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Cleaning schedule for increased energy efficiency on heat exchanger process: Sugar plant case study

D H A Sudarni*

Universitas PGRI Madiun, Madiun, Indonesia

*dhy.anayu@gmail.com

Abstract. THE process in a plant, which has had integration heat for energy recovery, fouling or the formation of a precipitate on a heat exchanger (heat an exchanger) often pose a problem in the production of operational. As increase energy consumption so as to cause economic loss. Loss can be reduced if it is undertaken cleansing routinely. Next up is how problems to timetable cleansing instrument an exchanger heat exchanger (heat in a complex in an industry that efficient). A schedule cleaning in heat may be based on knowledge about the behaviour of fouling how fast the thermal resistance. In general research will be conducted to use a calculation model of mathematics for scheduling optimizations cleaning on heat exchanger network (HENs and it can be applied in the chemical industry. Fouling increase to the function of time, in this study model mathematics developed to determine many the act of cleaning and time where the money to be cleared industry that operational can optimally.

1. Introduction

The incorporation of heat exchanger networks (HENs) is very important for heat energy recovery. In practice, sediment is often formed or commonly called fouling in heat exchangers. The formation of deposits or fouling on the surface of heat transfer can inhibit the ideal operation and cause economic losses [1]. One of these disadvantages is an increase in energy consumption and also in certain conditions there can be an unwanted plant termination only to clean the heat exchanger. Stopping the plant like this can be avoided in principle if on-line cleaning scheduling is applied from each heat exchanger [2]. One common way to reduce fouling is by applying Cleaning-In-Place (CIP) operations. This is especially true for processes that are influenced by quickly, such as in the dairy industry [3]. Energy saving, pollution reduction and energy optimization are intrinsically interrelated and this cluster of issues constantly grows in importance [4].

2. Method

2.1. Identifications constrains

Constraints are the rules that are manipulated to determines how a system operate under the provisions of. On this research, constraints would be decided be driven by demand from in order to get the results of a simulation optimizations the most optimal and logically in it is implemented. The determination of constraints to introduce is more detailed in sub section.



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2.2. Cleaning schedule model

The mathematical model in this study is an algorithm to determine the cleaning schedule in the range of 1 times the factory operation cycle (from start-shut down) which is the most optimal with predetermined constraints. The purpose of the optimal in this study is to produce the lowest cost so that the objective function of this modelling is the minimum cost of the utility. This model shows the fouling characteristics of a heat exchanger [5]. The assessment characteristics of the design exchange. Eq 1.

$$Q = U \cdot A \cdot \Delta T_{LM} \quad (1)$$

Characteristics (U) of time which means that at each operating time, (U_f) will lose its ability to recover energy due to fouling. Changes in the value of this (U_f) will have an effect on total energy recovery in the process. *equ 2*. According to Kern [6] the value of overall heat transfer coefficient (U) in a heat exchanger can be determined based on the type of flow (fluid) process and the type of exchanger used as follows table 1.

Table 1. Process data.

Type	Material	T _{in} (°C)	T _{out} (°C)	m.cp (W/hr.°C)
C1	Nira	98	105	0,26
C2	Nira	110	115	0,34
H1	Nira	124	121	0,84
H2	Nira	117	115	0,56

This optimization model, it is assumed the time used for cleaning is long enough, so that the load will increase to compensate for the energy requirements lost during clean time. This optimization remains the same, namely to minimize the additional costs of the utility cost due to fouling during the operating period. The cleaning scheduling model is formulated to minimize utility costs. The explained by Kren [4] that in practice, R_f value can be obtained from experience when the devices need be cleaned only once operation period. It depends on the radius of used pipe and also the fluid material that flow inside this device. Assumed that heat transfer area, A in m² are constant. This is making sense in the fouling problem there will be significant changes in the energy recovery. Exponential approach is used to explain how the heat transfer coefficient (U_f) decreases with time as a result of fouling.

$$U_f = a \cdot e^{-b \cdot t} \quad (2)$$

U_f and t are two variables that want to know their characteristics and relationships, so it can be concluded, that U_f value will change - change for each t, where t is the length of the production period. As for the coefficients an and b in the equation, can be calculated by observing the initial conditions and final conditions. For more detailed calculations can be seen in the attachment section. So that in the end there will be a characteristic equation between U_f (overall heat transfer coefficient in fouled conditions) and t (time) for each heat exchanger.

2.3. Cleaning schedule model with cleaning time

This optimization model, it is assumed that the time used for cleaning is long enough, so that the utility load will increase to compensate for the energy needs lost during cleaning time.

