SOME ASPECTS ABOUT THE INFLUENCE OF FOULING TO STEAM CONDENSER OF A POWER PLANT

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Abstract Condenser performance and reliability have a significant impact on the electric generation of a power plant. Steam condensers are prone to fouling and the reduction in heat transfer that results almost invariably has an impact on product cost. Fouling on the heat transfer surfaces increase the thermal resistance, thus reducing the heat transfer performance and it is possible to appear failures. The paper presents theoretical considerations about mechanism of fouling in steam condensers, models for fouling evolution in time and the effects of fouling to effectiveness of condenser and power plant efficiency.

Keywords: fouling, power plant, fouling resistance, heat surface, linear fouling, asymptotic fouling, pressure drop

1. INTRODUCTION

Fouling is the buildup of sediments and debris on the surface area of heat exchangers that inhibits heat transfer. The fouling appearance go to increasing of supplementary cost for the equipment overmeasure , supplementary energy consumed, change of corroded material and the stop of the installation for the maintenance activity[1]. From hydraulic point of view, fouling increase the wall roughness and fluid velocity. These go to larger drop pressure and increasing pumping energy. From thermal point of view, fouling represents a resistance at heat transfer in the equipment, and the overall heat transfer coefficient decrease and in the same time, heat surface lowers.

Fouling tends to increase over time, the trajectory being very site specific. Recognizing this, the Tubular Exchanger Manufacturers Association (TEMA) recommends that designers of heat exchangers include an allowable fouling resistance in their calculations, in order that some fouling can be tolerated before cleaning must be undertaken. Heat Exchange Institute (HEI) standards also include some fouling in their requirements for steam surface condensers [2]. In most cases heat exchangers have 30-60% excess area to compensate for fouling.

However, this may even have an adverse effect on the rate of deposit formation, if it results in low flow velocities or high surface temperature.
The fouling may be in the interior of the tubes or at the exterior of the steam condenser tubes. The interior fouling can caused two problems:

- Low heat transfer capacity →reducing the efficiency of steam condenser →lower vacuum →less efficient steam turbine operation ;
- Under –deposit corrosion→ through-wall leaks which permit cooling water to enter into high purity steam condensate.

2. MECHANISMS OF FOULING IN STEAM CONDENSERS

The plant condensation has a lot of roles in a power plant [1]:

- The steam from turbine condense under an advanced vacuum;
- Represents a condensate reserve in regenerative circuit;

Condenser is a shell and tube heat exchanger (or surface condenser) installed at the outlet of steam turbine in power plant.
There are several types of fouling, each forming depending on the type of fluid and conditions. The following are some of the more common fouling mechanisms in steam condensers:

1. Crystallization fouling;
2. Particulate/Sedimentation fouling;
3. Corrosion fouling;
4. Biological fouling
5. Debris or macrofouling.

In most cases, fouling is not due to a single mechanism [1], however, in many situations one mechanism will be dominant (figure 1).
1. Crystallization fouling occurs when the saturation point of dissolved constituents in the cooling water is exceeded and precipitation occurs directly on tube surface. This take place when cooling water is heated during the cooling process. The dissolved salts (calcium carbonate, calcium phosphate) will crystallize on the surface in the form of scale. When condenser tubes are scaled it is usually a widespread occurrence, and very detrimental to heat transfer. Even a thin layer of scale can cause a major reduction in heat transfer; for instance, manganese, silica, and calcium carbonate scales have been reported to cause losses in output capacity of 20 to 25 MW[4].

