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Evaluation of Vipertex Enhanced Heat Transfer Tubes under Fouling Conditions

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Heat transfer enhancement is important in the development of high performance thermal systems. Fouling of a surface occurs when settlement or growth of unwanted material contaminates the surface to the point that the surface can no longer be used. Deposits are the result of a series of complex reactions that cause deposits to form on the surface. Economic and technical problems associated with fouling in process systems are known and documented. Parameters that influence fouling include: surface geometry, surface temperature, surface material/finish, fluid dynamics, flow velocity and fluid properties. For many conditions, fouling can be reduced but not necessarily eliminated.
Vipertex™ enhanced surfaces are flow optimized process surfaces that increase heat transfer through a combination of factors that include: increasing fluid turbulence, secondary flow development, disruption of the thermal boundary layer and increasing the heat transfer surface area. In addition to heat transfer enhancement, the fouling rate of Vipertubes™ was much less than the rate of smooth tubes; additionally the total amount of fouling over a given time period was also less. This reduction in the rate of fouling is the result of secondary flow patterns that forms as a result of the patented Vipertex surface design. These secondary flows circulate near the tube surface and clean it, preventing the buildup of materials.
Several Vipertubes were studied here, with flow rate and temperature data being monitored for the duration of the study. The tubes are exposed to untreated lake water for various time periods. Transient observations and heat transfer measurements of the surfaces were obtained. Fouling results presented include instantaneous and total fouling amounts.
These observations support the conclusion that when compared to smooth tubes, Vipertubes provide superior thermal performance, providing heat transfer increases of more than 100 %. At the same time the surface of the Vipertubes also minimize the detrimental effects of fouling thus providing additional service time for Vipertex designs. Vipertex surfaces enhance heat transfer, minimize operating costs and recover more energy. These enhanced surfaces provide an opportunity to advance the design of many heat transfer products.

1. Introduction

Fouling is complex, costly, and affects many different industries. Deposits create an insulating layer that restricts the flow of heat between the fluids, causing process efficiency to be reduced. Despite numerous investigations and years of studying the

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formation of deposits on heat transfer surfaces, this remains a major process problem. This study will examine transient fouling of heat transfer tubes that have been exposed to untreated lake water and a temperature difference.

Deposit formation depends on the heat transfer surface, fluid dynamics and the environmental conditions. The flow, temperature and chemical composition of the fluid influence the composition of the deposit. Costs arise from the loss of energy, need for cleaning or repair, and monitoring. The economic impact of fouling is enormous and affects many designs. Industries in the United States estimate the total cost of all aspects of fouling to be in excess of a billion US dollars.

Fouling can cause contamination of the product being produced or interfere with the production process. Prevention and control of fouling is costly and time consuming. Despite numerous investigations regarding the formation of deposits on heat transfer surfaces, this is still a major design problem. This study will examine how enhanced tubes will react when exposed to untreated lake water.

According to Taborek et al. (1972a, 1972b) fouling can be divided into six distinctively different mechanisms: crystallization, particulate/sedimentation, chemical reaction and polymerization, coking, biological/organic material growth, and corrosion; with one or more of these fouling mechanisms occurring. Each mechanism requires a prevention and control technique unique to that mechanism. Also associated with these fouling deposits is the method that these deposits affect process characteristics. Two deposits of equal thickness can have different effects on the heat transfer since the resistance to heat transfer is based on deposit composition.

Recent studies have attempted to evaluate the effect of fouling associated with the optimal design of heat exchangers and their maintenance. Kukulka et al. (2004, 2007a, 2007b, 2008) investigated the effect of materials, surface coatings and finishes on fouling. Muller-Steinhagen et al. (2005) studied fouling mechanisms in heat exchangers. Sikos and Klemes (2010) discuss maintenance and reliability issues associated with heat exchangers and they present a maintenance optimization model. Gogenko et al. (2007) presents a model to size heat exchangers that includes a fouling thermal resistance factor for heat exchangers. The work performed in Gogenko et al. is extended in Arsenyeva et al. (2007) where they present a design optimization model of a heat exchanger that includes fouling parameters.

