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THE ENVIRONMENTAL EFFECT OF HEAT EXCHANGER FOULING

A CASE STUDY

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ABSTRACT

The paper provides data on the effects of heat exchanger fouling on power plant condenser efficiency and on the environmental impact. It also discusses the techniques that are currently being used and under development, for fouling control with special reference to biofouling in cooling water systems and power generation.

INTRODUCTION

Humankind is rapidly becoming aware that it faces at least four major interrelated problems food, water, energy and population- all are related to the environment and in particular to the climate. Bojkov (1978) almost thirty years ago, observed that it might be thought that technological improvements would minimise human dependence on climate. The requirement to satisfy the needs of humanity in the modern world far from being resolved, largely remains to this day, and represents a growing problem.

It was probably the energy crisis in the 1970s that sparked a serious interest in the conservation of energy, which has subsequently developed into concern for the environment. The Kyoto Protocol which seeks to reduce the so called "greenhouse gas" emissions recognised the potential problems for the environment from the continued release of combustion gases, notably carbon dioxide, to the atmosphere.

It is clear that industrial development in third world countries and increased consumption by industrialised nations, will lead to increased demands for energy. The major source of energy is the combustion of fossil fuels, although in the recent past, there has been an increasing interest in "renewable" sources of energy, in the light of the finite limits of fossil fuel availability. Some renewable sources of energy however still rely on combustion as the means of releasing the energy, such as biomass combustion and waste incineration. Attempts are made to ensure "carbon closure" i.e. in biomass combustion the carbon dioxide so released is capable of being utilised by associated crops or tree growth (Beeharry and Bott 2001).

A major contribution to the reduction of "greenhouse gas" emission can be made by attention to energy management where combustion of fossil fuel and other fuels is involved. The overall operation of the process must be considered, and each component that contributes to the overall process must be critically reviewed. Any saving in energy will also represent a reduction in "greenhouse gas" emission.

A wide range of industrial processes involves the transfer of heat energy between fluids principally, but also systems involving solids. The efficiency of the heat transfer process has a direct bearing on the overall process efficiency and particularly energy utilisation. It is well known that the performance of a heat exchanger, is directly affected by the accumulation of unwanted deposits, on the heat transfer surfaces, usually referred to as "fouling". As a result there is a shortfall in the energy available that has to be made up if product output is to be maintained. Not only do the deposits reduce the heat recovery, they can restrict fluid flow in the exchanger by narrowing the flow area. Furthermore the deposit usually presents a rough surface to the flowing fluid. The combined effect results in increased pressure drop for a given fluid throughput, with a further contribution to energy requirements, usually electrical power for pumping.

The loss of heat recovery and the additional energy for pumping, represent a loss of thermal efficiency. In turn, this increases the total energy requirement for the output of the process under consideration. In consequence, where the energy is supplied by combustion of fuel, there will be additional "greenhouse gas" emission.

THE EFFECT OF CONDENSER FOULING ON CARBON DIOXIDE EMISSIONS

Data relating to a 550 MW coal-fired power station are used as a basis for the case study on the impact of condenser fouling on carbon dioxide emissions at full power output. The boiler is capable of raising 1830 tonnes/h of steam at 1.68×10^6 kg/m^2 pressure and a temperature of 540^0 C. A simplified sketch of the layout of the plant is provided on Fig.1. The efficiency of the steam raising plant is 33%. In order to enhance the pressure driving force across the turbines by reducing steam pressure, steam is condensed in seawater-cooled condensers (high and low pressure). Relevant condenser data are given in Table1.

