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RESEARCH ON FOULING MECHANISM AND CLEANING TECHNOLOGY OF SHELL AND TUBE HEAT EXCHANGER

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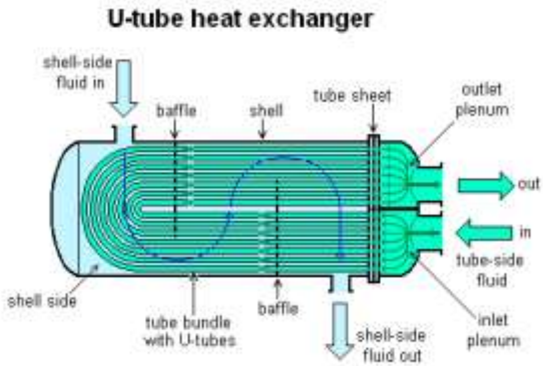
ABSTRACT
Fouling in shell and tube heat exchangers can result in low heat transfer efficiency due to the increase of heat resistance, large pump energy consumption from the high pressure drop in the shell side or tube side. This paper summarizes the fouling mechanism and cleaning technology of shell and tube heat exchanger. Fouling can be affected by fluid velocity, fluid composition, fluid flow state, and the structure of the shell and tube. Fouling can be reduced by using surface and fluid treatments, and removed by cleaning technologies, including high pressure water jet, mechanical and chemical approaches. Design of shell and tube heat exchanger can be improved to avoid fouling by adjusting the shell and tube structure, arranging the fluid flow sides, controlling the fluid velocity, and changing the temperature distribution of the shell and tube.

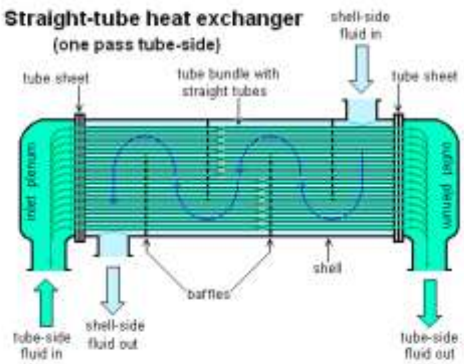
INTRODUCTION
Shell and tube heat exchanger is most widely used in industrial process and is suited for higher-pressure applications. It usually consists of a shell which is a large pressure vessel with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows through the shell to transfer heat between the two fluids. There can be various designs on the shell and tube. Figure 1 presents three typical shell and tube heat exchangers: (a) U-tube heat exchanger, (b) Straight-tube heat exchanger with one pass tube-side, and (c) Straight-tube heat exchanger with two pass tube-side [1]. Some shell and tube heat exchangers are designed four passes on the tube side.

In most industrial processes, heat exchanging fluids contain certain amounts of dissolved (such as Ca^{2+} and Mg^{2+}) or suspended materials. Design and operation of heat exchangers are still to a major extent determined by the process-related formation of deposits on the heat transfer surfaces, i.e., fouling. Since the thermal conductivity of such deposits is low, their resistance to heat transfer may well exceed that of the clean fluids, resulting in significantly reduced heat exchanger performance. Mariusz Markowski et al. [2] presented a novel method for on-line determination of the thermal resistance of fouling in shell and tube heat exchangers. It can be applied under the condition that the data on pressure, temperature, mass flowrate and thermophysical properties of both heat-exchanging media are continuously available. As a result, substantial safety margins in the design, pretreatment of hot/cold fluids and regular cleaning of equipment may be required [3]. Fouling types in shell and tube heat exchangers include scale, rust deposit, and particle fouling. C. Ahilan et al. [4] explored the development of an intelligent system to identify the degradation of heat exchanger system and to improve the energy performance through online monitoring system. Fouled/real system value was computed with online measured data. Overall heat transfer coefficient of clean/design system was compared with the fouled/real system. T. Takemoto et al. [5] used an improved method of analysis for the interpretation of fouling in shell and tube heat exchangers. It shows that the corresponding ‘apparent fouling resistance’ of a clean heat exchanger is higher the lower its temperature effectiveness.

