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MODELING OF THE DEPOSIT FORMATION ON SHELL AND TUBE HEAT EXCHANGER OF HASHEMINEJAD GAS REFINERY PLANT

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ABSTRACT

In this paper, several models for fouling of/in one of the converters were revised in the unit of gas refiner in oil and Gas Company of SARAKHS. Oil fouling is done in pipe. First, given data acquired from intended industrial unit, the extent of fouling resistance is calculated in various times using input temperature and input flow rate. it is necessary to mention that input temperature and flow rate don't have constant throughout time and as well as don't have regular falling or raising trend based on time. And for this reason the extent of changes in fouling resistance to time is as saw-tooth. so although the drawn linear model accords to data in some cases, it isn't efficient for exact designing. In non-linear model acquired from balancing fouling, the extent of increasing and decreasing have relatively accordance with the calculated extent. Finally, fouling threshold model was revised, which is true for Iran's petroleum. Here the extent of oxidization resulted from chemical reaction is calculated which is done in the range of surface temperature regarded, and also threshold curves for this converter was drawn and analyzed.

KEYWORDS: Heat Exchanger, Fouling, Threshold Model, Gas Refiner Unit

Heat exchanger is a tool which transfer heat energy from one fluid to one or more fluid containing a various temperature. Heat exchangers have very widespread applicability and were used in different industries such as powerhouses of generating electricity, refiners, nutritive industries, pharmacy, petrochemical industries, refrigerators, heater and cooler systems of buildings and generally in where is the issue of energy interchange. Additionally the necessity of saving in consuming energy and prevention of its waste and also attention to the problems of environment contamination make more tension of heat exchangers. These are in various forms such as kendenser, boilers, evaporators, kilns, coolers and heaters, and etc. meantime the role of shell-pipe heat exchangers is very significant so that almost nearly half of the whole of heat exchangers market is consisting this kind of those. The modeling of shell-pipe heat exchangers accompany with complexities and difficulties, which each one will be effective in expanding the model or its solution. most important problems and complexities existed in modeling equipments are being unclear the direction of fluid flow in shell due to geometrical complexities and existing a leakage and side flow, spreading the variations of shell and pipe exchangers and difference in their geometrical structure, the possibility of being double-phase of fluids in shell and pipe and the complexities of relations existing in compared with one-phase status, and as well as fouling phenomenon and its impact on transferring heat and falling the pressure inside heat exchangers.

The advantages of exchangers, following [2]:

1. Those cause a large level for transferring heat in low volume
2. Those have mechanical designing
3. Those have good stabilized manufacturing method
4. Those have use capability for a wide range of materials.
5. These can easily clean

STATEMENT OF THE TOPIC

Issues and Problems to Which Shell-Pipe Heat Exchangers are Encountered are Mechanical Tensions, Vibration, Erosion

Mechanical Tensions

Any exchanger is exposed to mechanical tensions from various sources and also temperature gradation and these mechanical tensions result from the structural techniques of exchanger. in most of the time there are unforeseen tensions at the moment of producing, transporting, and installing exchangers, which are imposed to those. [3]

Some of these tension mainly have very much difference at the moment of normal operation of equipments than manufacture time or ending work, which are tensions as a result of the reaction of construction

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fulcrums to exchanger weight and from connective pipes. Finally, tensions inside exchanger occur due to the conditions of flow procedure (especially pressure) when operation.

Vibrations

A very serious issue in designing exchanger mechanically speaking is the flow that cause vibration in tube. It is possible to occur several detriments because of tube vibration so that all of those are harmful, as causing pits in tube. In many of cases it, may encounter tube with adjacent tube so that cause a pit [4]. or the repeated pressure of tube near to @fulcrum such as pipe surface can cause crevices in tube and releasing pipe continuities and expediting corrosion faster. vibration are due to using consecutive and asymmetric forces to pipe.(but) most common in heat exchangers is fluid rotation movement in the length of pipe for example fluid flow among tube. asymmetric forces are rarely weak but those occur tens, hundreds, thousands times in second and the quantity of those will increase rapidly by raising the velocity of fluid, however these forces become inactive without a damage to pipe although it can oscillate in given frequency.(normal frequency)

Corrosion (Erosion)

One of the fundamental issues and problems in designing heat exchangers is corrosion issue, and means that a metal is corroding rapidly due to the friction of the inside fluid flow or among pipes. the extent of corrosion depends on metal - harder metals have less corrosion while another factors equal together, velocity, fluid density, and the geometry of system[1]. so mostly corrosion is more intensive in the inlet of pipe and in U curvature of tube.