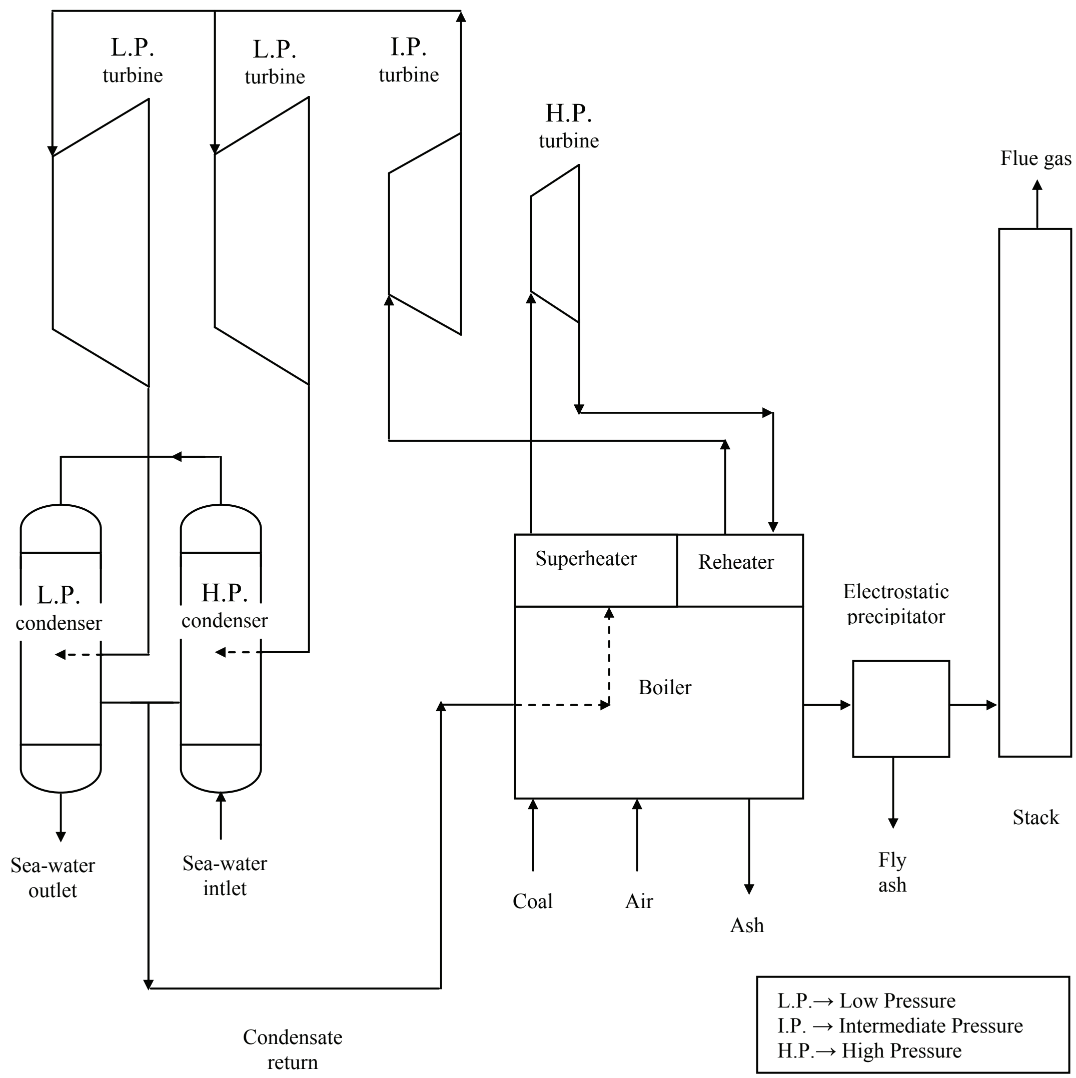

Fig. 1. Simplified sketch of power plant layout

Table 1. Condenser details (clean conditions)

	Low Pressure	High Pressure
Water outlet temp. ºC	26.57	29.28
Heat transfer area m^2	8420	8682
Steam temperature ºC	30.20	35.26
Steam pressure kg/cm^2	0.044	0.059
Heat transferred kW	332,885	329,263
Overall h.t.coeff. W/m^2 K	6211	6336

Assumptions

The following simplifying assumptions are made in the analysis:

1. The seawater is available at 21.1^{o} C which is the sea water temperature used as the basis for the design of the cooling water system. It represents the highest sustained temperature during the summer season.

2. The fouling on the waterside of the condensers is entirely due to biofilm accumulation [microbial deposition and growth]. In order to calculate the effect of different thicknesses of biofilm, it is assumed that the thermal conductivity of the biofilm is that of water since it is recognised that a biofilm is about 90% water.

3. Condensate leaves the respective condensers at their steam temperature i.e. the heat removed is latent heat.

4. Water salinity and associated data are taken from published tables (Beaton 1986)

5. The coal burnt in the boiler is taken to have a calorific value of 6110 kcal/kg with a combustible carbon content of 50%.

6. The condenser tubes are fabricated from aluminium brass.

Equations used in the calculations

For heat flow across the heat transfer surface.

$$Q = UA\Delta T \quad (1)$$

$$R_f = \delta / k \quad (2)$$

RESULTS and DISCUSSION

Table 1 gives the conditions for the two condensers operating under ideal clean conditions providing the basic data for the subsequent calculations. In the calculations a series of biofilm thickness is chosen and the effect of the fouling accumulation on the steam temperature determined and hence the associated steam pressure. The increase in the steam pressure results in a reduction of the driving force across the turbines. It is considered that this loss of energy availability has to be made good by increased steam production and hence an increase in the emission of carbon dioxide. Allowance is made for the efficiency of the boiler. The results of these calculations are given in Tables 2 and 3 and on Figs. 2 and 3, to illustrate the effect of biofouling on CO_2 discharge. There is a proportional increase with increased biofilm thickness.

