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Effect of Rigidized Textured Surfaces on Heat Transfer and Fouling of Enhanced Tubes

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Enhanced heat transfer surfaces are used extensively in the development of high performance thermal systems. Progress has been made in the development of enhanced tube design. Tubes that have been textured on both the inside and outside surfaces, with different helix angles and patterns have been used in experiments that evaluate the heat transfer of the tube. Heat transfer can be enhanced by altering the surface area that is in contact with the fluid or varying the fluid dynamics. Enhanced surfaces increase heat transfer because of the increased turbulence that results from the surface texture and the increased surface area. Enhanced tube patterns produced by Rigidized Metals Corporation show heat transfer performance gains between 7 and 30 percent.
A wide variety of industrial processes involve the transfer of heat energy between fluids. In some cases unwanted deposits may accumulate on enhanced surfaces and cause a resistance to energy transfer. These deposits reduce the heat transfer and can restrict fluid flow. The enhanced tubes evaluated in the fouling study were exposed to untreated lake water. Flow rates and temperature data were monitored for the duration of both the heat transfer study and during the fouling evaluation. After the prescribed time period, the tubes were taken off line and fouling evaluated. Transient observations, heat transfer data, fouling rates and roughness measurements of the tubes are given. The progressive change of surface appearance with increasing immersion times is presented. Correlations that relate surface roughness measurements of the tubes to the rate of fouling and heat transfer are compared for different cases. In general, the Rigidized Metals Corporation enhanced tubing increases heat transfer and does not promote fouling.

1.Introduction

Heat transfer enhancement has become popular recently in the development of high performance thermal systems. Enhanced heat transfer surfaces create a combination of: increased turbulence; secondary flow generation; reduction in thermal boundary layer thickness and increased heat transfer surface area. These factors will provide an increase in heat transfer. A variety of enhanced surface studies have been previously performed

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and include: a study of dimpled tubes by Kalinin et al. [1991] and J. Chen et al. [2001]; dimpled and helical tubes by Giovannini et al. [1991] and corrugated tubes by Marto et al. [1979]. Webb [1981] proposed a performance evaluation for enhanced surfaces that includes heat transfer, surface area, and pumping requirements.

Fouling is a very important and complex problem that extends into many fields; including industrial, chemical, health, and natural processes. The development of deposits is more rapid in fouling systems where nutrients are available. Fouling of surfaces takes place as a result of complex chemical reactions that cause deposits to form on process surfaces. A fouling conditioning film forms immediately upon contact and is a prerequisite for further fouling to occur. It is then followed by an accumulation phase which is characterized by rapid growth. Finally a pseudo-steady state fouling takes place when the accumulation becomes constant. Fouling formation depends on environmental factors, fluid properties and conditions, surface properties, and the geometric configuration of the process surface. Heitz et al. [1996] found that in systems with higher shear forces, the deposits may grow only to a few micrometers, while in other systems the deposits can reach several centimeters.

Costenton et al. [1987] defined biofouling as a process in which the surfaces collect growth and form biofilm.]. Muller-Steinhagen [2005] and Taborek [1972a, 1972b] have identified several distinct fouling mechanisms: crystallization, particulate/sedimentation, and biological/organic material. Efficiency of fouled process systems is reduced by the loss of flow through the tubes and a reduction in heat transfer resulting from an increase in thermal resistance. The economic impact of corrosion and fouling has been documented by Brennenstuhl et al. [1992].

2.Experimental Details

Smooth and enhanced steel, copper and stainless steel tubes 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. Enhanced heat transfer tubes were produced by Rigidized Metals, smooth tubes were stock items. Heat transfer of the non textured stainless steel tubes were compared to Rigidized textured enhanced tubes. Temperature of incoming lake water was preheated in separate tanks and maintained at approximately 70°F and 100 °F before entering the apparatus. Inlet water flow was constant at 0.035 liters/second. After the prescribed time, the tubes were drained and the samples dried.

The first step after drying was to observe and photograph the surface appearance of each tube. Photographs of the tube surfaces were taken using a Hitachi Digital Camera at two times magnification. This captured the characteristics of the deposits on each tube surface, inside and outside. Observations regarding each tube were made, with weights and surface roughness measurements taken. Surface roughness measurements were taken using PocketSurf I, a portable surface roughness gage with a traverse speed of 0.2” (5.08mm) per second and a probe radius of 0.0002” (5μm). Outside surface roughness measurements were taken at three different locations along the axis and along the entire length of the tube.

