ASPECTS REGARDING FOULING OF STEAM CONDENSER - A CASE STUDY

Roxana GRIGORE [1*], Adrian BADEA[2]

The paper makes a point to effect of fouling to steam condenser. The performance of the steam condenser is directly affected by fouling. It is presented a case study of a condenser of steam turbine DSL 50-1. In the paper are calculated the basic design heat transfer coefficient, the effective heat transfer coefficient and the fouling resistance of condenser. The study shows a presence of tube fouling or the presence of excessive amounts of air within the shell side of the condenser. The conclusions of the study is that the real variation of condenser fouling resistance in time is allied to variation presented in literature like saw-toothed fouling and for the studied condenser it is necessary to realize a correct maintenance policy.

Keywords: fouling resistance, heat surface, basic design heat transfer coefficient, effective heat transfer coefficient, steam condenser

1. Considerations about fouling of steam condensers

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 over measure, supplementary energy consumed, change of corroded material and the stop of the installation for the maintenance activity[1]. In fossil power plant, the energy is supplied by combustion of fuel, there will be additional “greenhouse gas” emission [2].

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.

The performance of the steam condenser is directly affected by fouling. Fouling can restrict fluid flow in the condenser by narrowing the flow area.

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

[1] Lecturer .eng. , University of Bacau , Romania (*Corresponding author)
[2] Prof., Power Engineering Department, University “Politehnica” of Bucharest, Romania

cleaning must be undertaken. Heat Exchange Institute (HEI) standards also include some fouling in their requirements for steam surface condensers [3]. 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.

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 (fig. 1).

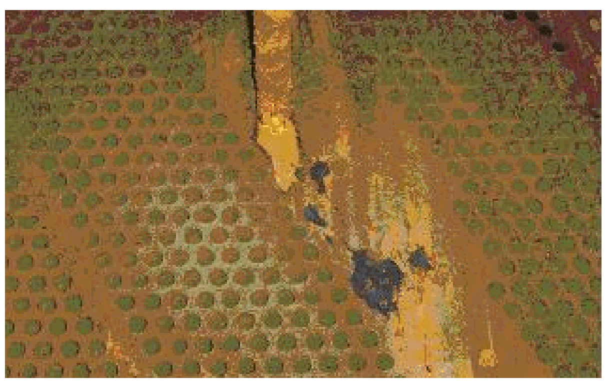

Fig. 1 Fouling on the brass tubes of steam condenser

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.

2. Case study

2.1 Heat transfer in surface condenser

In virtue of exploitation data, the study realizes the computation of fouling resistance at different times and different operating conditions for a condenser of steam turbine DSL 50-1 from CET Bacau.

The condenser plays two important roles [1]:

- It converts the used steam back into water for return to the steam generator as feedwater. This lowers the operational cost of the power plant because the clean and treated condensate is reused.
- It increases the cycle's efficiency.

The condenser of the steam turbine DSL 50-1 is water cooled- steam surface condenser with two-tube side passes [4]. The shell is fabricated from carbon steel and contains the heat exchanger tubes. At the bottom of the shell, where the condensate collects, an outlet is installed. A hotwell is provided. Condensate is pumped from the hotwell for reuse as feedwater for steam generator. The tube bundle and waterboxes are divided into two sections.

The main heat transfer mechanism in a surface condenser is the condensing of saturated steam on the outside of the tubes and the heating of the circulating water inside the tubes. Thus for a given circulating water flow rate, the water inlet temperature to the condenser determines the operating pressure of the condenser. The condenser generates a vacuum which increases the amount of energy extracted from the steam by the turbine. The condenser also serves as a low-pressure collection point for various vent and drain streams within the plant. Technical dates regarding condenser of the steam turbine DSL 50-1 are in the table 1 [4].

Table 1

Technical dates regarding condenser of the steam turbine DSL 50-1

Name		U.M.	Value
In steam space	Fluid flow	t/h	127,4
	enthalpy	kJ/kg	2319,598
	Inlet static pressure	bar	0,054
	Cleanliness factor	%	0,85
	O_2 maxim residual content	mg/kg	$(14\pm2)*10^{-3}$

	Outlet temperature for steam-air mixture	^oC	-
In cooling water space	Water quality	-	Filtrate untreated
	Inlet temperature	^oC	20
	Fluid flow	m^3/h	8000
	Velocity	m/s	1,7÷2
	Pressure drop	mH_2O	3,6
General	Minim difference between steam saturation temperature and outlet water temperature	^oC	-
	Passes number	-	2
	Tubes number	-	5860
	Heat exchange surface	m^2	3000
	Hotwell capacity	m^3	1,4

The tubes are made from brass (70%Cu, 30%Ni). Inside tubes diameter is 23mm and outside tubes diameter is 25 mm. The shell's internal vacuum is supplied and maintained by an external steam jet ejector system. The exploitation data utilized are mean values from six operating conditions, at different electric loads and thermal loads (table 2).