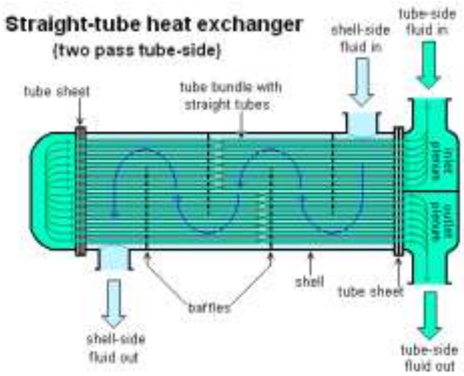
Figure:



(a)



(b)



(c)

Figure 1. Schematic diagram of common shell and tube heat exchangers

MECHANISMS OF FOULING FORMING

There are many factors affecting the fouling such as fluid velocity, fluid flow state, fluid composition and shell and tube heat exchanger structure. [6] For a fluid, the main factors that affect the fouling of shell and tube heat exchanger are the following aspects:

The flow velocity of the fluid

The effect of flow velocity on fouling should consider the effects of deposition and erosion of the fouling. For many kinds of fouling, the increase of flow velocity causes the increase of erosion rate more than the increase of deposition, therefore, the fouling growth rate decreases with the increase of flow velocity. However, in the actual operation of the shell and tube heat exchanger, the increase of the flow velocity will increase the energy consumption, therefore, the flow velocity is not the higher the better. Energy consumption and fouling should be considered together. Chao Shen et al. [7] investigated the effects of wastewater velocity and installation location of a shell-and-tube heat exchanger on particle fouling deposited within the heat exchanger. Both the asymptotic fouling resistances and the average particle diameter of fouling obtained with the heat exchanger installed at the suction-inlet of pump were larger than that with heat exchanger installed at the shoot-outlet.

The temperature of heat transfer surface

The temperature plays an important role in chemical reaction fouling and salt crystallization fouling. Increasing fluid temperature generally leads to the increases of chemical reaction speed and crystallization speed, so as to influence the deposition of fouling, resulting in the increase of fouling growth rate.

Material of heat transfer surface and its quality

For the common carbon steel or stainless steel, the deposition of corrosion products will affect the fouling. However, it is not easy to scale if non-metallic materials such as graphite or ceramics with good corrosion resistance are used. The surface quality of will affect the formation and deposition of fouling. The greater the surface roughness, the more conducive to the formation and deposition of fouling.

Fouling forming models

Fouling can be formed by four kinds of models [8] including curve 1, curve 2, curve 3, and curve 4 shown in Figure 2 and the equations can be expressed below.

Figure:

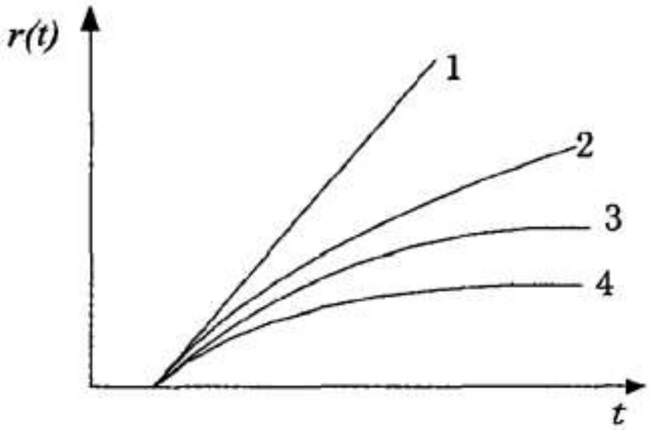


Figure 2. Sketch of fouling growing with time

Formulae:

$r(t)=Kt$ $\quad t\geq 0 \quad$ (1)

$r(t)=Kt^n$ $\quad t\geq 0 \quad$ (2)

$r(t)=K\ln t$ $\quad t\geq 0 \quad$ (3)

$r(t)=r^{\infty}[1\text{-}\exp(-t/\tau)]$ $\quad t\geq 0 \quad$ (4)

Fouling can be reduced by the impingement of fluid from the surface. As a result, the deposit of the surface in heat exchangers is affected by the superposition of the both increase and decrease. Dillip Kumar Mohanty et al. [9,10] used 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, and developed a local linear wavelet neural network based model to predict the temperature differences on both the tube and shell side and the heat exchanger efficiency. Mariusz Markowski et al. [11] elaborated a method of identification of the influence of fouling on the heat recovery in a heat exchanger network. Measurements of the mass flowrate and inlet and outlet temperature, and chemical composition are available for each process stream, this making it possible to evaluate fouling-induced reduction in the recovered energy flow.