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3.Results and Conclusions

Fouling observations including visible film, color change, corrosion, and deposit characteristics are given in Table 1. Surface roughness comparison is given in Figure 1 and weight gain measurements are given in Figure 2. The graphs show the increase in the surface roughness as a function of the time the tube was exposed to lake water. Each material showed an increase in the surface roughness from the original sample to the maximum sample time.

Comparing the increased surface roughness values over the time period shows a gradual increase in the roughness values with increasing immersion time. Figures 1 and 2 show that copper and textured stainless steel consistently had lower surface roughness than the other two samples. It is reasonable to say that this material/surface would reach steady state earlier than the other samples. Figure 1 shows that a textured inside surface reaches a maximum accumulation rate approximately at the same time period as the other samples and approaches steady state sooner than the other samples. Figure 2 shows that fouling accumulated the slowest on textured stainless steel. This is contrary to what would have been expected, and was due to the fluid dynamics produced by the textured surface. A further examination of textured heat transfer surfaces is under investigation.

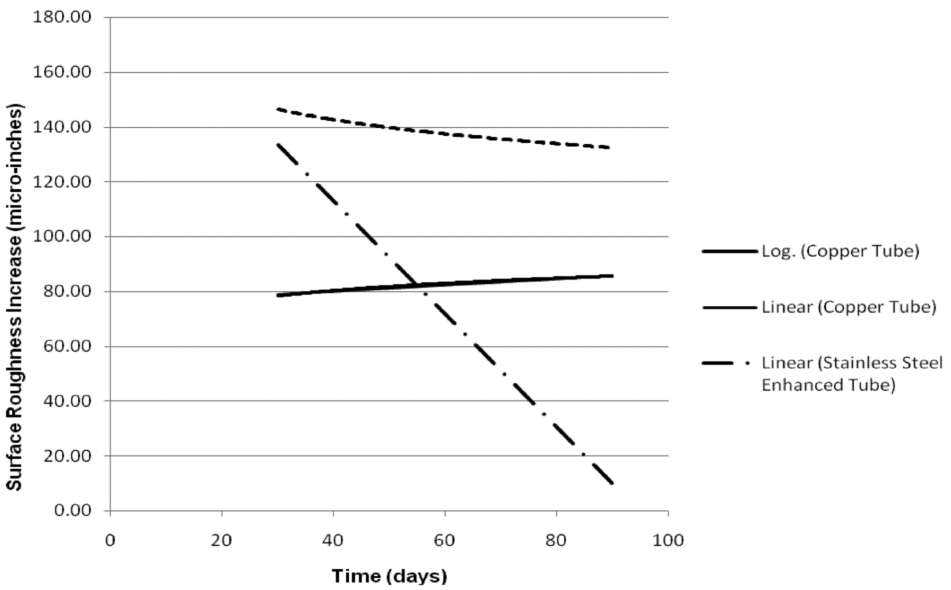

Figure 1. Inside Surface Roughness Increase for Various Tube Materials/Finish (70 ^{O}F inside tube fluid temperature and 100 ^{O}F ambient fluid temperature, flow rate of 0.035 litres/sec)

Table 1. Surface Appearance Observations for Various Materials vs. Time
(Inside Temperature 70 ^{O}F/ Outside Temperature 100 ^{O}F, Flow Rate 0.035 liters/sec)

Tube Materials	**Original**	**30 Day**	**60 Day**	**90 Day**
Copper Outside Surface	Smooth shiny surface.	Dusting tan deposits over green corrosion unevenly distributed top half only.	Same as 30 day no visible difference.	Overall tan deposits w/ corrosion overall outer surface uneven distribution. Thicker deposits and greater coverage area than 60 day.
Copper Inside Surface	Smooth shiny surface.	Thin layer of sediment on bottom of inside tube	More sediment than 30 day	Film overall inside- more sediment than 60 day
Stainless Steel Textured Outside Surface	Smooth shiny finish..	Very slight tan deposits	Extremely slight tan deposits outside less than 30 day.	Thick tan deposits much heavier than 60 day concentrated on top of pipe.
Stainless Steel Textured Inside Surface	Smooth shiny finish.	Slight sediment on inner bottom	Sediment inside bottom-more than 30 day.	More sediment inside tube than 60 day.
Stainless Steel Outside Surface	Smooth shiny finish.	Inconsistent tan deposits overall	Very slight dusting of tan deposits, less than 30 day.	Heavy tan deposits on upper ½ considerably thicker than 30 or 60 day.
Stainless Steel Inside Surface	Smooth shiny finish	Sediment deposits lower half of inside	More sediment inside lower ½ than 30 day	Less sediment inside than 60 day