The purpose of this optimization remains the same, namely to minimize the additional costs of the utility cost due to fouling during the operating period. The cleaning scheduling model was formulated to minimize utility costs. Eq 3.

$$\text{Utility cost} = Q \cdot k_q + n_j \cdot k_{c,j} + \left(\sum_{j=1}^j n_j \cdot Q_{HE,cl} \cdot \tau \right) \cdot k_q \quad (3)$$

With constraints from Eq 4 to Eq 6:

$$Q = \left(\sum_{j=1}^j \int_0^{t_e} Q_{HE,cl} \right) - \left(\sum_{j=1}^j Q_{rec,j} \right) \quad (4)$$

$$Q_{rec,j} = n_j \left(\int_0^{t_{clean}} U_f \cdot A \cdot \Delta T_{LM} \cdot dt \right) \quad (5)$$

$$t_{clean} = \frac{t_e}{n_j} - \tau \quad (6)$$

$Q_{HE,cl}$ is the heat load for each exchanger ($j = 1, 2, \dots$) and τ (day) is the length of cleaning time. t_e (days) is the production time in a production period. Variables A and ΔT_{LM} are considered constant throughout the production process.

2.4. Cleaning scheduling model with capacity tolerance heat exchanger

The constraints on this model are how much the tolerance of the capacity of the heat exchanger decreases, therefore cleaning scheduling will percent loss capacity. By using the Eq 7.

$$Q_{HE,cl} - (Q_{HE,cl} \cdot \%Q_{Loss}) = Q_{HE,cl} \cdot e^{-x \cdot t} \quad (7)$$

Where $Q_{HE,cl}$ is the heat exchanger and x is the fouling characteristic variable for heat exchanger.

3. Results and discussion

The optimization results using the second model, by setting the variable $kq = 0.005$ \$ / (BTU.hr-1), the variable $kc = 4.838$ \$ / cleaning action for the first HE, 3.143 \$ / cleaning action for the second HE, 1474 \$ / cleaning action for the third HE, and 499 \$ / cleaning action for the fourth HE and τ (cleaning time) for 1 day, 2 days and 3 days will get the results of the relationship of the characteristics of the total energy costs with the amount of cleaning (respectively for $\tau = 1$ day, 2 days and 3 days) so that it can be plotted as follows (figure 1, 2, and 3):

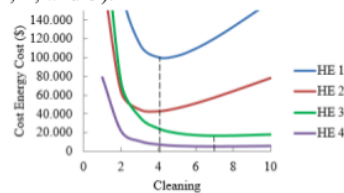


Figure 1. The ties of characteristics of the total energy cost with the amount for cleaning scheduling optimization with $\tau = 1$ day.

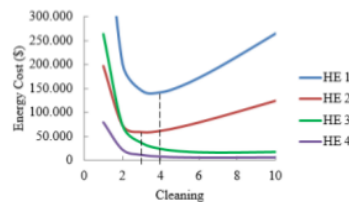


Figure 2. The ties of characteristics of the total energy cost with the amount for cleaning scheduling optimization with $\tau = 2$ day.

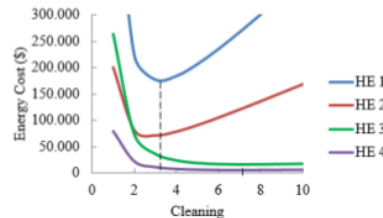


Figure 3. The ties of characteristics of the total energy cost with the amount for cleaning scheduling optimization with $\tau = 3$ day.

When viewed from the cleaning time based on the performance limits of the heat exchanger, the results will be obtained as in table 2.

Table 2. Performance limit of heat exchanger before cleaning for cleaning with $\tau = 1$ day, 2 days and 3 days.

HE	Q rec %		
	$\tau = 1$	$\tau = 2$	$\tau = 3$
1	90.3337	90.3337	87.3239
2	92.7744	90.4838	90.4838
3	93.7884	93.7884	93.7884
4	94.5051	94.5051	94.5051

This scheduling optimization is tolerance of the capacity of the heat exchanger decreases, therefore cleaning scheduling will follow based on the percentage loss capacity (the capacity of the lost device caused by fouling). Eq 7.

Table 3. Cleaning of exchangers with a tolerance of 10%, 20%.

Percent	HE 1	HE 2	HE 3	HE 4
	τ days			
10 %	77	105	70	80
20 %	164	223	149	169

There will be a time when the heat exchanger will be cleaned. So if applied to each exchanger, the following results will be obtained, for the first exchangers in a row for 10% Loss, and 20% Loss table 3.

4. Conclusion

Mathematical models have been developed for scheduling the cleaning of heat exchangers based on behavior of thermal resistance fouling against time following exponential functions. Cleaning scheduling optimization model if it requires the time obtained is less sensitive to the capacity of a small heat exchanger (the area of the heat exchanger) so that it has little impact on the costs incurred. As for the large capacity, the longer the cleaning time causes the cleaning frequency to decrease. Cleaning scheduling on heat exchangers is greatly influenced by the design and selection of the tools and process fluids used. Formulated the relationship characteristics equation between time with the output temperature of each exchange device (heat exchanger) as a real step to control the cleaning of the appliance.

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