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

# FOULING MONITORING IN POWER PLANT

**Akiya Kuboyama , Takuya Kuwahara , Mitsutaka Nakamura and Shigeo Iwahashi**

Mitsubishi Chemical Corporation, 3-10, Ushiodori, Kurashiki, Okayama, 712-8054, Japan

## ABSTRACT

Fouling on super heater tube in power plant is the cause of unplanned shutdown maintenance. Understanding how to prevent growth of fouling is necessary to get the stable power plant operation. A method to monitor the fouling resistance, $R_f$, of heat exchanger, especially super-heater of power plant, is presented. The historical hourly data of operating conditions are used to analyze $R_f$. The initial value of overall heat transfer coefficient, $U_{clean}$, and the current overall heat transfer coefficient, $U_{dirty}$, are needed to calculate fouling resistance. Since $U_{clean}$ is not constant but is affected by operating conditions such as shell/tube flow rate and temperature, a relationship between $U_{clean}$ and these operating conditions has to be developed to calculate $R_f$. To calculate $R_f$ at any operating condition, $U_{clean}$ has to be described by equation, using operating conditions. $U_{cal}$ equation that be built by some basic equations is fitted into $U_{dirty}$ using short term data after cleaning assuming that there is no fouling, $U_{dirty}$ is equal to $U_{clean}$. From $R_f$ trend, calculated from $U_{cal}$ and $U_{dirty}$, two types of fouling rate were observed. One is the fouling rate that is removable by using cleaning system, soot blowing. Another one cannot be removed using cleaning system. We evaluate the effect of countermeasures for fouling using this $R_f$ trend.

## INTRODUCTION

In studying the fouling process such as a heat exchanger, a lot of useful information can be obtained by understanding the fouling behavior. For example, trend of power plant performance or heat consumption rate, continuance operation term [1]. The current method of heat exchanger fouling management involves monitoring indirect parameters such as temperature difference, pressure drop, overall heat transfer coefficient, and so on. But these parameters are influenced by the change of operational conditions. Therefore, it is difficult to judge why the monitoring parameters change when the operating conditions were changed significantly. In this study, fouling rate is monitored by a direct index, the actual fouling resistance, $R_f$. For calculating $R_f$, plant side database, which is indirect parameters such as temperature, pressure and so on, are used.

## CALCULATE FOULING RESISTANCE

Amount of fouling can be defined by equation (1), assuming the thermal conductivity of the fouling material is constant.

$$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}} \tag{1}$$

The dirty overall heat transfer coefficient, $U_{dirty}$, is calculated by equation (2) and (3), using the measured values of one flow rate ($G_{tube}$) and four temperatures ($T_{tube,\ in}$, $T_{tube,\ out}$, $T_{shell,\ in}$, $T_{shell,\ out}$).

$$Q = G_{tube} C_p \left(T_{tube,out} - T_{tube,in}\right) \tag{2}$$

$$U_{dirty} = \frac{Q}{AF\Delta T_{lm}} \tag{3}$$

$U_{clean}$, the overall heat transfer coefficient in the case of no fouling, is determined by equation (4). $h_{i,clean}$ and $h_{o,clean}$ are film heat transfer coefficients of the tube side and shell side, respectively.

$$\frac{1}{U_{clean}} = \left(\frac{1}{h_{i,clean}} + \frac{1}{h_{o,clean}} + \frac{\delta}{k}\right) \tag{4}$$

If there is no fouling, $U_{dirty}$ is equal to $U_{clean}$.

$$U_{clean} = U_{dirty} \tag{5}$$

Ideally, $h_{i,clean}$ and $h_{o,clean}$ are estimated from correlations based on the heat exchanger configuration and the applicable process conditions. In this study, film heat transfer coefficients depend on flow rate. For simplification, $h_{i,clean}$ is calculated by modified equation (6) based on *Seider-Tite* equation, and $h_{o,clean}$ is calculated by modified equation (7) based on *Modefied Donohue* equation. As the results, equation (4) is written as equation (8).

$$h_{i,clean} = 0.023\frac{k}{D}\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33}\left(\frac{\mu}{\mu_w}\right) \approx \alpha\,\mathrm{Re}^{\beta} \tag{6}$$

$$h_{o,clean} = 0.287\left(\frac{DG}{\mu}\right)^{0.61}\left(\frac{C_P\mu}{k}\right)^{0.33} \approx \gamma\,\mathrm{Re}^{\eta} \tag{7}$$

$$\frac{1}{U_{clean}} \approx \frac{1}{U_{cal}} = \left( \frac{1}{\alpha \mathrm{Re}^{\beta}} + \frac{1}{\gamma \mathrm{Re}^{\eta}} + \frac{\delta}{k} \right) \qquad (8)$$

**RESULTS & DISCUSSION**

*Monitoring*

$U_{cal}$ is fitted into $U_{dirty}$ using 1800 data of one minute mean value, i.e. 30 hours data, during just after shutdown maintenance assuming that there is no fouling, $U_{dirty}$ is equal to $U_{clean}$. The fitting result between $U_{cal}$ and $U_{dirty}$ is shown in fig.1.

