



The effect of velocity variation on cooling tower water heat transfer fouling
by Mukesh Harilal Turakhia

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
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Abstract:

Fouling refers to the deposition of undesirable materials on heat exchanger surfaces. Fouling from cooling tower water is a serious problem in both power and chemical process industries. Experiments were carried out to study the possibility of using high velocity flush out as a method of controlling fouling using simulated cooling tower water. The bulk temperature and the heat flux were kept constant.

The results are reported in the form of fouling resistance, R_f , as a function of time. It was concluded that high velocity flush out was not effective for the system studied.

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Date ~~November 19, 1980~~ Dec. 16, 1980

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ON
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TABLE OF CONTENTS

	<u>Page</u>
Vita	ii
Acknowledgment	iii
List of Tables	vi
List of Figures.	vii
Abstract	viii
Introduction	1
Background	4
Fouling Measurement Techniques.	4
Theoretical Aspects	6
Previous Work	9
Research Objective	11
Experimental System.	13
Experimental Procedure	21
Preparation of Simulated Water.	21
Assembling the Test Section	23
Results and Discussion	25
Conclusion	30
Recommendation for Future Works.	31
Bibliography	32
Nomenclature	34

	<u>Page</u>
Appendices	
(A) Fouling Resistance Time Curves	35
(B) Details of Various Equipment	45

LIST OF TABLES

<u>Table</u>	<u>Page</u>
I Cooling water composition from various sources	3
II Water Preparation Summary.	22

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Definition of terms for data reduction.	5
2. Simplified flow diagram of the process.	14
3. Cross section of the test section	17
4. Details of electric heater.	18
5. Thermocouple attachment method.	19
6. Details of test section	20
7. Fouling resistance time curve for Run 3	36
8. Fouling resistance time curve for Run 5	37
9. Fouling resistance time curve for Run 6	38
10. Fouling resistance time curve for Run 7	39
11. Fouling resistance time curve for Run 8	40
12. Fouling resistance time curve for Run 9	41
13. Fouling resistance time curve for Run 10.	42
14. Fouling resistance time curve for Run 11.	43
15. Fouling resistance time curve for Runs 12 and 13.	44

ABSTRACT

Fouling refers to the deposition of undesirable materials on heat exchanger surfaces. Fouling from cooling tower water is a serious problem in both power and chemical process industries. Experiments were carried out to study the possibility of using high velocity flush out as a method of controlling fouling using simulated cooling tower water. The bulk temperature and the heat flux were kept constant.

The results are reported in the form of fouling resistance, R_f , as a function of time. It was concluded that high velocity flush out was not effective for the system studied.

INTRODUCTION

Fouling refers to any undesirable deposit on a heat exchanger surface that will increase the resistance to heat transmission. The chemical and process industries use large quantities of cooling water. In United States this usage (1) comprises about one third of the total water consumption for all purposes. Cooling water fouling of heat exchange equipment is a serious problem in both the electrical power and the chemical process industries. In fact, the magnitude of the problem is so great that fouling (2,3) has been referred to as the major unresolved problem in heat transfer.

Cooling water fouling may be caused by deposition of suspended solids, by microbial growth, by corrosion products and/or by crystalline deposits. In a commercial application it is usually a combination of these processes.

The most important process is the deposition of salts having inverse solubility characteristics. Such salts can be saturated or even unsaturated at bulk conditions but can be highly supersaturated on a hot surface area. Among the salts which have inverse solubility characteristics are calcium carbonate, calcium sulfate and some forms of silicon salts.

Table I shows the composition of cooling tower water from various sources. It can be clearly seen that the quality of water

varies from place to place. Crystallization is also associated with the deposition of suspended particles and corrosion, giving rise to loose crystalline deposits.

The fouling characteristics of a fluid in contact with a heat transfer surface are a function of a variety of parameters:

- (1) Geometry of heat transfer surface
- (2) Material of heat transfer
- (3) Temperature at interface between fouling liquid and heat transfer surface
- (4) Temperature of deposit
- (5) Velocity past heat transfer surface
- (6) Characteristics of fouling fluid.

Table 1. Cooling water composition from various sources.

	Montana Power Butte	Bozeman	Washington State Power Company	Columbia River Hanford	Missouri River Decatur (IA)	Yellowstone River Livingston
Calcium (as Ca)	207	15	150	20	80	23
Magnesium (as Mg)	205	25	-	4	20	8
Sodium (as Na)	676	0.14	-*	1	-	-
Iron (as Fe)	-	-	5	0.1	-	-
Chloride (as Cl)	106	4.5	-	1	11	10
Sulfate (as SO ₄)	2420	33	-	10	190	30
Silica (as SiO ₂)	150	-	-	6	-	21
pH	8	8.4	8.5	8.2	7.7	-
TDS	3964	205	-	90	-	170

* Data not available

3

3

BACKGROUND

Fouling Measurement Techniques

The effect of fouling in terms of fouling resistance is usually accounted (3) for in the design of heat exchange equipment by adding fouling resistances R_{fo} and $\frac{A_o}{A_i} R_{fi}$ to the fundamental equation of the overall heat transfer coefficient as:

$$\frac{1}{U_f} = \frac{1}{h_o} + \frac{A_o}{A_i} \frac{1}{h_i} + R_{fo} + \frac{A_o}{A_i} R_{fi} + R_w \quad (1)$$

The values of R_{fo} and R_{fi} are selected from tables of questionable accuracy with vague information as to the operating condition for which the fouling information was obtained. Often the magnitude of these two terms is of the same order or greater than the sum of other terms. This excess area therefore often accounts for more than half of the required areas and cost of heat exchanger.

