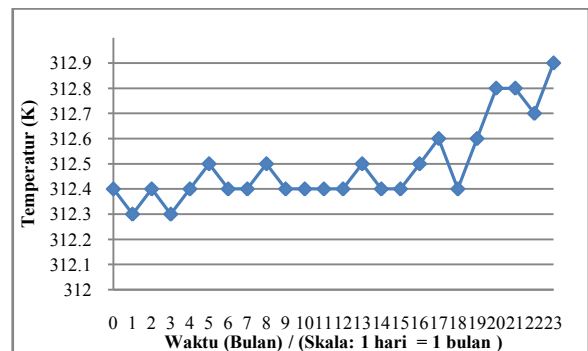The results from above calculations are then converted into graphic charts before conducting performance predictions.
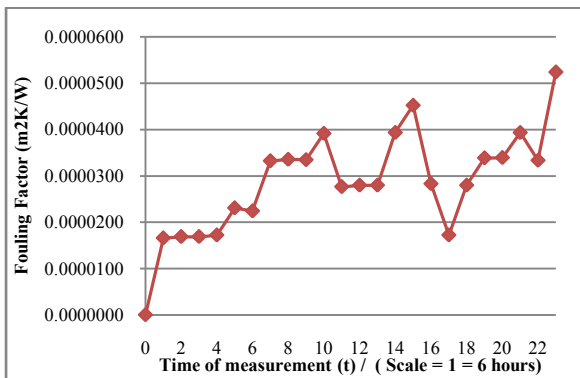

Picture 4. Charateristic of shell inlet temperature (T$_{hi}$)

Picture 5. Characteristic of shell outlet temperature (T$_{hi}$)

Picture 6. Characteristic of tube inlet temperature (T$_{ci}$)

Picture 7. Characteristic of tube outlet temperature (T$_{co}$)

Picture 8. Characteristic of Fouling Factor

♣ Prediction of designed heat exchanger performance

$$R_f = R_f^*.(1 - (e^{(-\frac{t}{tc})})) \qquad (6)$$

$$Rf^* = \frac{Rfn\,2}{(2\,.Rfn\,) - (Rfm\,)} \qquad (7)$$

R_f^* is then obtained to be 0,00002 m²K/W.

Thus, in order to determine the time that the fouling takes (tc) then another calculation should be done by using the equation

$$tc = tm\ln\left(\frac{Rf^*}{Rf^* - Rfm}\right) \qquad (8)$$

so that the predicted time of the fouling formed in the system (tc) is 5.5 months of operation.

By using equation (6), we can predict how a fouling layer is formed in the system after 23 months of operation. The prediction can be seen in an asymptotic graphic data as an approximation result shown in Fig. 9. This result of predicted characteristic of deposit development is obtained after 23 months of operation.
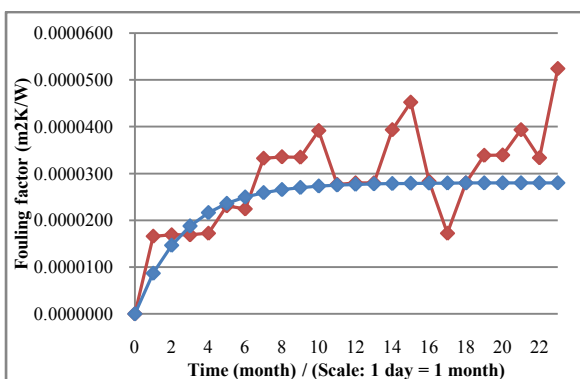
Picture 9. Asymptotic graphic of fouling formed after 23 months

This heat exchanger is planned to operate at constant thermal load (Qcst) and be scheduled for cleaning as the mean temperature difference of both fluids has reached 20% higher than the initial designed temperature of 7.6 K.

$$Qcst: \frac{\Delta Tmf}{\Delta Tmc} = 1 + U_c \times Rf^* \qquad (9)$$

thus,

$$\frac{\Delta Tmf}{\Delta Tmc} = \frac{7,68\ K}{6,4\ K} = 1,1\ K$$

Characteristic of both working fluids which flow in the system shows a tendency of forming deposit layers by 0.00002 m²K/W of asymtotic thermal resistant. Since the operation time of this heat exchanger is planned to be as long as 23 months, then the characteristic value of fouling factor can be obtained by the time of cleaning interval period is reached. Equation (6) can be used to observe the fouling factor after 23 monnths of operation.
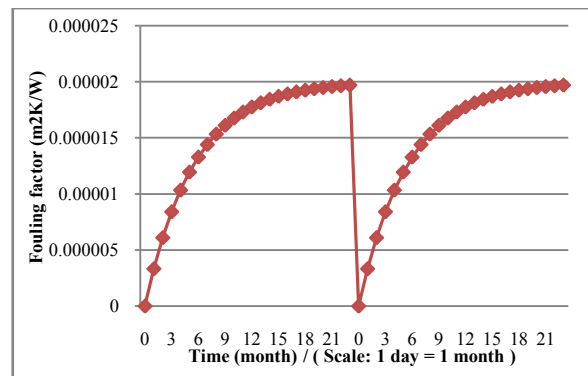
Picture 10. Prediction of cleaning interval

Overall heat transfer (Uf) of the designed heat exchanger can be determined by using equation (10).

$$\Delta T_{mf} = \Delta T_{mc}(1 + (U_c.R_f^*)) \qquad (10)$$

$$(Uc.Rf*) = (\Delta Tmf - 1)$$

$$Uc = \frac{\Delta T_{mf} - 1}{Rf^*}$$

By obtaining overall heat transfer (Uc) of 3571.4 W/m²K and using the equation

$$A = \frac{Qc}{Uc.\Delta Tmc} \qquad (11)$$

$$N = \frac{A}{\pi.Do.L} \qquad (12)$$

then the dimension (A) value of 0.25 m² and tube number (N) of 10 pieces can be obtained by using conventional method. On the next phase of analysis, recalculation is conducted on the results to observe characteristic of working fluids inside the system using data calculation and graphic.