Fouling Problems in Shell-Pipe Heat Exchangers

Fouling in the procedure has directed economical influence on profitability and generally impose considerable expenditures in order to cleaning exchangers on a refiner so that half of operational expenditure in oil distillation unit are expenses that spend to encounter with fouling. as well as, along with decreasing the efficiency of exchangers due to fouling, it is required to burn more fossil fuel for heating oil, which can itself cause increasing green-house gases and environmental contamination. furthermore it is used poisoned chemical materials for cleaning exchangers fouled so sewage resulted from those itself make intensive damages to environment therefore fouling in industry is a serious economical and environmental issue then it is necessary to consider this phenomenon more serious and fundamental.

FOULING CALCULATIONS

To obtain the quantity of fouling it should use basic equation of heat transferring in this manner (equation 1)[7].

$$R = \frac{1}{U_f} - \frac{1}{U_c} \qquad (1\text{-}3)$$

In the equation, U_c is total coefficient of heat transferring in clean status and U_f is total coefficient of heat transferring in fouling status it is necessary to mention that calculating fouling by this method has especial advantages ,following: in this method it is considered fouling formation in both directions of shell and pipe. as previously said, threshold models of fouling do not have that capability because those only consider fouling in pipe, and fouling resulted from chemical reaction[9].

Calculating total coefficient of heat transferring in clean status (U_c):

Total coefficient of heat transferring for cleaning surfaces is calculated by following equation, (equation 2), [9].

$$U_c = \frac{h_{jo} h_o}{h_{jo} + h_o} \qquad (2\text{-}3)$$

At above equation, h_0 is the coefficient of replacing heat transferring in shell and h_{jo} is the coefficient of replacing heat transferring in pipe based on its external diameter. (calculating total coefficient of heat transferring in fouling status $\mathbf{U_f}$):

Using the measured quantities of temperature and intensify of input water to the exchangers of Hasheminejad refiner, heat burden in both direction of shell and pipe, according to equation 3, was calculated and then compared together. in order to make sure of accuracy of measured quantities, heat burden is compared because if these quantities did not have sufficient accuracy then heat burden in pipe do not equal to heat burden in shell.

$$Q = \left(\dot{m} C_p \Delta T\right)_{shell} = \left(\dot{m} C_p \Delta T\right)_{tube} \qquad (3\text{-}3)$$

On the other hand, total heat burden is calculable through following equation through following equation.

$$Q = U_f A_0 F_T \Delta T_{lm} \qquad (4\text{-}3)$$

In this equation, U_f is total coefficient of heat transferring in fouling status, A_o is total surface of heat transferring, and F_T is the factor of temperature correction which calculated for exchanger intended through following equation [5].

$$F_T = \frac{\left[\sqrt{R^2+1}\Big/\ln[(1-S)/(1-RS)]\right]}{\ln\frac{2/s-1-R+(2/S)\sqrt{(1-S)(1-RS)}+\sqrt{R^2+1}}{2/s-1-R+(2/S)\sqrt{(1-S)(1-RS)}-\sqrt{R^2+1}}} \qquad (5\text{-}3)$$

$$R = \frac{T_1-T_2}{t_2-t_1} \qquad (6\text{-}3)$$

$$S = \frac{t_2-t_1}{T_1-t_1} \qquad (7\text{-}3)$$

T_1 and T_2 are respectively input-output temperature of hot fluid and t_1 and t_2 are input-output temperature of cold fluid. ΔT_{lm} is average temperature difference of logarithm which is such as F_T a function of input-output temperatures in (direction of) pipe and shell.