Assuming fouling occurs only on the heated side and the surface area are equal Equation (1) becomes

$$\frac{1}{U_f} = \frac{1}{h_o} + \frac{1}{h_i} + R_f + R_w \quad (2)$$

Solving for R_f

$$R_f = \frac{1}{U_f} - \left(\frac{1}{h_o} + \frac{1}{h_i} + R_w \right) \quad (3)$$

The term inside the bracket is the reciprocal of the overall heat transfer coefficient of the initially clean surface U_i

$$R_f = \frac{1}{U_f} - \frac{1}{U_i} \quad (4)$$

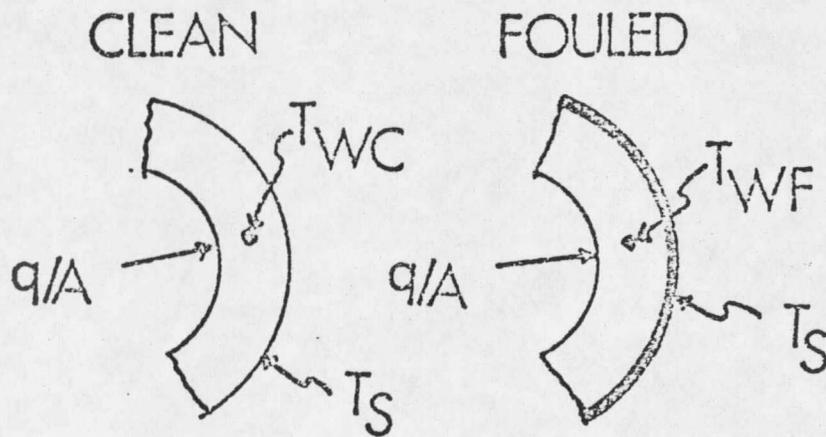


Figure 1. Definition of terms for Data reduction.

Therefore the fouling resistance can be determined by calculating the overall heat transfer coefficient of the clean and fouled tube.

for local fouling measurements, which determines the buildup of fouling at a single locality, the overall coefficient (9) is evaluated by

$$\frac{1}{U} = \frac{T_w - T_b}{q/A} \quad (5)$$

Thus, for a fouling test at constant velocity, heat flux and bulk temperature, the local fouling resistance is calculated as

$$R_f = \frac{T_{wf} - T_{wc}}{q/A} \quad (6)$$

Any change in h_o (due to the change in roughness of the fouled tube) will also change T_{wf} . A definition of terms is shown on Figure 1. To determine the surface temperature, T_s , it is required to know the thermal resistance of the portion of the wall between the thermocouple and tube wall. This thermal resistance can be determined by a Wilson plot (9).

Theoretical Aspects

Fouling rates can be expressed as a function of time with an initial resistance of zero. Two extreme cases in fouling processes are: (1) the fouling deposit continuously increasing with time and (2) asymptotic behaviour. The asymptotic behaviour lends itself to traditional fouling resistance concepts. A fouling resistance which increases with time sets the limit for shut down and cleaning.

Kern and Seaton (6) were first to recognize that a realistic mathematical model for fouling process must be based on material balance:

$$\frac{dR_f}{dt} = \phi_d - \phi_r \quad (7)$$

where dR_f/dt = the net rate of fouling accumulation, ϕ_d the deposition rate and ϕ_r the removal rate. Cooling tower fouling is basically a crystallization process with some noncrystalline sedimentation deposited and trapped in crystal. The deposition rate has been expressed in terms of reaction rate equation, i.e.,

$$\phi_d = kc_r^n \quad (8)$$

The effective reactant concentration, C_r , is a function of the concentrations and of the kind of material in the cooling tower water. The reaction rate constant, k , is an exponential function of the surface temperature. The removal rate, ϕ_r , depends on the hardness or adhesive force of the deposit, on the bond of the deposit to the surface, and on the shearing force, which is a function of the velocity of the system.