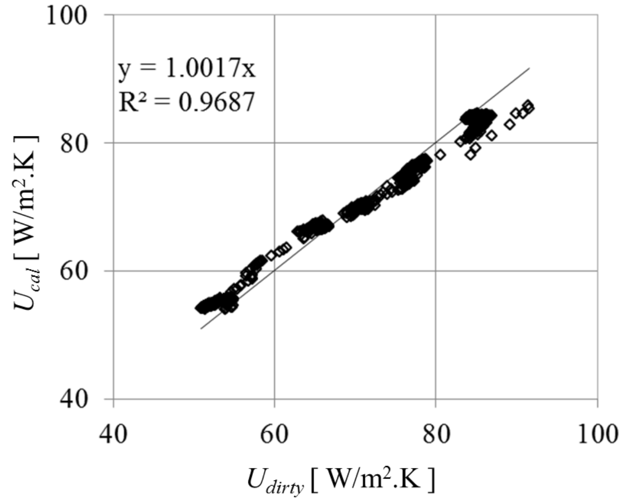


Figure 1 Comparison between $U_{dirty}$ and $U_{clean}$ during the exchanger's clean period

Time profiles of $U_{cal}$ and $U_{dirty}$ are shown in fig.2, using three hours mean value of one year. Calculated values of $R_f$ are shown in fig.3 for same time on fig.2. In the operation from 2013/6, there is negative fouling period, or induction period, about three months. Because of negative fouling, $U_{dirty}$ is larger than $U_{cal}$, $R_f$ is less than zero during this term. But, in the operation from 2014/1, after countermeasures for fouling, there is no significant negative fouling as shown fig.2 and 3. It must be effect of countermeasures for fouling such as tuning of soot blowing (one of cleaning system for power plant, blow steam toward fouling).

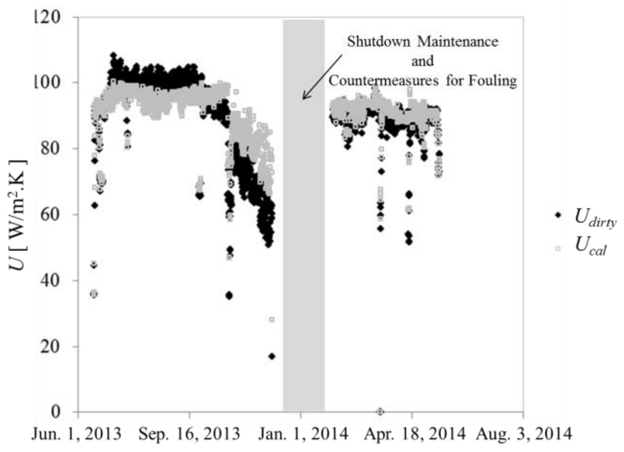


Figure 2 Comparison between $U_{dirty}$ and $U_{clean}$ profiles

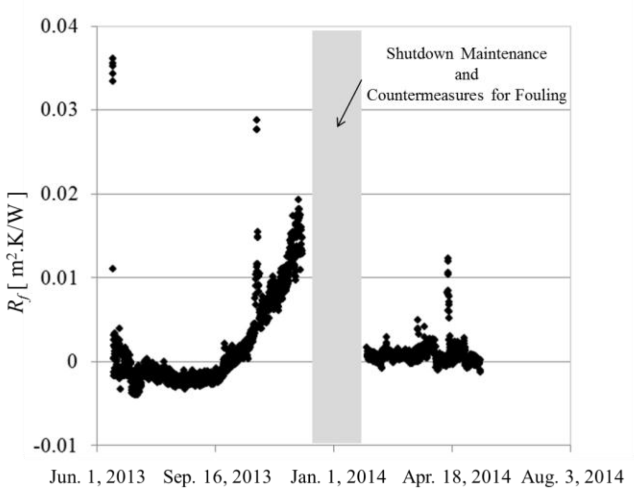


Figure 3 Profiles of fouling resistance

*Data analysis*

The $R_f$ profile is shown in fig.4, using one minute mean value of 2013/6/30 AM. The Fouling grows up in approximately constant rate ($dR_f/dt$) as shown as in fig.4 (1). After two hours go by, growth of fouling is stopped till soot blowing removes the fouling as shown as in fig.4 (2) and (3). But, soot blowing cannot remove fouling completely. There is other fouling rate, $dR_f'/dt$, that cannot be removed using soot blowing, than $dR_f/dt$.

