Proceedings of International Conference on Heat Exchanger Fouling and Cleaning - 2015 (Peer-reviewed) June 07 - 12, 2015, Enfield (Dublin), Ireland Editors: M.R. Malayeri, H. Müller-Steinhagen and A.P. Watkinson

Published online www.heatexchanger-fouling.com

EXPERIMENTAL INVESTIGATION OF FOULING OF BRAZED PLATE HEAT EXCHANGERS IN DISTRICT HEATING SYSTEMS

D.Taler¹, G.Jaglarz¹

¹ Cracow University of Technology, Faculty of Environmental Engineering, Institute of Thermal Eng. And Air Protection, ul. Warszawska 24, 31- 155 Cracow, Poland E-mail(Corresponding author): <u>dtaler@pk.edu.pl</u>

ABSTRACT

Fouling phenomena of plate heat exchangers is a significant issue in water heating systems. The paper presents results of the experimental study of 2 plate heat exchangers, which are installed in a district heating system. The objective of the paper is to determine an average thermal resistance of scale deposits on corrugated plates of the heat exchanger. Based on long-term continuous measurements of volume flow rate as well as inlet and outlet temperature of heating water and domestic hot water, the overall heat transfer coefficient is evaluated as a function of time. The thermal resistance of scale deposits can be determined after calculation of the heat transfer coefficients on both sides of the plate using a heat transfer correlation for the Nusselt number. The system will enable the scheduling periods of temporary shutdowns for cleaning to preserve the highest effectiveness of heat substations and to reduce energy consumption for water pumping.

INTRODUCTION

Plate heat exchangers are widely used in all energy and industry sectors. The frequency of application of PHE is the outcome of the high effectiveness and reliability of these devices. Irregular plate surface increases the heat exchange between fluids, however it intensifies the fouling phenomenon (Boxler et al., 2014). Heat exchangers with very high surface to volume ratio, for example micro heat exchangers, are very sensitive to crystallization fouling (Mayer et al., 2012).

After a certain operating time, the hot water that flows through the heat exchanger precipitates a lot of deposition. Fouling phenomenon, in spite of having an immense influence on district heating, is still a subject of research and debate. Functioning of PHE is negatively impacted in systems such as district heating because of crystallization, which is caused by the precipitation of insoluble salts (Bott, 1995). Usually due to increasing temperature the solubility of a salt increases, however, there are some salts characterized by inverse solubility such as CaSO4 (Lee et al., 2014). Depending on the designation of PHE and season the temperature of water might differ in the range from 45-130 Celsius degrees. At present, one of the most commonly used method for predicting the fouling impact in heat exchangers is observation of changes in heat transfer during operating time (Srbislay et al., 2012).

Fouling phenomena occurs as a complex science problem, which is influenced by many different factors such as: type of fluid, temperature, fluid velocity and type or geometry of plate heat exchanger (Taler et al., 2014). During last several years there was much research conducted on this subject; however it is still hard to precisely answer certain questions such as what is the accurate value of thermal conductivity ratio of scale deposition. Plenty of methods were applied to understand the fouling process. Examples of such include research on fouling in real-time with usage of non-invasive acoustic waves with low frequency (Merhab et al., 2011) or testing of influence of surface roughness on occurring carbonate calcium fouling (Chengwang et al., 2007).

As a result, a few methods were applied to mitigate fouling in heat exchangers. The first recommendation to decrease the possibility of scale deposition includes numerous methods that can be used in the design stage (Kho et al., 1999). Additionally cleaning might be used periodically such as mechanical or chemical solution (Kho et al., 1997). Chemical cleaning requires temporary shutdowns of the devices that cause losses in efficiency and generally might be responsible for corrosion.

When looking at the process of fouling phenomena of plate heat exchangers in district heating systems, it is important to notice that it plays a major role in heating. Due to scale deposition on the surface of heat exchangers their efficiency significantly decreases and, as a result, the exploitation costs increase. In extreme cases, excess fouling build-up can lead to the destruction of the heat exchanger. It becomes necessary to create proper exploitation conditions for using heat exchangers and, most of all proper optimization of cleaning periods.