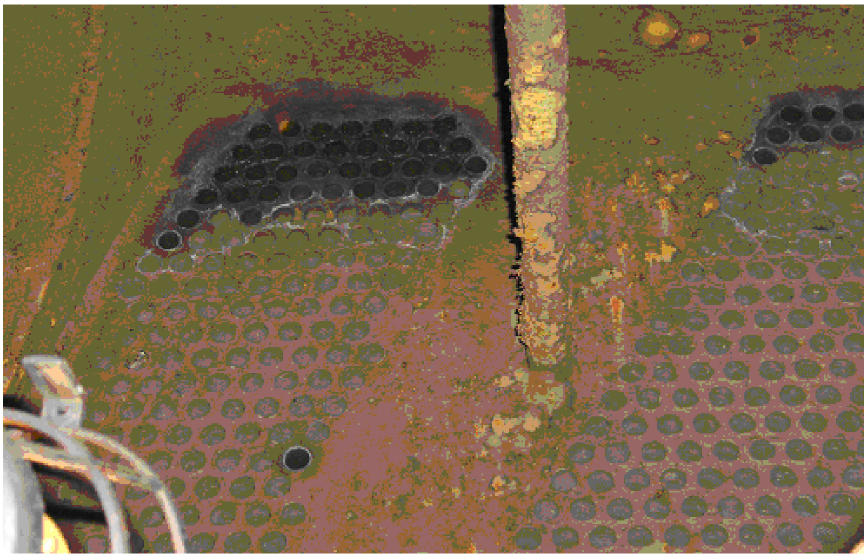

Fig 1. Fouling on the brass tubes of the steam condenser

2. Sedimentation is the deposition of dirt, sand, rust and other small matter (suspended solids). This can occur when river water (or sea water) is used.
3. Brass tubes are very susceptible to corrosion fouling. First, it is forming cuprous oxide (Cu_2O) film on the surface. After a period, in oxygenated water of high conductivity, it develops a fine layer of cupric oxide (CuO), which attack and pit the base metal. Corrosion can destroy surface area of steam condenser, creating costly damage.
4.Biological fouling can occur when types of bacteria, present in natural water, produce corrosive metabolic by-products.
5. Macrofouling of the condenser inlet tubesheet and tubes can occur by any substance whose size is close to, or greater than, tube internal diameter [4].
It is noticeable that in the high temperature zones, the fouling phenomenon is most presented than fouling in the down zones of the steam condenser (figure 2).

Fig 2. Fouling on the down front cover of the steam condenser

Usually, thermal conductivity of fouling is very low comparative with thermal conductivity of metal, and in majority cases, fouling resistance is greater then film resistance of the either sides of the wall. The increased resistance in heat transfer goes to decreased thermal load, leading to increased fuel. The porous fouling deposits increase the surface roughness of the metal and this causing a larger pressure drop.

3. MODELS FOR FOULING EVOLUTION IN TIME

The steam condenser deteriorates progressively after the fouling appears. Considerably time- years perhaps may elapse before it arrives at the condition where it can no longer perform adequately.
The fouling rate is defined as the difference between the deposition rate Φ_d and the removal rate Φ_r of the material from the heat transfer surface.

$$\frac{dR_d}{d\tau} = \Phi_d - \Phi_r \tag{1}$$

The fouling resistance at time t:

$$R_d(\tau) = \int_0^t (\Phi_d - \Phi_r) d\tau \tag{2}$$

Figure 3 shows three typical evolutions of steam fouling [1].

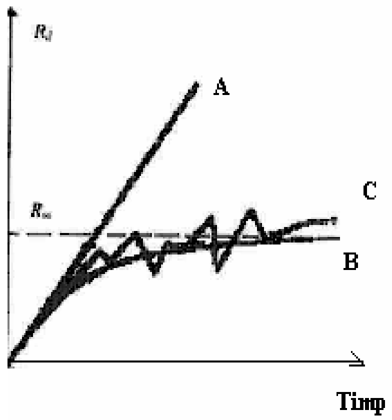

Figure 3. Typical evolutions of fouling
A- linear fouling; B-asymptotic fouling; C-saw-toothed fouling

The C evolution is the most appropriate evolution against reality. This evolution can be idealized like evolution C from figure 4.

