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Development of Enhanced Heat Transfer Tubes

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Heat transfer enhancement has become popular recently in the development of high performance thermal systems. Enhanced surfaces increase heat transfer because of the increased surface area and the increased fluid turbulence that results from the surface design. Increase heat transfer is accomplished using the newly developed Rigidized three dimensional, enhanced heat transfer surfaces. Heat transfer rates have been evaluated over a wide range of conditions using these enhanced tubes, for a variety of different surface configurations.
A wide variety of industrial processes involve the transfer of heat energy. These processes provide a source for energy recovery. These surfaces enhance heat transfer through a combination of factors that include: increasing fluid turbulence, generating secondary fluid flow patterns, disturbing the boundary layer and increasing the heat transfer surface area. Additionally, the Rigidized 2EHT Series Enhanced Tubes minimize fouling. All these factors lead to an increase in the overall heat transfer coefficient.
Several enhanced tube configurations were studied here, with transient observations and heat transfer measurements of the surfaces presented. The patented three dimensional enhanced heat transfer tubes produced by Rigidized Metals Corporation show heat transfer performance gains in excess of 100 % for the Rigidized 2EHT series enhanced tubes. Rigidized enhanced surfaces can be used with alloy tubes and is able to increase heat transfer at low flow rates. Rigidized surfaces enhance heat transfer, minimize cost and save energy. Development of an enhanced alloy tube, produced under ASTM/ASME 249 standards, provides a very important and exciting advancement in the design of heat transfer products.

1. Introduction

Enhanced heat transfer surfaces create a combination of: increased turbulence; secondary flow generation; disturbed boundary layer and an increased heat transfer surface area. These factors lead to an increase in heat transfer and a prolonged product life. A variety of enhanced surface studies have been previously performed and include: a study of dimpled tubes by Kalinin et al. (1991) and Chen et al. (2001), dimpled and helical tubes by Giovannini et al. (1991), Gee and Webb (1980) studied the effect of

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enhanced tube geometrical factors. Marto et al. (1979) studied corrugated tubes. Vincente et al. (2002) discussed heat transfer and pressure drop of helically dimpled tubes. Recently, Christians et al. (2010a, 2010b) studied film condensation of refrigerants on enhanced tubes.

One of the considerations for assessing the effectiveness of augmented surfaces is economic and includes: initial development cost, capital cost, operating cost, and maintenance cost. Reliability and safety issues are also important. The relationship between the thermal and hydraulic performance must also be considered in the design and are addressed in the ASME/ASTM standards. Operational variables include the rate of heat transfer, pumping power, pressure drop, heat transfer, flow rate and fluid velocity. Webb (1981) proposed performance criteria for flow in tubes and includes increased heat transfer, reduced surface area, and reduced pumping power.

In the case of a heat exchanger where there is a one-for-one replacement of smooth tubes with enhanced tubes of equal length there is an increase heat transfer for a constant fluid flow rate; however the pumping power of the enhanced tube exchanger is greater due to increased friction. Alternatively, pumping power could be kept constant by reducing the tube-side velocity. For constant flow area and pumping power, the tube length and flow rate would be reduced. Enhanced tubes will reduce pumping power for a constant heat transfer and flow rate.

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. Muller-Steinhagen (2005) studied fouling mechanisms in heat exchangers.

Fouling of a surface occurs when growth of organisms contaminates the surface until it can no longer be used. It also 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.

Fouling is complex, costly, and affects many different industries. These deposits create an insulating layer that restricts the flow of heat between the fluids and results in a loss of energy. Deposits cause process efficiency to be reduced. Development is more rapid in systems where adequate nutrients are available. Fouling thickness varies with environmental conditions. Deposit formation depends on the environmental surroundings and the process surface. The flow, temperature and chemical composition of the liquid all influence the formation of the deposit. A low or stagnant flow allows growth to easily attach to the process surface. Surface properties also impact the formation of the deposit. The economic impact of fouling is enormous. Costs arise from the loss of energy, need for cleaning or repair, and monitoring. Recent studies have attempted to evaluate the effect of fouling associated with the optimal design of plate heat exchangers and their maintenance. Sikos and Klemeš (2009) 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 plate heat exchangers that includes a fouling thermal resistance factor for plate 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 plate heat exchanger that includes fouling parameters.

Müller-Steinhagen and Zhao (1997) investigated the development of stainless steel surfaces with low surface energy created by ion implantation. These surfaces reduce fouling accumulation without the inherent disadvantages of surface coatings. Zhao et al. (2008) further studied the advantages of ion-implanted stainless steel surfaces. Their experimental results showed that these implanted stainless steels, particularly SiF_3^+ implanted stainless steel performed much better than untreated stainless steel in reducing bacterial attachment. Rosmaninho et al. (2007) studied modifying stainless steel process surfaces for use in the dairy industry.