FOULING-DETERMINATION

Fouling of plate heat exchangers is a serious problem in water heating systems. The paper presents results of the experimental study of 2 plate heat exchangers, which are installed in a district heating system. The objective of the paper is to determine an average thermal resistance of scale deposits on corrugated plates of the heat exchanger. Based on long-term continuous measurements of volume flow rate as well as inlet and outlet temperature of the heating water and domestic hot water, the overall heat transfer coefficient is evaluated as a function of time. The thermal resistance of scale deposits can be determined after calculation of the heat transfer coefficients on both sides of the plate using a heat transfer correlation for the Nusselt number. The heat transfer rate of the heat exchanger, which is fouled, can be raised by increasing the fluid velocity, but this could be only a temporary energy intensive solution. The already conducted measurements and analysis indicate that a permanent observation of changes in deposits thermal resistance over time is fully possible. It is planned to build a computer system for continuous monitoring of the degree of fouling of all heat exchangers installed in the heating system of the big city. The system will enable the scheduling periods of temporary shutdowns for cleaning to preserve the highest effectiveness of heat substations and to reduce energy consumption for water pumping.

HEAT EXCHANGERS

The objective of this research was to determine the fouling in two different plate heat exchangers. Both are part of the heating system, however, they are supplied directly from CHP Plant. Fouling resistance is described as a component of overall thermal resistance in the heat exchanger. The first device having the power of 89 kW is used for hot water production and the second with the power of 302,4 kW for heat production. Heat exchangers have been used for four years without cleaning. The first one with the power of 89 kW have been replaced with the same new device without fouling to compare the difference.



Fig. 1 Plate heat exchanger

Table 1. Characteristics of PHE.

| Key statistics | PHE 1 | PHE 2 |
|--|-----------------|-------|
| Heat transfer surface, m ² /plate | 0.027 | 0.081 |
| Number of plates | 30 | 50 |
| Channel capacity, Liter | 0.06 | 0.21 |
| Plate material | Stainless steel | |
| Temp. max, °C | 180 | 180 |
| Temp. min , °C | -10 | -10 |
| A ,mm | 343 | 466 |
| B ,mm | 122 | 256 |

| E ,mm | 85 | 142 | |
|-------|-----|-----|--|
| D ,mm | 65 | 170 | |
| C ,mm | 285 | 380 | |

THEORETICAL FORMULATION OF THE PROBLEM

Over last few decades, plenty of methods have been applied to determine fouling in heat exchangers. Because the devices are located at a live location, it has been decided to monitor a few parameters during operating time. Application of on-line method simplifies observation in thermal resistance changes and makes it possible to receive approximate value.

Certain parameters have to be measured in order to apply these methods:

- V_h volumetric flow rate of the hot fluid, m³/s
- \dot{V}_c volumetric flow rate of the cold fluid, m³/s
- $T_{h,in}$ inlet temperature of hot fluid, ^oC
- $T_{h,out}$ outlet temperature of hot fluid, °C
- $T_{c.in}$ inlet temperature of cold fluid, °C
- $T_{c,out}$ outlet temperature of cold fluid, °C

Total rate of heat transfer between two fluids can express in three different ways:

$$\dot{Q}_h = \dot{m}_h c_h (T_{h,in} - T_{h,out}) \tag{1}$$

Cold fluid

$$\dot{Q}_c = \dot{m}_c c_c (T_{c,out} - T_{c,in}) \tag{2}$$

• Based on heat exchanger surface and heat transfer coefficient

$$\dot{Q} = kA\Delta T_m \tag{3}$$

where \dot{m}_h – mass flow rate of hot fluid, kg/s, \dot{m}_c – mass flow rate of cold fluid, kg/s, $T_{h,in}$ – inlet temperature of hot fluid, °C, $T_{h,out}$ – outlet temperature of hot fluid, °C,

 $T_{c,in}$ – inlet temperature of cold fluid, °C, $T_{c,out}$ – outlet temperature of cold fluid, °C, k – overall heat transfer coefficient, W/m²K, A – heat exchange surface, m²,

 ΔT_m - the log mean temperature difference, K.