The removal rate is proportional to the ratio of shear stress to the bonding resistance of the fouling layer to shear off, that is:

$$\phi_r = C_1 (\tau/R_b) \quad (9)$$

Fouling deposits are sheared off by the fluid at planes of weakness. The probability of the presence of a weak plane is proportional to the thickness of the deposit. Therefore, the bond resistance can be expressed as follows:

$$R_b = \Psi \left(\frac{1}{x_f}\right)^m \quad (10)$$

where Ψ is a proportional constant and is a function of deposit structure. If the discussion is limited to cooling tower water, Ψ will be a function of flow velocity, composition and character of the suspended solids. Substituting 8, 9, and 10 into 7 gives

$$\frac{1}{K_f} \frac{dx_f}{d\theta} + \frac{C_i \tau x_f}{\Psi} = KCr^n \quad (11)$$

Solving,

$$R_f = \frac{x_f}{K_f} = A \exp\left(\frac{-C_i K_f \theta}{\Psi}\right) + \frac{KC_r^n \Psi}{C_i \tau K_f} \quad (12)$$

$$\text{IC } R_f = 0; \quad \theta = 0$$

Therefore,

$$A = -\frac{KC_r^n \Psi}{C_i \tau K_f} = R_{fo}^* \quad (13)$$

$$R_f = R_{fo}^* (1 - e^{-B\theta}) \quad (14)$$

where

$$B = C_i \frac{\tau K_f}{\Psi} \quad (15)$$

As seen from equation (13), the asymptotic fouling resistance R_{fo}^* ,

is a function of surface temperature, velocity, deposit structure and effective reactant concentration.

Previous Work

Hasson and co-workers (5) studied the initial deposition of calcium carbonate scale under conditions of constant heat flux. They found the deposition rate increased by 20% with a 20°F increase in surface temperature.

Knudsen and Storey (4) investigated the effect of surface temperature on the asymptotic fouling resistance for simulated cooling tower water. In contrast to Hasson's work, the asymptotic fouling resistance was found to be a strong function of temperature, changing by a factor of 20 with a surface temperature change of 60°F.

Watkinson, et al., (7) studied calcium carbonate scaling under conditions of constant wall temperature. The surface temperature decreases as scaling proceeds, thus making these data difficult to compare with those obtained at constant heat flux, where the surface temperature essentially remains constant.

Bott and Pinheiro (10) studied the velocity and temperature effects on Biological fouling. The slime thickness decreased with the increase in fluid velocity. It was found that temperature variation of only 5°C for two runs at the same Reynold's number

resulted in an increase of nearly 70% in the slime mass. The kinetics of bacteria growth is the key factor in determining the slime development.

Norrman and coworkers (12) studied the control of microbial fouling in circular tubes with chlorine. They found that the addition of chlorine caused partial film removal with a consequent increase in suspended particles.

RESEARCH OBJECTIVE

Previous work and theoretical aspects in fouling experiment have traditionally followed the build up of fouling at fixed operating conditions. A commercial operation can seldom be kept at fixed operating conditions for a long period of time. For example in a cooling water system, the velocity or temperature might change, or a leak might occur that could change the water quality.

Two examples as a result of change in operating conditions were reported by HTRI (8). In the first example, a fouling asymptotic was being approached when an acid leak occurred, changing the quality of water which gave a rapid increase in fouling resistance and a new secondary asymptote. The second example was as a result of a study to determine the high velocity flush out of the fouling deposits. The velocity was increased from approximately 3 ft/sec to 12 ft/sec. The fouling did indeed decrease considerably, all loose crystalline and sedimentary structure apparently being flushed out. The original velocity was restored and an extremely rapid build-up of fouling was observed. The new level of fouling which established itself in an asymptotic manner was actually higher than the original one.

The objective of this research was to experimentally study and analyze the effect of the velocity variation of cooling tower water, and to investigate the possibility of using high velocity flush-out as a method of controlling fouling. The experiments were started at

fixed operating conditions until an asymptotic form of fouling vs. time curve was obtained. Then the velocity was varied from a low velocity to high velocity in a cyclic manner.

Since fouling is a slow process the time required between these step changes in velocity was long enough to enable a good extrapolation of fouling vs. time curve. By changing the velocity in a cyclic manner, attempts were made to determine if fouling resistance levels off after a long period of time.

The result of the experiments gave insight into the extent to which velocity fluctuation effects fouling in industrial heat exchangers.

EXPERIMENTAL SYSTEM

The flow diagram of the experimental system is as shown in Figure 2. It essentially consisted of a test section, a storage tank, a centrifugal pump and a concentric tube heat exchanger.

The test section was an annular flow duct consisting of an outer transparent 1-inch I.D. acrylic tube (for visual observation) and a concentric 5/8-inch O.D. copper tube. The fluid flowed axially through the annular space between them. The copper tube had an electrically heated section of 6.5 inches, located about 12 inches from the fluid inlet.

A schematic cross section of the heated section is shown in Fig. 3. It consisted of a 9.9 inch long cartridge heater (0.495 inches, O.D., 240V 1000W), as shown in Figure 4. The lead wire from the electric heater was connected to a wattmeter and then to a 22V electric source.

The heat flux or the power input to the electric heater was varied (and easily held constant) by a power-stat and measured by a wattmeter.

Three copper constantan thermocouples were imbedded in the tube wall, as shown in Figure 5. It was important to install the wire in such a way that it would provide a minimum obstruction to the flow. The temperature measured by the thermocouples gave a