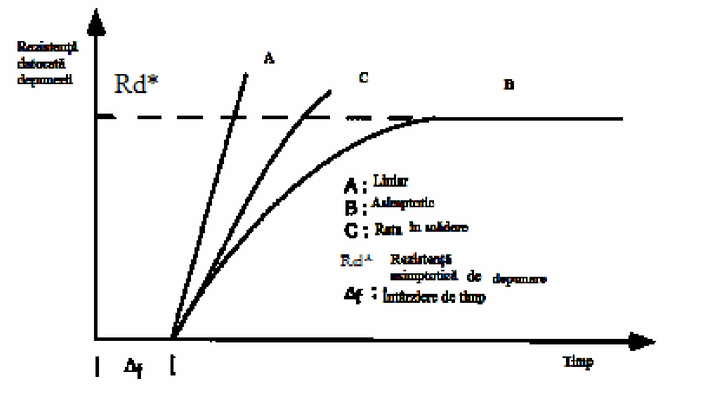

Figure 4. Ideal evolutions of fouling in steam condenser

A: Linear fouling occurs when the difference between the deposition rate and the removal rate is constant (3):

$$k_d = (\Phi_d - \Phi_r) = \text{constant} \tag{3}$$

The fouling resistance at time t:

$$R_d(\tau) = k_d \times \tau \tag{4}$$

This type of fouling describes adherent and hard deposits [5].

C: Falling rate fouling occurs when the difference between the deposition rate and the removal rate decreases as a function of the fouling resistance. This difference decreases to 0 only when fouling resistance approaches ∞ [5].

$$\frac{dR_d}{d\tau} = \frac{\beta_1}{R_d} \tag{5}$$

$$R_d(\tau) = \sqrt{\left\{(R_d)^2{}_{t=0} + \beta_1 \times \tau\right\}} \tag{6}$$

Parameter β_1 from equation (6) is a constant of proportionality. This type of fouling occurs when the build up of fouling inhibits the deposition of new material. This is the case when fouling results from corrosion of the metal surface. The build up of corrosion products increases the resistance to the diffusion of oxidizing agents, slowing down the corrosion process [5].

B: Asymptotic fouling occurs when the difference between the deposition flux and the removal flux decreases with increasing fouling resistance. The difference becomes 0 for some finite value of the fouling resistance R_d^* named asymptotic fouling resistance.

$$\Phi_d = \text{constant} \tag{7}$$

$$\frac{dR_d}{d\tau} = \Phi_d - \frac{\beta_1}{R_d} \tag{8}$$

$$R_d(t) = R_d^*(1 - e^{\tau\beta_2}) \tag{9}$$

In equation (8), β_1 is a constant of proportionality. The time constant for asymtotic fouling, t_d is the reciprocal of the parameter β_2. The deposition rate is expressed as:

$$R_d^* = t_d \times \Phi_d \tag{10}$$

The progresion of the asymptotic fouling is shown in figure 5:

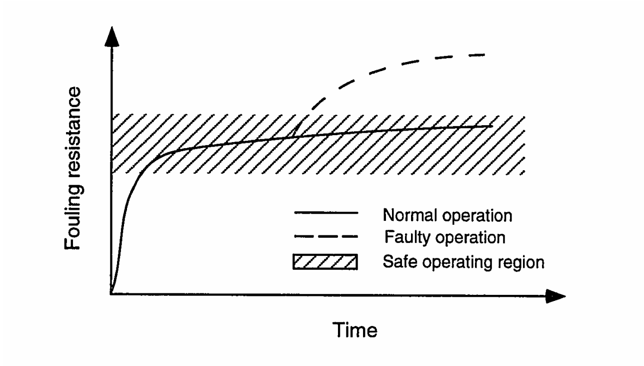

Figure 5. The progression of the asymptotic fouling

Asymptotic fouling occurs when the deposition rate is constant and the removal rate increases linerly with the respect of the thickness of deposits.. In figure 6 is presented a cross –section area of a tube with fouling.