Table 2

Data for study case

No.	**Names**	**u.m.**	**1**	**2**	**3**	**4**	**5**	**6**
1.	Turbine steam inlet mass flow	t/h	322	324,6	228,6	277,5	183,3	327,3
2.	Turbine steam inlet temperature	^oC	546.5	537	544,8	532,5	530	544
3.	Turbine steam inlet pressure	ata	123,4	134,1	131,5	133,6	135,8	127,9
4.	Wet steam inlet temperature t_b	^oC	32,4	37	34,5	38	35	36
5.	Cooling water inlet temperature t_{a1}	^oC	12	14,3	14,5	13	11,3	16
6.	Cooling water outlet temperature t_{a2}	^oC	22,6	24,5	24,4	24,8	21,4	25,7

7.	$\Delta t= t_{a2}-t_{a1}$	^oC	10,6	10,2	9,9	11,8	10,1	9,7
8.	$\delta t=t_b-t_{a2}$	^oC	9,8	12,5	10,1	13,2	13,6	11,7
9.	Mean cooling water temperature t_{am}	^oC	17,3	19,4	19,45	18,9	16,35	20,85
10.	Cooling water density ρ	kg/m^3	998,679	998,284	998,274	998,382	998,842	997,983
11.	Heat capacity at constant pressure c_p	kJ/kg^oC	4,18652	4,18479	4,18476	4,18518	4,18741	4,18379
9.	Cooling water flow $\dot{m}_a$	m^3/h	7085	7088,4	7083,2	7108,2	7054,1	7052,6
10.	Measured Electric Power	MW	58	52,1	51	55	30	52,5

2.2. The computation of overall heat transfer coefficient for clean steam surface

The overall heat transfer coefficient for clean steam surface of the condenser is the basic design heat transfer coefficient.

The method applied is HEI (Heat exchange Institute) method [3]. The relation is:

$$k = C \times \sqrt{w} \times \varphi_c \times \varphi_t \times \varphi_\delta \ [W/m^{2o}C] \quad (1)$$

where w [m/s] is the average cooling water velocity inside tubes, C- diametral tube constant, $C \times \sqrt{w}$ is heat transfer factor (HEI C factor) at 70 F (21^{o}C), φ_c – dimensionless cleanliness factor, φ_t – dimensionless correction factor for inlet cooling water temperature, φ_δ –dimensionless correction factor for tube material and gauge.

$$C = 2458 - 5{,}512 \times d_{ext} \quad (2)$$

where d_{ext} [mm] is outside tube diameter.

$$\varphi_c = 0{,}85, \text{ for cooper alloys.} \quad (3)$$

For the determination of φ_t it is next relationship:

$$\varphi_t = 0{,}604113 + 0{,}174847\left(\frac{t_{a1}}{10}\right) + 0{,}03751\left(\frac{t_{a1}}{10}\right)^2 - 0{,}015046\left(\frac{t_{a1}}{10}\right)^3 \quad (4)$$

φ_δ=1, for brass tube with thickness < 1,25mm.

The average cooling water velocity inside tubes w [m/s] can be determined from continuity equation:

$$w_a = \frac{\dot{m}_a}{S_c} \tag{5}$$

where $S_c = \frac{\pi \times (d_{\text{int}})^2}{4 \times n_{tr}} \times n$ [m^2] is the transfer area, d_{int} [mm] – inside tubes diameter, n_{tr}=2 number of passes, n=5860 number of tubes.

2.3. The computation of effective heat transfer coefficient

The effective heat transfer coefficient for a steam condenser may be calculated from the Fourier equation:

$$k_{ef} = \frac{\dot{m}_a \times \rho \times c_p \times (t_{a2} - t_{a1})}{S \times \Delta t_{med}} \text{[W/m}^{2\text{o}}\text{C]} \tag{6}$$

where S [m^2] is the heat exchange surface and Δt_{med} is log mean temperature difference.

$$\Delta t_{med} = \frac{\Delta t_{high} - \Delta t_{low}}{\ln \frac{\Delta t_{high}}{\Delta t_{low}}} \tag{7}$$

Δt_{high} is the higher terminal temperature difference; Δt_{low} is the lower terminal temperature difference in accordance with the configuration condenser.

$$\Delta t_{high} = t_b - t_{a1}; \Delta t_{low} = t_b - t_{a2}$$

2.4. The determination of fouling resistance

Having established the value of k_{ef}, it is then compared with the basic design heat transfer coefficient (k_c), adjusted for any deviation in fluid flows from the original design values [5]. The fouling resistance may be calculated from;

$$R_f = \frac{1}{k_{ef}} - \frac{1}{k_c} [m^{2o}C / W] \tag{8}$$

The value of R_f calculated using equation (8) represents the effect of fouling on both the insides and outsides of the tubes.

