AQUARIUS TECHNOLOGIES PTY LTD
WATER QUALITY CONTROL

Unit 1, 23 Richland Avenue
Coopers Plains Q 4108
PO Box 71 Coopers Plains Q 4108

T: +617 3274 4750
F: +617 3274 4736
W: www.aquariustech.com.au

Quality System
Quality Endorsed Company ISO 9001 Lic 5403

Biofilm Effects on Heat Transfer of Heat Exchangers

Biofouling is a general term referring to undesirable effects due to attachment of microorganisms at liquid – solid interfaces of heat exchangers and condensers. The microorganisms produce a slime layer which is a terrific heat insulator. Biofouling on the inside surface of heat exchanger tubes limits the heat exchangers performances drastically and causes pronounced increase in heat transfer resistance. The resulting energy losses in condensers and heat exchangers are of major concern in all industries.

Biofouling is not limited to microbial activity, it can enhance some of the more commonly known fouling phenomena, such as precipitation or crystallization (scaling) and corrosion. Biofouling is particularly acute in industrial cooling water systems. It's been observed almost 80% decrease in the performance of a cooling system over a 7-week period, due to biofouling.

The attached simplified calculations show that a very tiny layer of biofilm which is not visible to the naked eye can reduce the heat transfer rate significantly due to increased resistance against heat transfer. For instance 5 Micron biofilm can cause about 67% reductions in heat transfer of Copper tubes; and 12.5% and 18.5% of Carbon Steel and Stainless Steel tubes respectively. Even 1 Micron biofilm can reduce the heat transfer of Copper tubes by about 30%.

These simple calculations show that restrictions to heat transfer in most condensers and heat exchangers are costing many systems money in energy wastage.

How to Overcome the Problem

"Prevention is better than Cure". Biofilm monitoring procedures are slow and most cooling towers are not equipped with them. There is no instant method to discover the problem and frequent cleaning of heat exchangers is not practical. The best way to prevent biofouling and its resulted energy losses is to keep the system under a reliable antibacterial treatment. The treatment methods which rely on timer injections and are not based on online continuous measurement and monitoring can be associated with biofouling risk.

ORP control provides a continual monitoring system and is yet recognized as the easily measurable and the most reliable parameter which assures a system is under correct and effective Biocide treatment. As long as ORP is set correctly to keep the Chlorine residual between 0.3-0.5ppm, not only is there no risk of biofouling, but also the Chlorine is low enough not to cause corrosion. A suitable Corrosion – Scale inhibitor program combined with ORP (and pH) control will be the best way to keep the condensers' pipes clean and to make the cooling tower work efficiently without energy loss.

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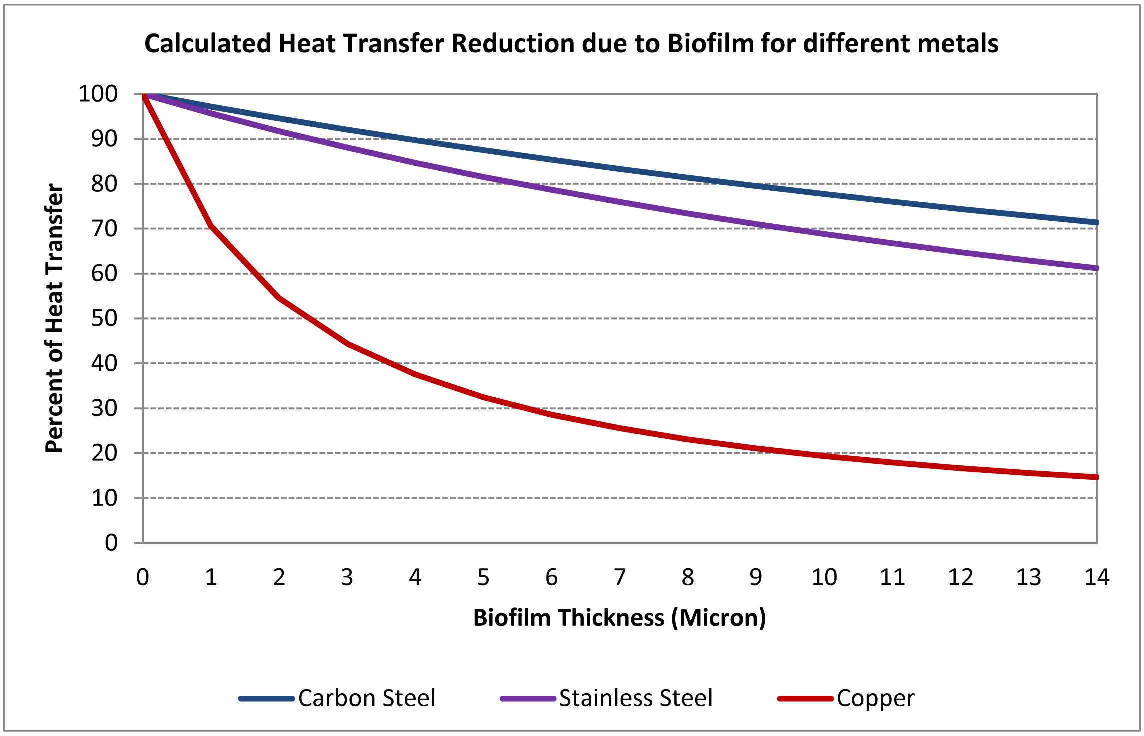
Reduction in Heat Transfer considering different thicknesses of Biofilm