The overall heat transfer coefficient is defined as

$$\frac{1}{k} = \frac{1}{\alpha_h} + \frac{\delta_{z,h}}{\lambda_{z,h}} + \frac{\delta_{met}}{\lambda_{met}} + \frac{\delta_{z,c}}{\lambda_{z,c}} + \frac{1}{\alpha_c}$$
(4)

where α_h - hot stream heat transfer coefficient, W/m²K,

 α_c - cold stream heat transfer coefficient, W/m²K,

 $\delta_{z,h}$ - thickness of deposition on hot fluid side, m,

 δ_{met} – thickness of plate, m, $\delta_{z,c}$ – thickness of deposition on cold fluid side, m, $\lambda_{z,h}$ - thermal conductivity of deposition on hot fluid side, W/mK, λ_{met} – thermal conductivity of plate, W/mK, $\lambda_{z,c}$ – thermal conductivity of deposition on cold fluid side, W/mK. Transformation of equation (3) gives k

Transformation of equation (3) gives k

$$k = \frac{\dot{Q}}{A\Delta T_m} \tag{5}$$

Mean rate of heat transfer is defined as

$$\dot{Q}_m = \frac{\dot{Q}_h + \dot{Q}_c}{2} \tag{6}$$

The thermal resistance is given by

$$r_o = \frac{\delta_{z,h}}{\lambda_{z,h}} + \frac{\delta_{z,c}}{\lambda_{z,c}} \tag{7}$$

The thermal resistance is determined from equation (4) to give

$$r_o = \frac{1}{k} - \frac{1}{\alpha_h} - \frac{\delta_{met}}{\lambda_{met}} - \frac{1}{\alpha_c}$$
(8)

RESULTS

The objective of this research was to determine fouling in two different heat exchangers. The measurements were led for 80 days and enabled experimental indication of a fouling factor with the application of the formulas mentioned above. As the part of complex analysis following values and ratios have been taken into consideration: fluid temperatures (Fig. 2, Fig. 6), fluid flows (Fig. 3, Fig. 7), heat transfer coefficients (Fig. 4, Fig. 8), which gave the outcome of fouling thermal resistance (Fig. 5, Fig. 9).



Fig. 2 Inlet temperature of the hot fluid and outlet temperature of the cold fluid.



Fig. 3 Hot and cold fluid volumetric flow rate changes in PHE 1.

Due to changes in volumetric flow rate (Fig. 3), the fluctuations in heat transfer coefficient occur (Fig. 4). Because of time variations in hot fluid flow rate, heat transfer coefficient of hot fluid varies with time and ranges from 1000 to almost 3000 W/m²K. The inlet temperature of the hot fluid is high at the beginning of the measurement and systematically decreases due to the increased flow rate.

Empirical correlation for the Nusselt Number, which is used in empirical determination of fouling degree, has been applied to determine the heat transfer coefficients

$$Nu = 0.332Re^{1/2}Pr^{1/3} \tag{9}$$

where

$$\alpha = \frac{Nu\lambda}{D_h} \tag{10}$$



Fig. 4 Heat transfer coefficient of hot and cold fluid in PHE1



Fig. 5 Changes in thermal resistance in PHE 1

According to Figure 4, it can be observed that overall fouling thermal resistance significantly changes with time. After 24 days of research, the plate heat exchanger has been replaced with another new one with the same specification and size. During the first 24 days of the observation, it should be noticed that the level of fouling thermal resistance is high with the average value of $0.00327 \text{ m}^2\text{K/W}$. The explanation of this resistance value is the operation time of the heat exchanger. The heat exchanger was used for almost four years without cleaning. After this time, fouling resistance significantly decreased due to the fact of heat exchanger replacement. With the new device, the average fouling resistance is significantly lower at the level of $0.00043 \text{ m}^2\text{K/W}$.

Changes in operating conditions cause fluctuations during the whole observation time. As the effect of devices being part of the water supply network it is impossible to maintain stable operating conditions. The usage of plate heat exchanger changes due to the consumption of hot and cold water. Additional important factors are the number of people using water, which differs every day and also it depends on weekday.

In PHE 2 which is part of the heating system, the fouling phenomena is exactly the opposite. The maintenance conditions are more stable as shown in the following figures.



Fig. 6 Inlet temperature of the hot fluid and outlet temperature of the cold fluid.



Fig. 7 Hot and cold fluid volumetric flow rate changes in PHE2



Fig. 8 Heat transfer coefficient of hot and cold fluid in PHE2

According to the Figures 7 it can be noticed that no significant changes in volumetric flow rates occur. As a result, the heat transfer coefficient remains constant as well.



Fig. 9 Changes in thermal resistance in PHE 2

During 80 days of measurements stable and permanent changes in fouling thermal resistance can be observed. Obtained results show some fluctuations, which are caused by velocity flow rate differences. However, significant is a constant increase of fouling resistance ranging from 0.00054 to 0.0006 m²K/W in plate heat exchanger. As the PHE 1, this device was installed four years ago and is operated till today without specific, chemical cleaning. During operating time, mechanical cleaning might occur as a natural mechanism deriving from operation conditions.

