

Prediction of Heat Exchanger Fouling Time

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ABSTRACT

Heat exchangers operating in process industries are fouled during operations and results in decrease in the thermal efficiency of a heat exchanger. Once the thermal efficiency decreases to a minimum acceptable level, cleaning of the equipment becomes necessary to restore the performance. This paper uses C-factor as a tool for investigation of the performance of a heat exchanger due to fouling which consequently gives information regarding the extent of fouling developed on the heat transfer surfaces. The fouling parameters are predicted by measurements of flow rate and pressure drop. In contrast to most conventional methods, the extent of fouling can be detected considering the flow rate and pressure drop when the heat exchanger operates in transient states. The C-Factor is first calculated through out cleaning period and then compared with the clean and the design value. The results show that the proposed tool is very effective in detecting the fouling developed and the corresponding degradation in heat transfer efficiency of a heat exchanger. Hence the results of this work can find applications in predicting the reduction in heat transfer efficiency due to fouling in heat exchangers that are in operation and assist the exchanger operators to plan cleaning schedules.

I. INTRODUCTION

The accumulation of scale, organic matter, corrosion products, coke, particulates or other deposits on a heat transfer surface is a phenomenon called fouling that costs the process industries heavily. These deposits degrade heat exchanger performance over time compared with "clean" conditions at start up. The fouling layer is a conductive resistance to heat transfer that must be accounted for in the design heat transfer coefficient. Fouling thickness and thermal conductivity both contribute to the resistance. Simultaneously reduced cross sectional flow area also increases pressure drop in the fouled region

Although a significant numbers of engine valve-actuation systems including cam-based and cam less mechanisms have been already introduced

by several researches and companies, only few types of these systems (mainly cam-based) have been employed on commercial vehicles due to the liability, durability and cost issues. Cam-based valve systems offer reliable and durable functionality, the cam less valve trains can vary valve lift and more timings to a greater extent comparing to the cam-based types. Among various categories of cam less mechanisms, the electromagnetic actuator system is the most desired one.

Fouling is a complex phenomenon and its accurate prediction based on current knowledge is quite a difficult task. At the design stage fouling of the outer surface of the tubes is accounted for by making allowances for the added thermal resistance that the deposited layers introduce to the heat transfer surface. This is essentially achieved by increasing the heat transfer surface area in the heat exchanger. According to Garret-Price et al. the general practice is to design heat exchangers with an average oversize of about 35% in terms of surface area. Another approach is the implementation of the percentage OS (over surface index) as described by Kakac et al.

To enforce compliance with critical pressure and operational criteria, heat exchangers must be cleaned often, according to a regular maintenance schedule. However, unnecessary cleaning leads to system downtime and waste of water and chemicals, which increases costs and causes ecological problems. Therefore the cleaning schedule should be optimal so that the exchanger can run for a maximum possible period without hindering the efficiency of the plant. The scheduling of cleaning interventions can be based on the prior knowledge of the time behaviour of the thermal resistance deposits in the individual exchanger [4,5]. This is possible if the operating parameters have been measured and recorded during previous production methods. The classical detection methods are based on study of the heat transfer coefficient or the effectiveness, temperature measurements, ultrasonic or electrical

measurements and weighing of heat exchanger pipes .

Heat exchanger monitoring methods range from the very simple to the very complex . The simplest form of monitoring has always been to open up exchangers at a turnaround and look for fouling or corrosion. This method is a final report on the success or failure of a program. However, by the time it is implemented, it may be too late. The plant may have been running inefficiently or even have been forced to shut down if there was a problem. This method gives no indication of when or why a problem happened, which makes troubleshooting difficult. Besides ultrasound measuring is a popular technique for monitoring the evolution of fouling . The estimation of the fouling thickness is also possible by using temperature and heat flux measurements. This simple form of monitoring is carried out by comparing the terminal temperature differences which take into account the difference between the hot fluid outlet temperature and the cold fluid outlet temperature . Also the difference between the hot fluid outlet temperature and the cold fluid inlet temperature known as the approach temperature can be used as a valuable tool for fouling measurement of multipass heat exchangers..The idle speed control problem of a spark-ignited engine equipped with a camlessvalvetrain is considered.