Table 2.a Low Pressure Condenser operating and calculated data.

δ µm	R_f m^{2}K/W 10^4	R_t m^{2}K/W 10^4	U W/m^{2}K	ΔT ºC	T_s ºC
0	0	1.61	6211	6.36	30.20
10	0.16	1.77	5633	7.02	30.85
50	0.82	2.44	4105	9.63	33.47
100	1.61	3.26	3066	12.90	36.73
300	4.95	6.56	1523	25.96	49.79
500	8.26	9.87	1013	39.02	62.86
750	12.39	14.00	714	55.35	79.18
1000	16.52	18.13	552	71.68	95.51

Table 2.b Low Pressure Condenser operating and calculated data.

δ µm	P_s kg/m^2	F_s kg/h	$Heat_{addl}$ kcal/h	$Coal_{addl}$ kg/h	Carbon kg/h
0	440	493760	0	0	0
10	456	494030	33046	16	8
50	529	495174	174178	86	43
100	640	496701	362798	180	90
300	1265	503102	1066440	529	264
500	2322	509857	1747262	867	433
750	4757	518837	2678031	1328	664
1000	8823	528414	3531875	1752	875

Table 2.c Low Pressure Condenser operating and calculated data.

δ µm	$C0_2$ produced kg/h	Increase $C0_2$ %
0	0	0
10	30	0.01
50	158	0.04
100	330	0.08
300	970	0.23
500	1589	0.37
750	2435	0.57
1000	3211	0.75

Table 3.a High Pressure Condenser operating and calculated data.

δ µm	R_f m^{2}K/W 10^4	R_t m^{2}K/W 10^4	U W/m^{2}K	ΔT ºC	T_s ºC
0	0	1.58	6336	5.99	35.26
10	0.16	1.74	5743	6.60	35.88
50	0.82	2.39	4177	9.08	38.36
100	1.63	3.21	3116	12.17	41.45
300	4.89	6.47	1545	24.54	53.82
500	8.16	9.73	1027	36.92	66.20
750	12.24	13.81	724	52.38	81.66
1000	16.31	17.89	559	67.85	97.13

Table 3.b High Pressure Condenser operating and calculated data.

δ µm	P_s kg/m^2	F_s kg/h	$Heat_{addl}$ kcal/h	$Coal_{addl}$ ºkg/h	Carbon kg/h
0	590	490426	0	0	0
10	611	490724	33171	16	8
50	694	491922	147342	73	36
100	816	493422	305764	152	76
300	1518	499612	940638	467	233
500	2695	506046	1614547	801	400
750	5252	514585	2481345	1231	615
1000	9354	523610	3277137	1625	813

Table 3.c High Pressure Condenser operating and calculated data.

δ µm	$C0_2$ produced kg/h	Increase $C0_2$ %
0	0	0
10	30	0.01
50	134	0.03
100	278	0.06
300	855	0.20
500	1468	0.34
750	2256	0.52
1000	2980	0.69

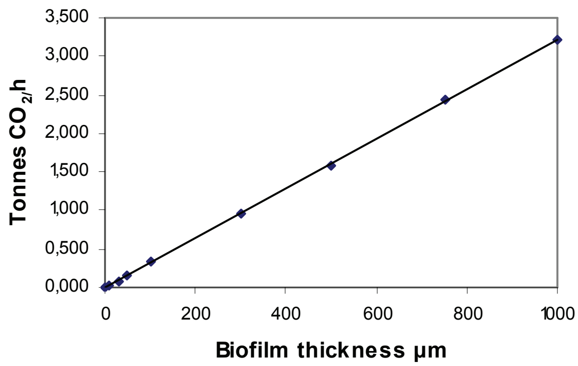

Figure 2 Additional $C0_2$ produced by increasing biofilm thickness (L.P. condenser)

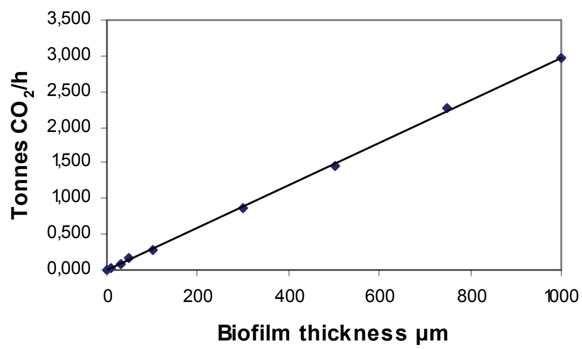

Figure 3 Additional CO_2 produced by increasing biofilm thickness (H.P. condenser)