$$\Delta T_{lm} = \frac{(T_1-t_1)(T_2-t_2)}{\ln(T_1-t_1)/(T_2-t_2)} \qquad (8\text{-}3)$$

Using the quantity calculated in equation 3, left side of equation 4 is obvious . also in the right of equation 4 the quantities of $A_{o,}$ F_T, and $\Delta T_{lm}$are obvious so total coefficient of heat transferring in fouling status is obtaining by equation 9.

$$U_f = \frac{Q}{A_0 F_T\,\Delta T_{lm}} \qquad (9\text{-}3)$$

Finally, the quantity of fouling formed in exchanger is obtained by replacing the quantities of Uf and Uc in equation 1.

$$R = \frac{1}{U_f} - \frac{1}{U_c} \qquad (10\text{-}3)$$

The Method of Linear Modeling

$$R_f = \alpha(t - t_1) \qquad (1\text{-}4)$$

$$R_f = \alpha t - \alpha t_1 \qquad (2\text{-}4)$$

Differential equation of linear equation

$$y = ax + b \qquad (3\text{-}4)$$

In the equation, $Y=R_f$ and x=t

At here R_f and t - we have those from the chart of fouling changes than time - replace in equation. We can obtain a and b, respectively gradient and intercept, by regression.

$a = \alpha$X=t

* b= - αt_1

*$t_1 = -\frac{b}{\alpha}$

Now we have t_1 then can also obtain α and instead of different t can achieve different R_f and as a result the chart R than time will draw as linear.

The Method of Non-Linear Modeling

Karen and siton have proposed a model based on it distinguish physical content of fouling.

Extracting the model of karen and siton from balancing foul

$$\frac{dx_f}{dt} = K_1 CM - K_2 \tau X_f$$
(1-5)

*:fouling rate analogue to first degree reaction

*: velocity of separation

*: the constant of formation velocity

*: the concentration of foul-maker factor

*: the intensify of fouling flow

*: thickness of fouling layer in time t

*: shear tension which is obtaining from equation $\frac{f\rho u^2}{2}$

*: the friction coefficient which is calculated from equation $\frac{16}{Re}$

assuming that c and m is constant we can integrate as so, which of course this assumption is rational for heat exchangers of monotonous flow.

$$\frac{dx_f}{d\tau} = K_1 CM - K_2 \tau X_f \qquad (2\text{-}5)$$

$$\frac{dx_f}{dt} + K_2 \tau X_f = K_1 CM$$

which is analogue following linear equation

$$\frac{dy}{dt} + p(x)y = q(x) \qquad (3\text{-}5)$$

$p(x) = K_2\tau$

$q(x) = K_1 CM$

$y=x_f$

So above equation is a linear equation. integral factor for a linear differential equation with variant coefficient is proposed by following data. $exp\int P(x)dx = exp\int K_2\tau dt = exp[K_2\tau t]$ (4-5)

The statement of $exp[K_2\tau t]$ is multiplied in primary equation.

$$exp[K_2\tau t]\times\frac{dx_f}{dt} + exp[K_2\tau t]\times K_2\tau x_f = exp[K_2\tau t]\times K_1CM \quad (5\text{-}5)$$

this equation is equal to following equation.

$$d/_{dt}\left(e^{K_2\tau t}.x_f\right) = K_1CM.e^{K_2\tau t} \quad (6\text{-}5)$$

$X_f = x_{f,h} + x_{f,p}$ *

$$\int\frac{d}{dt}\left(e^{K_2\tau t}.x_{f_h}\right) = 0 \Rightarrow e^{K_2\tau t}.x_{f_h} = c_1 \Rightarrow x_{f_h} = \frac{c_1}{e^{K_2\tau t}} \quad (7\text{-}5)$$

$$\int\frac{d}{dt}\left(e^{K_2\tau t}.x_{f_p}\right) = \int K_1CM.e^{K_2\tau t} \Longrightarrow \quad (8\text{-}5)$$

$$\int e^u = \frac{1}{u'}e^u$$

$$e^{K_2\tau t}.x_{f_p} = \frac{K_1CM.e^{K_2\tau t}}{K_2\tau} \Rightarrow x_{f_p} = \frac{K_1CM}{K_2\tau}$$