2. Experimental Details

Smooth and enhanced stainless steel tubes (see Table 1) were evaluated at the Great Lakes Research Center of the State University of New York College at Buffalo for varied amounts of time using surface water from Lake Erie (see Table 2). Changes in heat transfer of the smooth stainless steel tubes were compared to the EHT series of Vipertube™. Temperature of incoming lake water on the hot side was preheated in separate tanks and maintained at approximately 70 °F (21.1 °C) before entering the apparatus, the cold side temperature was the temperature of the lake. The make-up of the water used at the Great Lakes Center does not vary greatly. Inlet water flow was constant at 3.79 L/min. After the prescribed time, the tubes were drained and the samples dried.

Figure 1 shows the general setup of the tube in tube test apparatus used in all heat transfer and fouling evaluations. Samples were held in horizontal positions as shown in Figure 1. After drying the sample, the next step was to observe and photograph the appearance of each tube. Photographs of the tube surfaces were taken using a Hitachi Digital Camera at two times magnification. Observations regarding each tube were made, with weights taken.

Table 1: Geometric and surface details of: (a) Vipertex 2EHT (Type 304 L stainless steel) Enhanced Tube (b) Vipertex 1EHT (Type 304 L stainless steel) Enhanced Tube (c) Smooth Stainless Steel Tube (Type 304 L stainless steel).

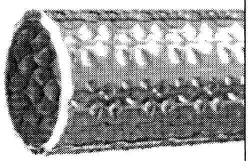
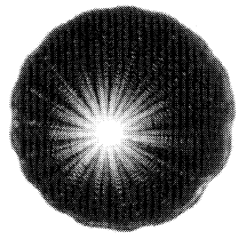
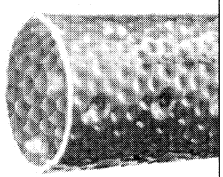
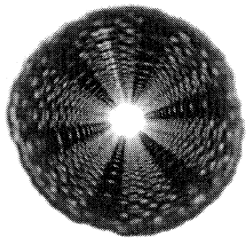
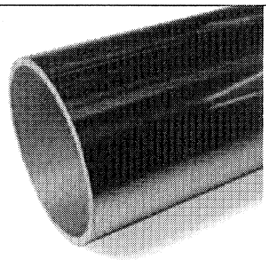
Description	Surface	Cross Sectional View
(a) Vipertube 2EHT: Type 304 stainless steel, type D finish, ASTM 249 pressure tube. Diameter 0.0625 in (0.0159 m) and 0.375 in (0.009525 m).		
(b) Vipertube 1EHT: Type 304 stainless steel, type D finish. Diameter 0.625 in (0.0159 m)		
(c) Stainless steel smooth tube: Type 304, type D finish, ASTM A249 pressure tube. Diameter: 0.375 in (0.009525 m) and 0.625 in (0.0159 m).		

Table 2: Lake Erie Water Composition and Characteristics

CATIONS	PPM IONS	PPM $CaCO_3$
Ca	36.58	91.45
Mg	9.43	38.84
Na	13.92	30.35
K	2.12	2.71
Fe	0.10	0.27
Cu	0.01	0.01
Ba	0.02	0.02
Sr	0.14	0.16
Al	0.061	0.338
Mn	0.000	0.000
TOTAL		164.15

ANIONS	PPM IONS	PPM $CaCO_3$
OH	0.00	0.00
CO_3	0.00	0.0
HCO_3	117.07	96.00
SO_4	38.4	39.98
Cl	22.49	31.71
NO_3	0.00	0.00
F	0.00	0.00
TOTAL		167.69

Total Dissolved Solids PPM Ions = 240.79
Total Dissolved Solids PPM $CaCo_3$ = 168.68
Total Hardness PPM as $CaCO_3$ = 130.29
Total Alkalinity PPM as $CaCO_3$ = 96.00
Fouling Index = 5
pH of Water = 6.80

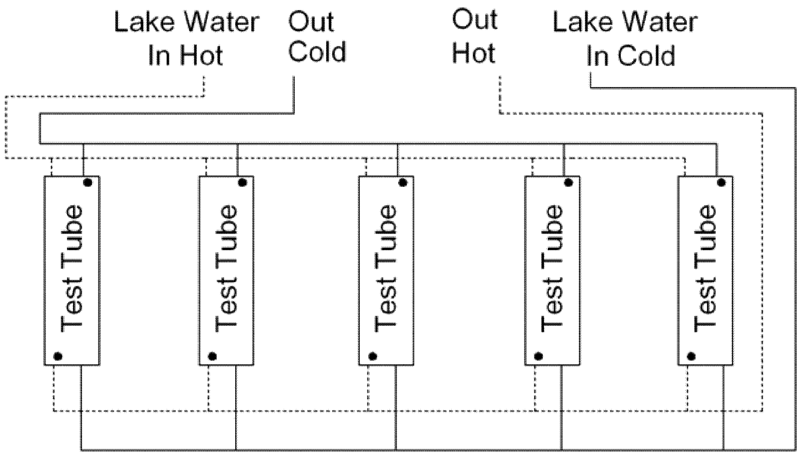


Figure 1: General Experimental Arrangement to Evaluate Fouling Performance of Heat Transfer Tubes Using a Tube in Tube Test Apparatus.