As would be expected, as the thickness of the biofilm increases the carbon dioxide emissions increase in proportion to the thickness of the biofilm. For the thickest biofilm studied (10^3μm) the sum of the additional carbon dioxide produced amounts to 6.2 tonnes per hour. Although this is a relatively large discharge of carbon dioxide, it represents only a relatively small percentage of the total carbon dioxide produced by the power station when operating on full load. Nevertheless if, this additional emission could be reduced or avoided altogether, it would constitute a significant contribution to the aims of the Kyoto Protocol. This could be achieved through effective biofilm control.

In the Introduction mention was made of the increased pressure drop caused by the accumulation of deposits on heat transfer surfaces. In this study calculations were made on the effect of thickness of a "rough biofilm", on pressure drop. Based on these assumptions it was possible to calculate the additional energy required to pump the water through the condensers, due to the presence of various thicknesses of biofilm.

It was found that the additional carbon dioxide so produced, was insignificant compared to the effects of the reduced heat transfer. It is clear however, that effective control of unwanted deposits on heat transfer surfaces has a major part to play in care of the environment.

The control of the unwanted deposits in cooling water is often accomplished by the use of chemical additives that include; corrosion inhibitors, dispersants, detergents, threshold treatment to restrict crystal formation, crystal modifiers, biodispersants and biocides.

Many governments and regulatory bodies have laid down stringent regulations for the control of emissions of noxious substances into air, water and land. The choice of chemical additives employed to control fouling in the cooling water system therefore, is likely to be affected by the regulations.

The severity of the fouling problem will also affect the choice of antifouling agent. In the power station on which the calculations reported in this paper, have been made, chlorine is used as the biocide and the local regulations restrict the residual chlorine concentration in the discharge to 0.2mg/l. In order to meet the regulations particularly in respect to chlorine, because of its serious effect on the environment, it may be necessary to treat cooling water before discharge back to the source. The cost of this requirement could be high. Alternatively it is possible to employ so called "environmentally friendly" biocides. Biocides such as hydrogen peroxide and ozone, which break down to give the environmentally acceptable bi-products; water and oxygen. There are also available, complex organic additives that breakdown to acceptable residues.

In place of chemical additives it is possible to employ physical methods of control. The circulation of sponge rubber balls with the cooling water, the Tapproge system, is used successfully for the control of biofouling in cooling water circuits. Some techniques that are currently in the development stage for cooling water application include the circulation of polymer fibres with the water, the use of improved designs of insert inside tubes and ultrasound (Bott 2001). The exclusive use of physical techniques however, has implications for the elimination of *Legionella* which is often the subject of regulation. A combination of relatively low biocide concentration and physical method (ultrasound or tube insert) has also been shown to be effective for biofouling control in cooling water applications. This could be a solution to severe biofouling problems and at the same time, satisfy regulations in respect of noxious chemical discharge (Tianqing and Bott, 1998, Wills et al, 2002).

In addition to biofouling power plants experience fouling on the heat transfer surfaces of the boiler. The extent of the potential fouling is very dependent on the quality of the fuel burnt in the steam-raising plant. The problem is likely to be worst in coal-fired and domestic refuse-fired plant. The problem is due to the incombustible material present in the fuel carried forward as particulate matter that deposits often in the molten state, on the heat transfer surfaces. Oil-fired equipment may suffer similar problems, but to a lesser degree. In comparison gas-fired boilers are less susceptible to fouling deposits. The inefficiencies in energy utilisation introduced by the presence of these deposits will lead to an increase in CO_2 emission, as in the condenser system.

CONCLUSIONS

The calculations demonstrate that the presence of unwanted deposits on heat transfer surfaces in power station steam condensers can increase the discharge of "greenhouse" gases. The extent of the increase is of course dependent upon the thickness of the deposit. Fouling in boiler plant will also increase the discharge although this has not been calculated in this case study.

NOMENCLATURE

A Surface area, m^2
C_p Specific heat capacity at constant pressure, J/kgK
D Diameter, m
F Flow, kg/m^2
g Acceleration due to gravity, m/s^2
k Thermal conductivity, W/mK
P Pressure, kg/m^2
Q Heat flow, kcals/h
R Heat transfer resistance, m^2K/W
T Temperature, K
U Overall heat transfer coefficient, W/m^2 K
HP and LP High and low pressure respectively

ΔT Temperature difference, ºC
δ Biofilm thickness, μm
η efficiency

Subscripts

addl addtional
c clean
con condensate
f fouled
s steam
t total

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