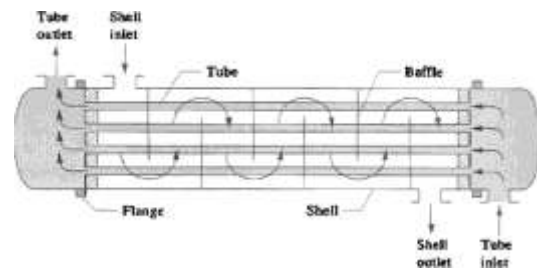
In practice the most complete and thorough method of measuring efficiency and fouling of a heat exchanger uses the overall heat transfer coefficient and fouling factor. This method uses both the hot and cold side data to determine the overall efficiency of the exchanger in terms of various performance parameters . But unfortunately the thermal analysis does not give clear information regarding the fouling formation as it is too much complex to distinguish between the cold and hot fluid side fouling. Secondly the changes in hot fluid characteristics due to variation in operational conditions make it almost impossible to compare the results meaningfully. All of these shortcomings lead to the thought of introducing a new parameter that can provide the most reproducible and consistent results while being easy to calculate. The aim of this paper is to introduce such a factor called the C-factor which can be utilized to predict the fouling formation effectively.

II. MATERIALS AND METHODS

Experimental set-up

Experiments were conducted on a 1-1 shell and tube heat exchanger. The Fig. 1 shows the schematic diagram of a 1-1 shell and tube heat

exchanger. The cold water was allowed to flow through the tubes while the hot water in the annular area between the shell and the tubes. The water source was the common tap water. The flow of the two liquids is counter-current in direction.



1-1 Shell and tube heat exchanger.

Experimental procedure

The experiments were conducted with water both as the hot and the cold fluid. The geyser used for heating the water was set with a cut-off temperature of 100 °C. For every set of data it was waited until steady state is reached. At the steady state the inlet and outlet temperatures of both the hot and cold fluids do not change for a particular flow rate. The experimentation involved four major steps.

- i. Operating Boundaries.: First of all the operating boundaries of the heat exchanger was determined. Then the heat exchanger was operated at various combinations of cold and hot water flow rates ranging from 2000 LPH to 5000 LPH. Then an operating space was determined by plotting hot water flow rates versus hot water temperature.
- ii. Tube Side Analysis.: Initial trials were conducted keeping the hot water flow rate constant while varying the cold water flow rates. After each increase in cold water flow rate, it was waited until the flow rates reached steady state.
- iii. Shell Side Analysis.: This time step 2 was repeated except the cold water flow rate was maintained constant and the hot water flow rate was varied.
- iv. Data Duplication.: The procedure of steps 2 and 3 were repeated a few times to achieve steady state and to ensure that the data was reproducible.

Instrumentation

The C-factor principle is quite effective in carrying out the detection of fouling in industrial equipments without much

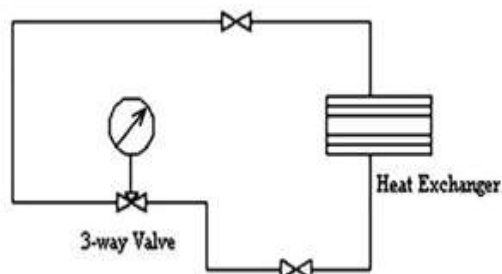


Fig. 2. Heat Exchanger fitted with single pressure gauge with 3-way valve for monitoring pressure drop.

additional instrumentation. Although some special instrumentations are required, but the cost can be justified by the predictive value of this method.

Once a critical heat exchanger is identified for the application of C-factor principle, the measurements required for analysis are the flow rate and pressure differential. For measurement of pressure differential a single or differential pressure gauge is mounted on the heat exchanger as shown in Fig. 2. To measure the pressure differential, one point on each side of the exchanger outside of any screens or other orifices or obstructions were taken into consideration. By using small diameter tubes, fluid is tapped into each line and then both are connected to a single or differential pressure gauge to measure the pressure differential.