2.5. The values calculated

The values calculated are presented in the next table:

Table 3

Values calculated for the heat transfer rate and fouling resistance

No.	Names	u.m.	1	2	3	4	5	6
1	S_c	m^2	1,205	1,205	1,205	1,205	1,205	1,205
2	w_a	m/s	1,633	1,634	1,626	1,639	1,626	1,642
3	C	-	2320	2320	2320	2320	2320	2320
4	φ_c	-	0,85	0,85	0,85	0,85	0,85	0,85
5	φ_t	-	0,842	0,887	0,858	0,862	0,828	0,918
6	φ_δ	-	1	1	1	1	1	1
7	k_c	$W/m^{2o}C$	***2122***	***2236***	***2157***	***2176***	***2082***	***2321***
8	Δt_{med}	^oC	14,458	17,096	14,491	18,476	18,124	14,617
9	k_{ef}	$W/m^{2o}C$	***2011***	***1636***	***1872***	***1756***	***1522***	***1809***
10	R_f	$m^{2o}C/W$	$2,602*10^{-5}$	$1,64*10^{-4}$	$1,353*10^{-5}$	$1,098*10^{-4}$	$1,767*10^{-4}$	$1,215*10^{-4}$

The diagram from fig.2 presents the real variation of condenser fouling resistance in time. The moments of time are the moments when exploitation data was collected.

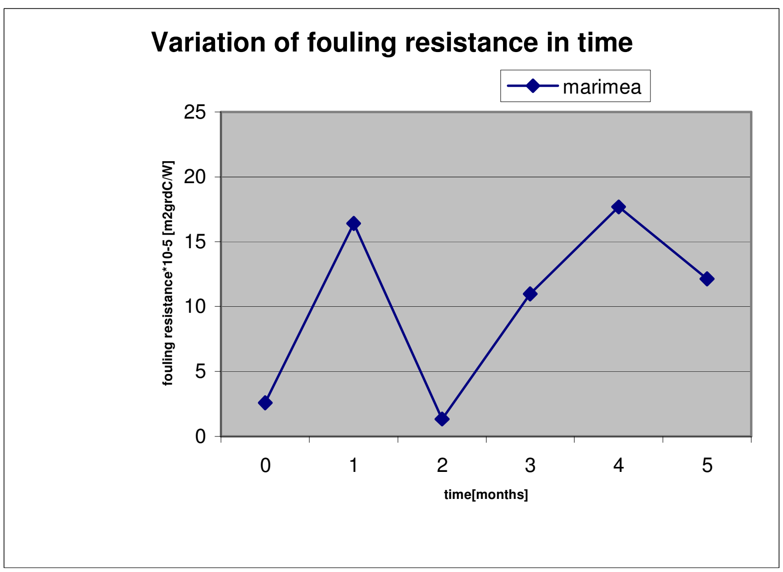

Fig. 2 Real variation of fouling resistance in time

3. Conclusions

The real variation of condenser fouling resistance in time is allied to variation presented in literature [1], variation named saw-toothed fouling**.** To improve confidence in these calculations, it is also important that k_c be verified from test conducted after the steam condenser has just been cleaned. In the presented case, the used exploitation data was from three months after the cleaning of steam condenser. Because of this, it is represented in diagram the superior allure of the real variation saw-toothed fouling.

Researchers established for δt and Δt the next recommended value: $\delta t = (6 \div 7)\ ^oC$ and $\Delta t = (10 \div 12)^oC$. Values for δt are greater then recommendation values. These values are due to the presence of tube fouling or the presence of excessive amounts of air within the shell side of the condenser.

Condenser tube fouling has been found to have a significant impact on condenser performance and on CO_2 emissions [2].

Because of these, it is necessary to put into effect a correct maintenance policy for steam condenser. For the application of this policy, there are a lot of technologies which remove fouling and deposits from condenser tubes and identify the location of air and water in leakage into the condenser [6].

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