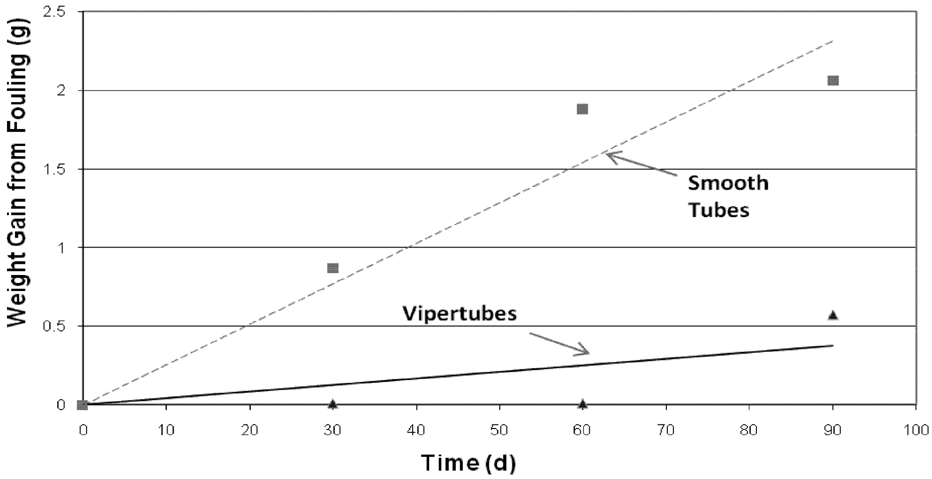


Figure 2: Fouling Weight Increase for Vipertex Enhanced EHT Series Tubes Compared to Smooth Tubes for 70 ºF (21.1 ºC) Inside Tube Fluid Temperature and Approximately 50 ºF (10 ºC) Ambient Fluid Temperature with a Flow Rate of 3.79 L/min.

3. Results

Several stainless steel tubes with various surface finishes were evaluated. These samples were placed in test cells at the Great Lakes Research Center for varied amounts of time, with once though water from Lake Erie circulated. After the prescribed time, the test apparatus was drained and the samples were dried. As each set of tubes was removed from the test chamber, observations about the conditions of each tube were made. These observations included: visible film, color change, corrosion, deposit characteristics, etc. Each material showed a weight gain and with an increase in the surface roughness from the original sample to the sample at 90 d. Figure 2 details the fouling results of all Vipertex tubes [1EHT, 2EHT, 0.0375 in (0.009525 m) and 0.625 in (0.0159 m)] and smooth tubes [0.375 in (0.009525 m) and 0.625 in (0.0159 m)]. The slope of the best fit line that describes the fouling in the smooth tube is 0.0257 compared to 0.0041 for the Vipertex EHT series of tubes. An order of magnitude difference is considerable for this short time period and shows the dramatic decrease in the rate of fouling that takes place with Vipertube for the same set of conditions.

4. Conclusions

Comparing the amount of fouling over the time period shows a gradual increase in the fouling rates with increasing immersion time. Vipertex 1EHT and 2EHT Stainless Steel tubes had lower fouling rates than smooth tubes for any time period. This was expected due to the enhanced tube surface. It is reasonable to say that the smooth tube would fail sooner than the Vipertube samples.

This study showed the thickness of the deposit became more visible the longer the tube was in the lake water and is correlated through the use of fouling weight gain. Not only does the length of time affect the amount of fouling, but the temperature of the ambient also has an effect and is currently being evaluated. Vipertex tube surfaces foul slower than smooth tubes due to the secondary wall enhancement on Vipertubes that produce secondary flows that clean the tube walls; providing a self-cleaning design for most fouling conditions. More detailed examinations of other surface patterns, different geometries and a wider range of temperature differences are currently being studied.

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