+ **Prediction of designed heat exchanger performance by fouling factor dan time function of conventional design**

In order to find out the global coefficient of overall heat transfer (U) during (t) = 23 months, we can use equation (13).

$$U = \left(\left(\frac{1}{U_c}\right) + \Sigma Rf\right)^{-1} \tag{13}$$

$$\Delta T_{mf} = \Delta T_{mc}(1 + (U_c \times R_f)) \tag{14}$$

$$\Delta Tm = \left(\frac{(Thi - Tco) - (Tho - Tci)}{\ln(Thi - Tco)/(Tho - Tci)}\right) \tag{15}$$

$$Tco = \left(\frac{(313,5 - Tco) - (311 - 304)}{\ln(313,5 - Tco)/(311 - 304)}\right) \tag{16}$$

$$mco = \frac{Qact}{Cpc \cdot (Tco - Tci)} \tag{17}$$

By using above planned calculation, then we can get the picture about thermal characteristic of a heat exchanger designed by using conventional method. The results of performance prediction by cold fluid temperature and cold fluid mass flow rate of the cooling fluid can be seen on Picture 11 and picture 12, respectively.
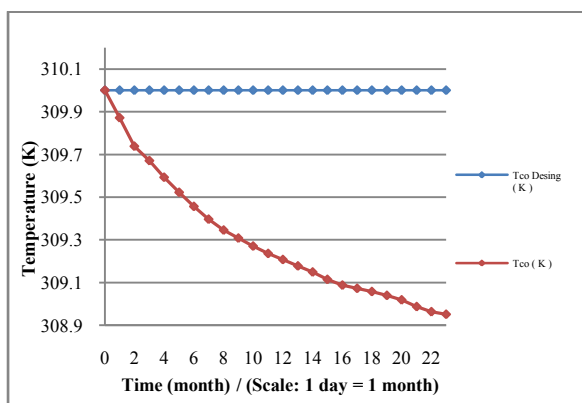
Picture 11. Cold fluid temperature out
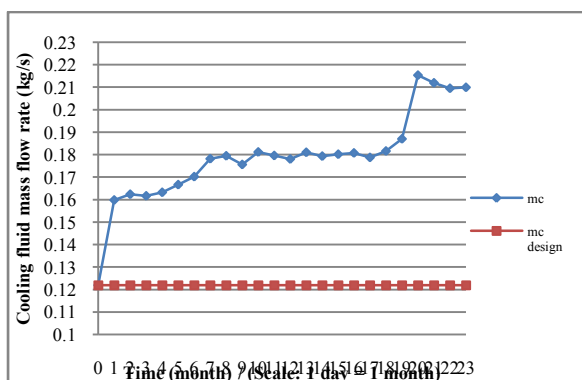
Picture 12. Mass flow rate of cooling fluid

V. CONCLUSIONS

The temperature of outgoing cooling water at initial start up is the same with the one of initial designed specification, T_{co} = 310 K, so is the cooling water mass flow rate, m_{co} = 0.122 kg/s.

During 23 months of operation, the outgoing temperature of cooling water must be decreased to maintain constant thermal load.

Power for pumping fluid should be raised by stages or by using an additional equipment which is able to either automatically or conventionally control the speed of mass flow in the piping system.

REFERENCES

[1] Ramesh K. Sahah and Dusan P Sekulic 2003. Fundamentals of Heat ExchengerDesing. John Wiley & Son, INC. Hoboken, New Jersey.
[2] Ricahard. C. Byrne. 2000. Standard of the Turbular Excharnger Manufactures Association, standards of the Turbular Exchanger Manufacture Assocition, INC. New York,.
[3] Epstein, *N.* 1978. *Fouling in Heat Exchangers,* Heat Transfer Engineering, vol 6, New York,.
[4] Keith Escoe, A., *Mechanical Design of Process Systems,* vol. 2, Gulf Pub. Company, Houston Texas, 1986.
[5] Soekardi. C. April 2001. Prediksi karakteristik termal sebuah penukar kalor dampak pemilihan faktor pengotoran konstan, Poros, 4 No 2, 141-150.
[6] Soekardi.C. April 2002. Implikasi Perancangan Sebuah penukar kalor dengan faktor Pengotoran dan fungsi waktu terhadap kinerjanya pada kondisi operasi beban thermal konstan, Poros, Vol. 5. NO. p. 129-137.
[7] Thurmarimurungan M. 2006. Performance Analysis of Shell and TubeHeat Exchanger Using Miscedle System. American Journal of Applied Sciences.
[8] Yulianto S. 2010. Analisa Perancangan Alat Pendingin Jenis Shell And Tube Dengan Cleaning Interval yang Bervariasi. Tesis Program Studi Teknik Mesin Universitas Pancasila.