now we are setting the quantities of two equations x_{f_p} and x_{f_h} in the main equation

$$x_f = \frac{C_1}{e^{K_2\tau t}} + \frac{K_1CM}{K_2\tau} \quad (9\text{-}5)$$

using following conditions to obtain C_1:

t=0

x_f=0

namely, any fouling is not formed in time 0

$$0 = C_1 + \frac{K_1CM}{K_2\tau} \Rightarrow C_1 = -\frac{K_1CM}{K_2\tau} \quad (10\text{-}5)$$

$$x_f = \frac{-\frac{K_1CM}{K_2\tau}}{e^{K_2\tau t}} + \frac{K_1CM}{K_2\tau}$$

$$x_f = \frac{-K_1CM}{e^{K_2\tau t}.K_2\tau} + \frac{K_1CM}{K_2\tau}$$

$$x_f = \frac{-K_1CMe^{-K_2\tau t}}{K_2\tau} + \frac{K_1CM}{K_2\tau} \quad (11\text{-}5)$$

now we write this equation as so

$$\Rightarrow x_f = \frac{K_1CM}{K_2\tau} - \frac{K_1CMe^{-K_2\tau t}}{K_2\tau}$$

$$x_f = \frac{K_1CM}{K_2\tau}\left(1 - e^{-K_2\tau t}\right) \quad (12\text{-}5)*$$

fouling resistance is calculated by following equation

$$R_f = \frac{x_f}{k_f} \quad (13\text{-}5)$$

now we replace the formula containing star in above equation

$$R_f = \frac{K_1CM}{k_fK_2\tau}\left(1 - e^{-K_2\tau t}\right)$$

$$\boldsymbol{R_f = R_f^*(1 - e^{-K_2\tau t})} \quad (14\text{-}5)$$

$$\boldsymbol{\beta = K_2\tau}$$

The Model of Fouling Threshold

This model has attributed the sentence of fouling * to the Re number and it is designing a briefer form the findings of saleh et al on the australian light petroleum [9].m

$$\frac{dR_f}{dt} = \alpha Re^{\beta}exp\left[\frac{-E}{RT_f}\right] - Re^{0.4} \quad (1\text{-}6)$$

in this equation E is the activation energy and to obtain it, it should draw fouling rate in terms of the contrary of film temperature.

in order to obtaining film temperature we can use following equation.

$$T_f = T_b + 0.55(T_s - T_b) \quad (2\text{-}6)$$

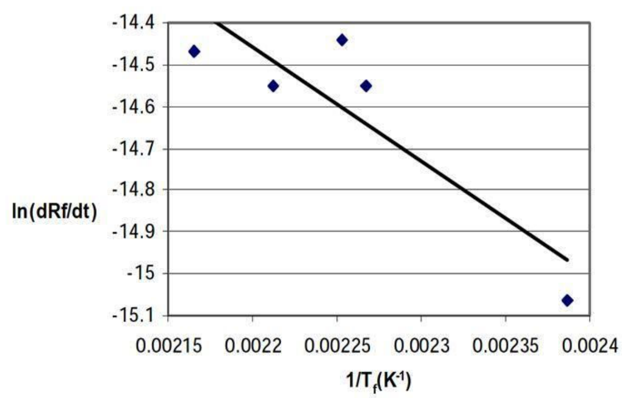

Figure 1-6: Obtaining E in terms of fouling rate and the contrary of film temperature

FINDINGS

Findings Resulted From Fouling Calculations Based On Input and Output Temperature