CONCLUSIONS

Undertaken research enables determination of fouling factor in different types of plate heat exchangers use for different purposes (hot water production and heating). All heating equipment has been installed four years ago and works continuously till today. The heat exchanger used for hot water production has been replaced with a new one for purposes of this study. Few parameters have been observed such as fluids temperature or velocity flow rate and on this basis after some calculations the investigation of fouling phenomena came to fruition. The following conclusions can be drawn on this research:

In PHE 1 level of fouling resistance was at a high level because of worse quality of water from district network (bacteria, microorganisms, water hardness deriving from salts). However, after device replacement fouling resistance decreased more than seven times.

In PHE 2 steady increase in the thermal resistance can be observed ranging from 0.00054 to 0.0006 m²K/W.

Mechanical cleaning might occur as a natural mechanism deriving from operating conditions. However, chemical cleaning should be planned accurately to optimize the operation of the heat exchanger.

NOMENCLATURE

- Aheat exchange surface, m^2 D_h hydraulic diameter, m
- k overall heat transfer coefficient, W/m^2K
- \dot{m}_h mass flow rate of hot fluid, kg/s
- \dot{m}_c mass flow rate of cold fluid, kg/s
- Nu Nusselt number, hD_h, dimensionless
- $T_{h,in}$ inlet temperature of hot fluid, ^oC
- $T_{h.out}$ outlet temperature of hot fluid, °C
- $T_{c,in}$ inlet temperature of cold fluid, °C
- $T_{c,out}$ outlet temperature of cold fluid, ^oC
- α_h Hot stream heat transfer coefficient, W/m²K
- α_c cold stream heat transfer coefficient, W/m²K
- $\delta_{z,h}$ thickness of deposition on hot fluid side, m
- δ_{met} thickness of plate, m
- $\delta_{z.c}$ thickness of deposition on cold fluid side, m
- ΔT_m the log mean temperature difference, K
- $\lambda_{z.h}$ thermal conductivity, W/mK
- λ_{met} thermal conductivity of plate, W/mK
- $\lambda_{z,c}$ thermal conductivity, W/mK

Subscript

- c cold
- h hot
- i inlet
- o outlet
- w wall
- z deposition

REFERENCES

Boxler C., Augustin W. Scholl S., Composition of milk fouling deposits in a plate heat exchanger under pulsed flow conditions, *Journal of Food Engineering* 121(2014) 1-3

Mayer M., Bucko J., Benzinger W., Dittmeyer R., Augustin W., Scholl S., The impact of crystallization fouling on a microscale heat exchanger, *Experimental Thermal and Fluid Science* 40 (2012) 126-131

Bott T.R., Fouling of heat exchangers, 1995, *Elsevier* Science and Technology Book

Lee E., Jeon J., Kang H., Kim Y., Themal resistance in corrugated plate heat exchangers under crystallization fouling of calcium sulfate (CaSO₄), *International Journal of Heat and Mass Transfer* 78 (2014) 908-916

Srbislay B., Branislav M. Jakimovic, Dragan Mandić, Dragan Petrović, Experimental fouling factor on plate heat exchangers in district heating system, *Energy and Buildings* 50 (2012) 204-262

Taler D., Jaglarz G., Current issues in energetics, Conference Materials – Energetics 2014, Wrocław, Poland

Merhab B., Nassar G., Nongaillard B., Delaplace G. Leuliet J.C., Design and performance of a low-frequency non-intrusive acoustic technique for monitoring fouling in plate heat exchangers, *J.FoodEng.* 82 (2007) 518-527

Chengwang Lei, Zhongxiao Peng, Thomas Day, Xinping Yan, Xiuqin Bai, Chengqing Yuan, Experimental observation of surface morphology effect on crystallization fouling in plate heatg exchangers, *Int. Commun. Heat Mass Transfer* 38 (2011) 25-30

Kho T., Müller-Steinhagen H., An experimental and numerical investigation of heat transfer fouling and fluid flow in flat plate heat exchangers, *Trans IChemE*, Vol 77, Part A, March 1999

Kho T., Zettler H.U., Müller-Steinhagen H., Effect of flow distribution on scale formation in plate and frame heat exchangers, *Chem. Eng. Res. Des.* 75 (1997) 635-640