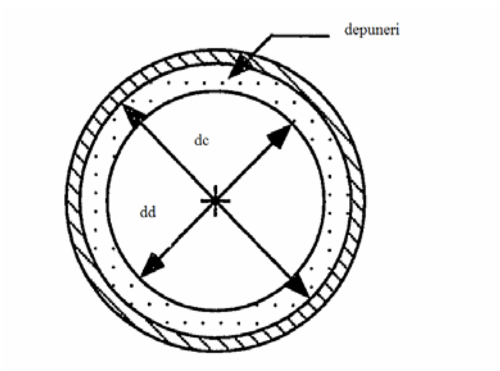

Figure 6. Cross-section area of a tube with internal fouling

d_d – inner diameter of tube with fouling[m]
d_c – inner diameter of clean tube [m]
Thermal resistance of fouling influences overall heat transfer coefficient for all steam condenser.
The heat transfer coefficient for the steam condenser with fouling (effective heat transfer coefficient) may be calculated from the Fourier equation:

$$k_d = \frac{\dot{m}_a c_p \left(t_2 - t_1\right)}{S\Delta t_{med}} \qquad (11)$$

where $\dot{m}_a$ [kg/s] is the fluid flow, c_p [kJ/kgK] is the heat capacity at constant pressure, t_1,t_2 – the inlet temperature, the outlet temperature, respective, for cooling water, S-the heat transfer surface, Δt_{med}- log mean temperature difference.

$$\Delta t_{med} = F\frac{\Delta t_{high} - \Delta t_{low}}{\ln\frac{\Delta t_{high}}{\Delta t_{low}}} \qquad (12)$$

Δt_{high} is the higher terminal temperature difference, Δt_{low} is the lower terminal temperature difference and F is the factor applied to the Δt_{med} in accordance with the configuration condenser.

The fouling resistance may be calculated from the equation:

$$k_d = \frac{1}{R_d + \frac{1}{k_o}} \text{[W/m}^2\text{K]} \qquad (13)$$

where k_d is the heat transfer coefficient for the steam condenser with fouling and k_o is the heat transfer coefficient for clean steam condenser.

The pressure drop depends on the friction factor *f* and the fluid velocity *u*. A decrease in cross-section area of the pipe due to fouling results in increased fluid velocity. The fouling deposits also increases the roughness of the pipe in higher friction factor values.

The relationship between the fouling resistance and the increase in pressure drop are presented in [6] :

$$\frac{\Delta p_d}{\Delta p_c} = \left(\frac{w_d}{w_c}\right)^2 = \left(\frac{d_d}{d_c}\right)^4 = \exp\left(\frac{8k_d R_d}{d_c}\right) \qquad (14)$$

where Δp_d, Δp_c are the pressure drop for pipe with fouling, clean pipe, respectivelly,w_d, w_c fluid velocity in with fouling, clean pipe, respectivelly, k_d- heat transfer coeficcient for pipe with fouling deposits. The relationship is base don the assumption that the fouling debris are deposited uniformly on the tube walls. The increase in the pressure drop is implicitly linked to the increase in resistance of heat transfer.

4. CONCLUSIONS

Researchers realized a lot of fouling models, but not a general predictive model. This, because, the interaction between particulates a fluid flow is very complex, in special in the turbulent field. The temperature gradient between the flow field ant the condenser surface makes the achievement of a model more difficult. Fouling depends on the type of steam condenser and type of cooling water; each type of condenser will suffer fouling in unique way.

Fouling is unbeneficial for steam condenser, in principal, for two reasons:

- The thermal resistance of fouling layer increases the resistance to heat transfer and reduces the effectiveness of condenser;
- The cross-section area is reduced and this causes an increase in pressure drop across the equipment.

A number of research efforts were concerned in fouling removal and condenser cleaning techniques, which is the part of maintenance phase. Reliable knowledge of fouling economics is important when evaluating the cost efficiency of various cleaning techniques.

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