The use of a single or differential pressure gauge is advantageous rather than two separate gauges to measure the pressure differential.

- As there is only one measurement, therefore no much cumbersome calculations are required.
- Only one instrument needs to be calibrated for better accuracy of the system.
- No correction is required for different elevations.
- A differential pressure gauge can be suitably set up for continuous monitoring.

The accuracy in flow measurement affects the usefulness of the C-factor. The flow is measured by using a Doppler flow metre. Once the flow and differential pressure are known, the C-factor can be easily determined by using the mathematical formula.

Fouling behaviour of heat exchanger

From previous work, the C-factor can be correlated to fouling factor by considering a uniformly thick

calcium phosphate scale of thickness 1.5 mm. The previous performance of the exchanger is illustrated in Fig. 3 and Table 1. The expected fouling factor is 0.003

Design Fouling Factor.	Fouling Factor (f)	C-Factor	C-Dirty/C-Clean
Clean	0	1040	100%
Design-clean	0.0005	980	94%
	0.001	930	89%
	0.002	785	76%
Design-dirty	0.003	680	65%

Table 2
C-factor of heat exchanger during cleanup.

Day	Flow (LPH)	Pressure drop (kPa)	C-Factor
1	2305	25	461
2	2213	23	459
3	2204	23	457
4	2336	29	433
5	2288	26	449
6	2291	27	443
7	2325	27	449
8	2325	29	435
9	2310	28	439
10	2310	29	425
11	2241	25	448
12	2388	26	469
13	2128	21	470
14	2126	20	479
15	2129	19	492
16	2886	11	882
17	2864	12	864
18	2845	11	858

which is considered as dirty value for design calculations in almost all chemical process plants. At this dirty level of fouling, the C-factor got dropped to about 35% of the design value. For a value of fouling factor value of (f) 0.002, the C-factor dropped around 24% from the designed value. Though this is an exemplary value of the exchanger considered for analysis, but the correlation for any specific exchanger in field application can be calculated by using commercially available packages such as Hextran program.

III. RESULTS AND DISCUSSION

The experiments were conducted over a time span of around 2 years from February 2008 to April 2010. For every acquisition of data, steady state is reached allowed to reach. However in this work the experimental data during a cleanup program is presented for illustrating the significance of the C-factor.

The design specifications of the heat exchanger show a flow rate of 2700 LPH with a pressure drop of 7.6 kPa for the hot fluid flowing through the tubes. Hence the C-factor corresponding to design specifications is calculated to be

$$C = V / \sqrt{\Delta P} = 2700 / 7.6 = 980$$

The flow rate and the pressure differential were changing during the cleanup. From the variations of the C-factor as illustrated in the Table 2, it can be concluded that the exchanger was undergoing fouling since C-factor dropped from 461 to 433. A comparison of these values of C-factor with the design value of 980 shows a drop of around 56%. This clearly indicates that the exchanger was heavily fouled.

Initially pretreatment was done by circulating a cleaning solution of polyphosphate, surfactant, and antifoam to remove light rust, calcium carbonate scale and hydrophobic materials deposited on the tube surface. The temperature was maintained at 60e80 °C and the pH was controlled in the range of 5.5e7.0. It was interesting to note that there was slight improvement in the C-factor value from 425 to 469 during the pretreatment phase before beginning of tannation. The results of the pretreatment phase are summarized in Fig. 4.

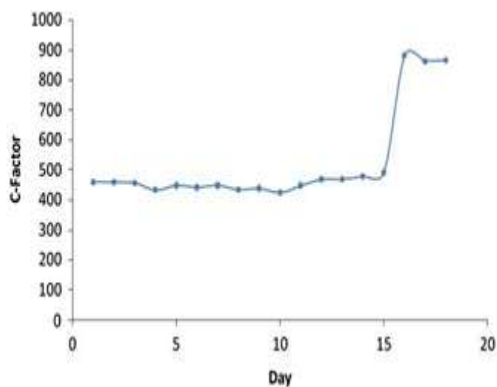


Fig. 4. C-Factor of the heat exchanger during cleanup.