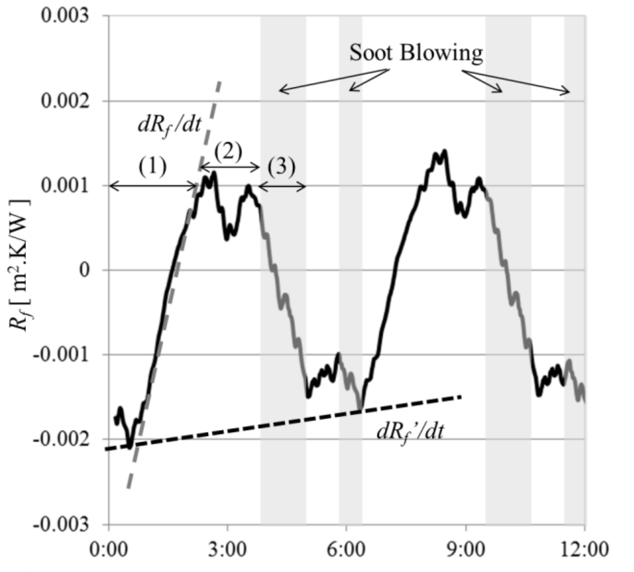


Figure 4 Profile of fouling resistance (2013/6/30)

To get the stable power plant operation, the latter fouling rate, $dR_f'/dt$, is important. Therefore, comparison between $dR_f'/dt$ profile before and after countermeasures for fouling would be instrumental to evaluation of countermeasures for fouling. Comparison result is shown in fig. 5. It is clear that $dR_f'/dt$ after countermeasure term is closer to zero than $dR_f'/dt$ before countermeasures (When the soot blowing removes accumulated fouling, $dR_f'/dt$ gets the minus value). It would say most of fouling is removed by soot blowing, and it is reason why no negative fouling in operation from 2014/1. That is to say, countermeasures such as tuning of soot blowing are effective to get stable power plant operation. The $dR_f'/dt$ analysis enables evaluation of countermeasures for fouling even at the induction period.

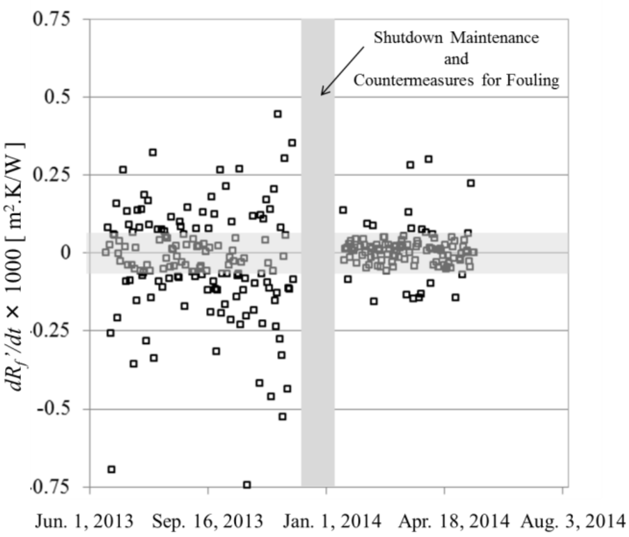


Figure 5 Profile of $dR_f'/dt$ (2013/6~2014/6)

**CONCLUSIONS**

Fouling analysis was applied to power plant.

1. Negative fouling was observed in actual plant.
2. Applying $dR_f'/dt$ analysis enables evaluation of countermeasures for fouling even at the induction period.
3. Effect of countermeasure for fouling was confirmed in actual plant.

**NOMENCLATURE**

| | |
|---|---|
| A | heat transfer area of exchanger, $m^2$ |
| $C_p$ | specific heat, kcal/kg.K |
| D | tube diameter, m |
| F | correction factor, dimensionless |
| G | mass flow rate, kg/s |
| h | film heat transfer coefficient, $W/m^2.K$. |
| k | thermal conductivity, W/m.K |
| Q | heat transfer rate, W |
| $R_f$ | fouling resistance, $m^2.K/W$ |
| T | temperature, K |
| $U_{dirty}$ | dirty heat transfer coefficient, $W/m^2.K$ |
| $U_{cal}$ | calculated heat transfer coefficient, $W/m^2.K$ |
| $U_{clean}$ | clean heat transfer coefficient, $W/m^2.K$ |
| $\Delta T_{lm}$ | log mean temperature difference, K |

**Greek letters**

| | |
|---|---|
| $\alpha$ | parameter |
| $\beta$ | parameter |
| $\delta$ | tube thickness, m |
| $\gamma$ | parameter |
| $\eta$ | parameter |
| $\mu$ | viscosity, kg/m.s |

**REFERENCES**

[1] T. Kuwahara, C. Wibowo, A. Kuboyama, M. Nakamura, Y. Yoshihiro, Heat Transfer Engineering 780(2014)36