Biofilm Thickness		Percent of Reduction in Heat Transfer		
Micron	(mm)	Carbon Steel Tubes	Stainless Steel tubes	Copper tubes
1	0.001	2.79	4.34	29.46
2	0.002	5.42	8.31	45.45
3	0.003	7.92	11.97	55.56
4	0.004	10.29	15.35	62.50
5	0.005	12.54	18.48	67.57
6	0.006	14.68	21.38	71.43
8	0.008	18.66	26.61	76.92
10	0.01	22.28	31.19	80.65
12	0.012	25.60	35.23	83.33
14	0.014	28.64	38.83	85.37

The results of calculated reduction in heat transfer due to biofilm are tabulated above. Please see the next page for modelling and calculation details.

The following diagram shows the fraction of Heat transfer (in Percent) when biofilm grows.



Note: The above graph if for representing the effect of biofilm on heat transfer rate and should not be used to compare the heat transfer rates of different metals.

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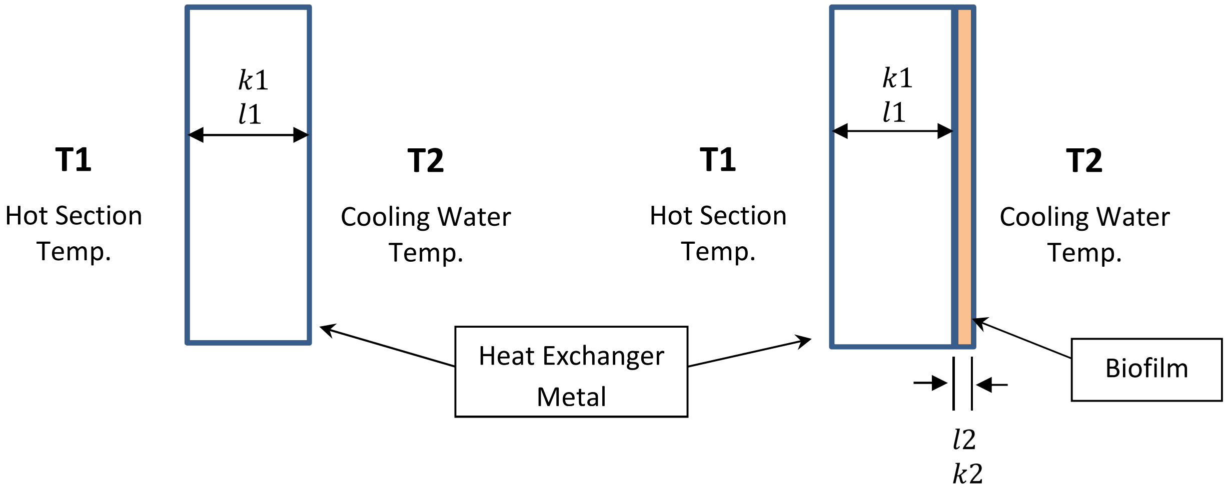
Simplified modelling of reduction in heat transfer rate in Condensers and Heat Exchangers due to Biofilm

A simplified model was developed using Fourier's low of conduction. The model includes conduction heat transfer only but provides good estimations on biofilm effects on heat transfer (compared with available papers). A precise model including convection heat transfers in both side of tubes and heat conduction in tubes and biofilm will be complex and will require more data for calculations. However, we will be more than happy to assist the companies who want to develop a comprehensive model to predict the systems' behaviour when are affected by biofouling.

In both following systems T1 represents the steam (or process) temperature and T2 represents the cooling water temperature.

System 1: Heat Exchanger without biofilm **System 2: Heat Exchanger with biofilm**



Heat transfer rate in System 1 and System 2 according to Fourier's low of Conduction:

System 1: $Q_1 = \frac{T1-T2}{l1/k1}$ System 2: $Q_2 = \frac{T1-T2}{l1/k1 + l2/k2}$

Percents of Reduction in Heat Transfer: $\Delta Q\% = \frac{Q_1 - Q_2}{Q_1} \times 100$

Let: $l1 = thickness\ of\ heat\ exchanger\ tubes$; $k1 = Thermal\ conductivity\ of\ metal$

$k2 = Thermal\ Conductivity\ of\ Biofilm$: $0.6\ W/m.K$

Here are the parameters used for calculations:

Carbon Steel tubes: $l1 = 2.5mm$; $k1 = 43\ W/m.K$

Stainless Steel tubes: $l1 = 2.5mm$; $k1 = 68\ W/m.K$

Copper tubes: $l1 = 1.6mm$; $k1 = 400\ W/m.K$

The results of calculations are available in page 2.