STRATEGIES OF SOLVING FOULING

Fouling usually happens on surface during the fluid passing through it. There are three kinds of approaches to address the fouling: surface treatment, fluid treatment and fouling cleaning. Surface treatment technology is used to select the surface coating material and structure to change the condition of heat exchange surface to release the fouling accumulation [12]. Some chemicals such as scale inhibitor and corrosion inhibitor can be added into the fluid for the reduction of fouling forming. Fouling cleaning is usually performed by high pressure water jet, mechanical and chemical methods.

High pressure water jet fouling cleaning
High pressure water jet fouling cleaning use a utility to generate high pressure water for cleaning. Compared with the traditional water jet cleaning, high pressure water jet cleaning technology is more reasonable and suitable for using the property of water and its cleaning effect is better, and more widely used. Some large cleaning machines have the jet pressure at 50-140MPa and the flow rate at 50-60L/min [13]. The pressure and flow rate of the jet is determined by actual cleaning components and the fouling types. The main disadvantages of high pressure water jet fouling cleaning include, during the cleaning process, the strong vibration generated by high pressure water jet and very big noise pollution; at the same time it is not very ideal to the fouling with high viscosity.

Mechanical fouling cleaning
Mechanical fouling cleaning is to remove the deposit from the surface by using fluid flowing, mechanical tools, sound wave etc. to provide the power. The mechanical fouling cleaning method is commonly used for shell side cleaning. The online mechanical fouling cleaning method can be usually used for tube side cleaning by using the rubber ball or other objects similar to the fluid density. This method is suitable for particle fouling, biological sticky dirt and other small hardness of dirt. Mechanical fouling cleaning has the main shortcomings including the disassembled equipment; long cleaning time, high cost, low efficiency, inconvenience to the rapid discharge of deposit, the interruption of the system, etc.

Chemical fouling cleaning
Chemical fouling cleaning is to add acids or alkalis into the fluids to minish the adhesive force between fouling and surface so as to remove the fouling. The cleaning agent and corrosion inhibitor should be selected according to the material of heat exchanger and the chemical cleaning agent should be determined according to the type of fouling. The limitations of chemical fouling cleaning include that a circulation system requires to be established for the cleaning fluid; the seriously blocked equipment should not be applied; unexpected equipment corrosion will happen if there is only a very small mistake; the cleaning waste must be treated before discharge; the cost is relatively high.

Improvement of design
Shell and tube heat exchanger can be considered for new design from the following aspects:

(1) The simple structure is the first choice to avoid the formation of fluid dead zone because it will be more difficult to clean in more complex structure after fouling. Sirous Zeyninejad Movassag et al. [14] presented the results of tube bundle replacement of a segmental shell and tube heat exchanger with a helical heat exchanger, to reduce fouling and pressure drop of the critical heat exchanger and as a result reduce operation and maintenance costs.

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(2) The tube side of shell and tube heat exchanger is usually easy to clean, but the shell side is difficult to clean. Therefore, usually the fluid of corrosive or high pollution is arranged in the tube side, cleaning fluid passes in the shell side, such as water, steam, etc.

(3) The fluid velocity in shell and tube heat exchanger should be controlled. The fluid velocity in tube side is usually more 2m/s as a large flow pressure drop will not happen for the fluid with low viscosity. The fluid velocity in shell side should be around 1m/s. Increasing the fluid velocity can increase the shear stress at the interface between the fluid and the fouling layer, and increase the denudation force to the fouling layer.

(4) Introducing the effect of temperature on fouling into the design of heat exchangers is shown to be quite complex because the final, design-fouling resistance depends on the history of operation [15]. The temperature distribution should be adjusted if the rise of temperature will increase the formation of fouling. This can be achieved by changing the fluid velocity or the number of tubes of the exchanger.

CONCLUSION

Fouling in shell and tube heat exchanger not only strongly affects the heat transfer efficiency by increasing the heat resistance, but also increases the pressure drop of the system. The factors of affecting the fouling in shell and tube heat exchanger include the fluid velocity, the temperature of heat transfer surface, the material of heat transfer surface and its quality, and the fouling forming models. Fouling problem can be solved by high pressure water jet, mechanical tools, chemical reaction, and the improvement of design including simple structure to avoid dead zone of fluid, arrangement of fluid in shell and tube sides, fluid velocity and temperature distribution in the shell and tube heat exchanger.

ACKNOWLEDGEMENTS

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