During the tannation phase followed by pretreatment, the tubes were circulated with hydrolyzable tanning extracts of solution concentration between 250 and 300 ppm and a pH of 4.5e6.0. During this phase spanning over 15e18 h, the C-factor increased gradually from 469 to 492.

Fig. 5 shows the variation of fouling factor during this cleaning phase. It indicates that the fouling factor reaches a maximum value of 0.0039 while the corresponding C-factor value attains a value of 433. For the specified operating conditions of the exchanger, the design dirty value of fouling factor is 0.003 which indicates that the exchanger is heavily fouled corresponding to the operating condition when C-factor has dropped to 433. Similarly during this period of study the lowest value of fouling factor attains a value of 0.00086 during the citration phase when the corresponding C-factor attains a value of 866. The design clean fouling factor is 0.0005 while the design clean C-factor for the exchanger is 980. It can be well understood that towards the end of the citration phase.

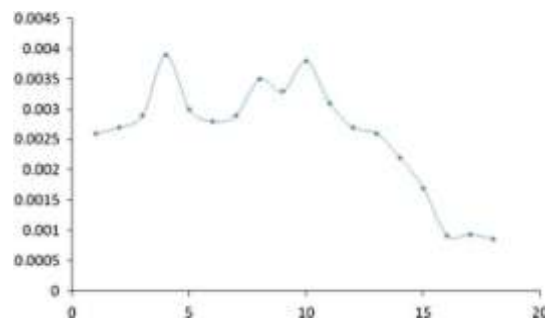


Fig. 5. Fouling resistance factor during cleanup

Fig. 6 indicates that when the exchanger is heavily fouled, the cleanliness factor drops down to 34% and simultaneously the C-factor reduces to 425 which is around 43% of the designed value. Towards the end of the cleaning phase, the C-factor rises up to 882 which is 90% of the designed clean value. At this stage of operation the cleanliness factor reaches approximately 80%. Hence the C-factor can be used as an indicative parameter to specify the cleanliness factor and hence the operating condition of a heat exchanger subjected to fouling.

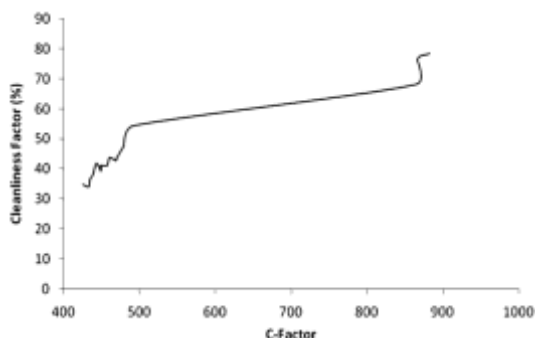


Fig. 6. Variation of cleanliness factor (CF) with C-Factor.

IV. CONCLUSION

In the present study the use C-Factor is used as an invaluable tool for investigation of performance of a shell and tube heat exchanger under fouling condition. The C-factor can be used for preparing cleaning schedule in chemical process industries so that the idle time can be reduced to possible minimum and simultaneously the heat exchanger running with poor performance can be avoided. The C-factor gives an indication of the extent of fouling on the heat transfer surface which can not be estimated from the outside of the exchanger body. prediction of fouling without opening the exchanger which is very much a complicated process. As compared to other online methods of fouling monitoring, the use of C-factor eliminates the measurement of end temperatures and effect of changes in properties of both hot and cold fluids during operation. Thus systematic calculation of C-factor with accuracy in measurement of flow and pressure drop provides an effective means for prediction of decrease in heat transfer efficiency for effective preventive maintenance scheduling of the heat exchanger. Besides, this analysis uses only two factors namely flow and pressure drop for which neither much more special instrumentation nor cumbersome mathematical calculation is required. This can be used for continuous monitoring of a heat exchanger system and improved maintenance scheduling.

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