Table 2. Surface Appearance Observations for Various Materials vs. Time
(Inside Temperature 100 ^{O}F / Outside Temperature 70 ^{O}F, Flow Rate 0.035 liters/sec)

Tube Materials	**Original**	**90 Day**
Copper Outside Surface	Smooth shiny surface.	Tan deposits, strands of thicker deposit areas on sides- green corrosions under deposits.
Copper Inside Surface	Smooth shiny surface.	Sediment heavier inside than 90day.
Stainless Steel Textured Outside Surface	Smooth shiny finish with diamond shaped texture.	Thicker tan deposits concentrated on top of pipe- some areas of rust color film.
Stainless Steel Textured Inside Surface	Smooth shiny finish with diamond shaped texture.	Sediment in lower bottom of pipe
Stainless Steel Outside Surface	Smooth shiny finish	Flaking tan deposits- thicker than 90 day
Stainless Steel Inside Surface	Smooth shiny finish	Sediment in lower bottom of pipe

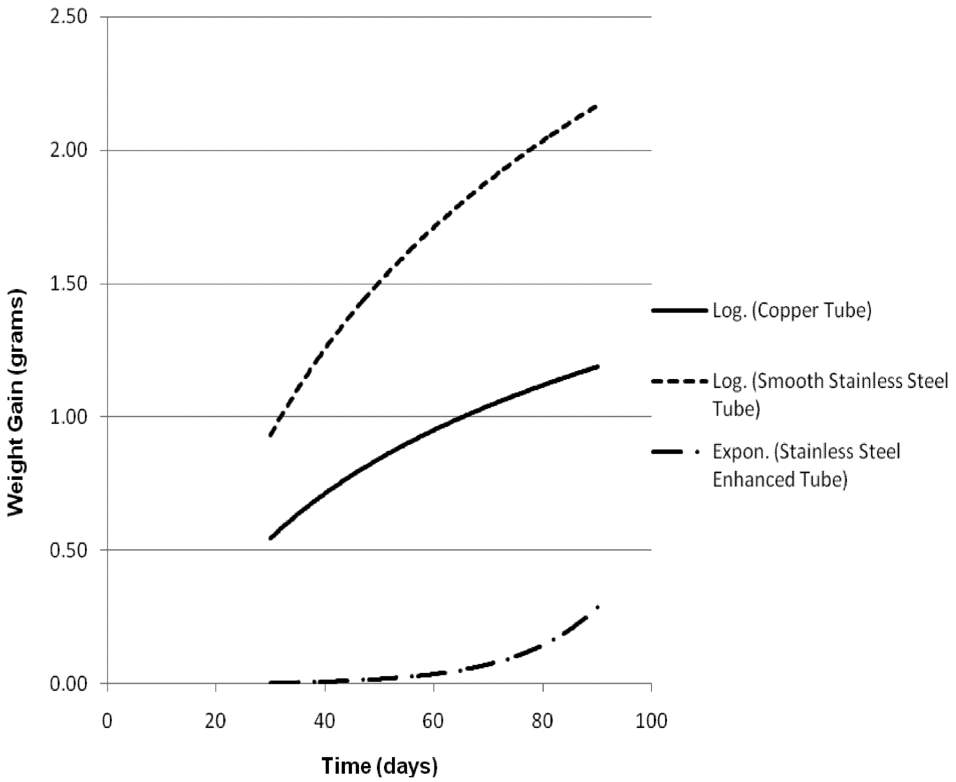

Figure 2 Fouling weight gain for various tube materials /finish (70 ^{O}F inside tube fluid temperature and 100 ^{O}F ambient fluid temperature, flow rate of 0.035 litres/sec)

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