With increasing fouling thickness on the surfaces of heat exchanger pipes and in addition to falling heat operation of exchangers, reducing their pressure also increase and need to use more energy in pumping feed in order to stabilize the capacity of unit. the status shown in figure 2 is named saw-tooth and occur more in industrial centers which fall into suddenly changes and disordered operational conditions. here the changes of fouling resistance do not have a raising and falling trend regular and are drawn as saw-tooth because of irregular changes of flow rate and input temperature in times, in other words different points of chart. of course in some of these points, this strongly and suddenly increasing or decreasing represented in chart as up and down ticks are considered as an error in measuring and we disregard these points in modeling. the chart of petroleum fouling in exchanger intended obtained in accordance with figure 2. this chart show the action of petroleum fouling procedure in exchanger after some 3 years of servicing. as shown, the action of petroleum fouling procedure in this industrial exchanger is as saw-tooth, mentioned in figure 2. the rising and falling of fouling chart results from the actions of different operational conditions and also complex nature of petroleum fouling procedure. although have yet remained unknown the impact of different factors and tens of longer parameters on the behavior of petroleum fouling but it can said through a rule of thumb: the extent of fouling formation increase if the intensity of oil flow decrease and the temperature of input flows to exchanger increase (raising the chart of fouling) and naturally it is decreased petroleum fouling if the intensity of petroleum flow increase and the temperature of input flows to exchanger decrease (falling the chart of fouling).

It is required to mention that those factors efficacious on petroleum fouling are the inclination of asphalten absorption to mental surface and fouling surface, the mechanism of surface reactions, the presence of suspended particles in petroleum flow, the impact of various elimination, and the impact of produces resulted from corrosion.

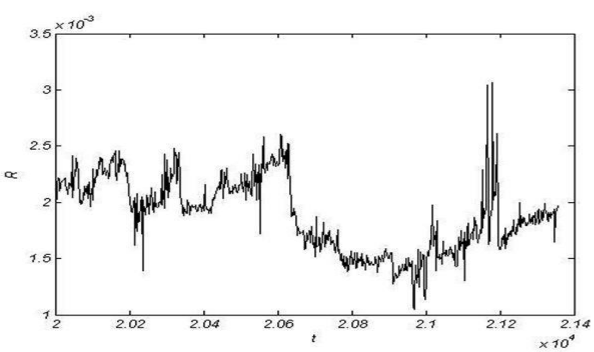

Figure 1: The changes of fouling resistance quantity in terms of time on the basis of input - output cold - hot temperatures

Revising Findings Resulted From Linear Model

In this method it has been used linear equations related to fouling. if we draw the changes of fouling resistance in the exchanger to time, then it is achieved one straight line with decreasing trend (figure 1) of course this result do not agree with the result expected because it is expected that however time increases, the extent of fouling resistance increases. this difference is due to changes in flow rate and input temperature and that input data for modeling has not been entered from time 0 and we assume that 20000 hours has spent from starting exchanger. it means that after spending time and grow fouling to a critical extent due to increasing input velocity or changes of input temperature, fouling resistance is decreasing because of reducing fouling thickness.

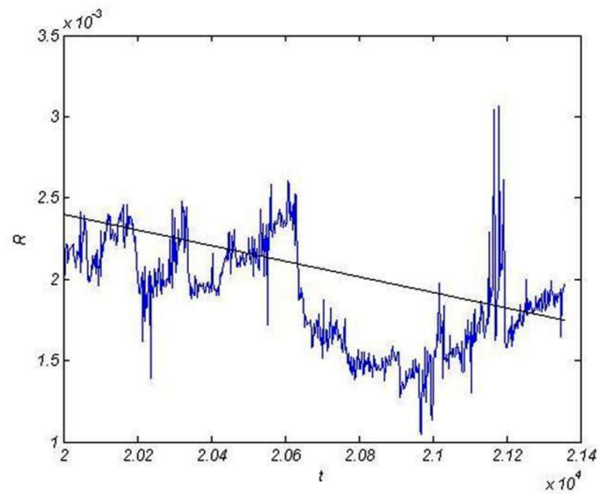

Figure 2: Comparing the linear model with the quantities resulted from fouling resistance changes

Findings of Non-Linear Model of Fouling

Most of the fluid features and foul-maker material are in the model and thus findings resulted are infinitely near to findings resulted from calculations. since the drawn model (figure 3) follow a pattern determined according to equations, this model do not show some cases in which has obtained a suddenly increasing or decreasing in calculations and of course these cases are a part of calculations error. exact disagreement of this model with findings resulted from calculation can probably consider as accuracy as constants used.

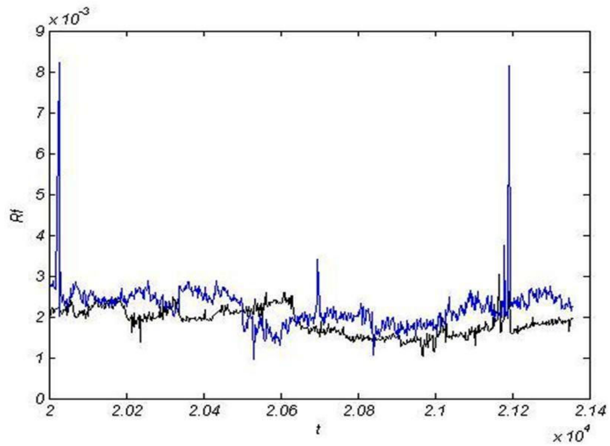

Figure 3: Comparing the non-linear model with the chart of fouling calculations on the basis of input and output temperatures

Finding of Threshold Model of Fouling

Oil has been formed very various components so that action and reaction among these components have not yet recognized absolutely. traditional analysis methods usually do not be able to analyze complex procedures containing a number of independent variables. especially although the extent of influence of these variables on another has not been distinguished completely. in the threshold models, different factors have been proposed to form or furbish fouling which in some of those it is addressed to the factors of shear tension , in some cases foul transferring, and in some velocity but because the combination of input feed percentage and chemical and physical properties is variable thus it cannot say which one give optimal result. it was shown the impact of temperature on fouling in figure 4. as seen, the influence of partition temperature is very intense and significant. based on this figure, raising temperature increase fouling intensity and if fluid temperature of exchanger shell is less than 202 degree of centigrade, fouling rate decrease less than half [6]. any oil depending to its structure become unstable in given temperature range and is formed asphaltene fouling in its mass [8].

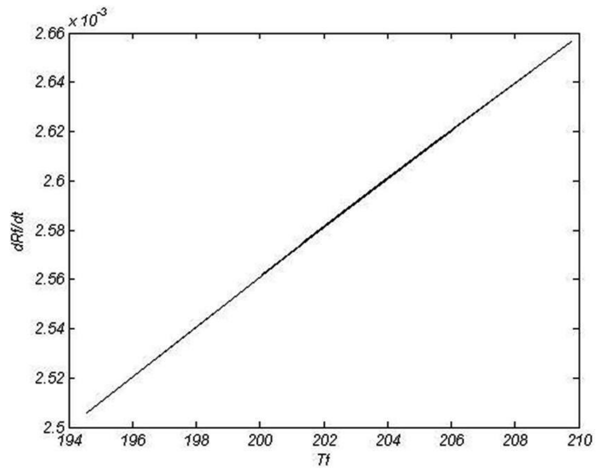

Figure 4: The changes of fouling resistance in different times in terms of film temperature

CONCLUSION

In this paper and using (empirical) industrial information gathered relative to exchanger 1604 in hashemi nejad gas refinement unit , some 675 data for modeling of oil fouling were used via linear, non-linear, and the threshold of fouling using mat lab software. following data were selected as the inputs of model:

1) Input temperature of oil, 2) output temperature of oil, 3) a bulky flow rate of oil, 4) time ,and the quantity of fouling calculated by equations of heat transferring was used as the output of the model.

The form of fouling resistance changes to time drawn as saw-tooth due to the irregular changes of input temperature and flow in different times.

The linear model drawn rather accord with the findings of calculations. of course considering that graph is linear, this model do not be able to foresight the quantity of fouling precisely.

In non-linear model there are most of the fluid characteristics and foul-maker substantial as a result the finding resulted is near to the findings of calculations and show the changes of fouling.

In threshold model, the influence of partition temperature is very intensive and considerable and when increasing temperature ,the fouling intensity increase.

Increasing the intensity of petroleum flow cause increasing shear tension in partition and consequently cause separating part of the fouling of partition.

As shown in the findings of fouling threshold model, fluid velocity inside pipe had a considerable influence on fouling intensify and increasing velocity decreased fouling.

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