2. Experimental Details

Heat transfer and fouling studies were performed. The heat transfer experimental apparatus consists of an annular test section, two water tanks, mixing chambers, flowmeters and pumps. The liquid is in an open or closed loop on the tube side and in an open loop on the inside of the tube. Two centrifugal pumps provide the fluid circulation. Flow can be arranged in a parallel flow or a counter flow arrangement. Water temperature is regulated with an inline heater that holds the temperature within 0.1 °C. Data ports are installed throughout the test apparatus. Data is sampled digitally at the desired intervals and stored.

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 6 liters/minute. After the prescribed time, the tubes were drained and the samples dried.

3. Results

Rigidized Enhanced Heat Transfer Tubes provide a three dimensional textured alloy tube that is produced according to ASTM 249 specifications. These tubes provide a reliable means to increase heat transfer as well as a means to decrease fouling for systems that include fouling. These tubes are also useful for two phase applications.

Several tubes (copper, plain carbon steel, and stainless steel) with various surface finishes were tested. Two types of studies were performed, heat transfer and fouling. In both tests, the enhanced tubes outperformed smooth tubes.

In the case of fouling tests, the tubes were placed in tanks at the Great Lakes Research Center for varied amounts of time, with once though water from Lake Erie circulated. Observations included: visible film, color change, corrosion, deposit characteristics, etc.

Each material showed an increase in the surface roughness. In Figure 1, it can be seen that a smooth material/surface would reach steady state earlier than an enhanced tube, indicating that fouling occurs at a faster rate for smooth tubes. This may differ from what would have been expected and is due to enhanced flow conditions that the surface texture provides.

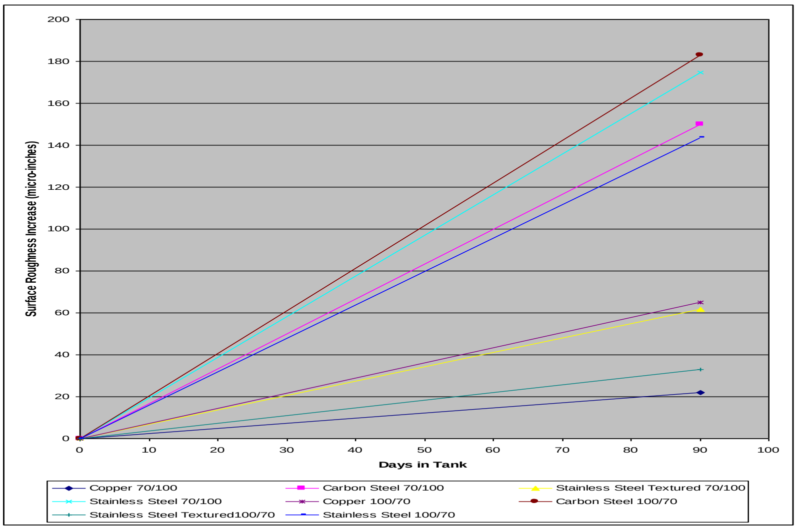


Figure 1: Comparison of outside surface roughness for various tube materials for different inside and outside tube fluid temperatures for a flow rate of 0.035 L/s Caption of (70/100) implies that 70 deg F inside tube fluid temperature /100 deg F outside ambient fluid

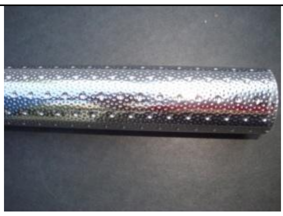
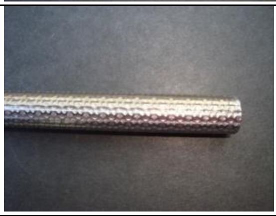
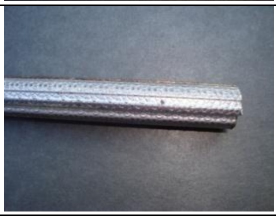
This study showed the thickness of the deposit became more visible the longer the tube was tested and is correlated through the use of the surface roughness measurements presented. Not only does the length of time affect the amount of fouling, but the temperature of the ambient also has an effect.

Heat transfer of the non textured stainless steel tubes were compared to Rigidized textured enhanced tubes. Tests were run in a parallel flow and counter flow arrangements. Results determine that the secondary enhancements cause disturbances near the wall, while the primary enhancements will disrupt the boundary layer farther from the surface. Table 1 shows heat transfer results for some of the Rigidized 2EHT Series Enhanced Tubes, some values of heat transfer increase in excess of 120 %.

4. Conclusions

Rigidized enhanced tube configurations were studied here over a wide range of temperature, flow and fouling conditions. Fouling observations and heat transfer measurements of the tubes are given. Three dimensional heat transfer tubes minimize fouling and show heat transfer performance gains in excess of 100 % for the Rigidized 2EHT series of enhanced tubes. These enhanced tubes are produced under ASTM/ASME 249 standards and can be produced using various alloys. They increase heat transfer at low flow rates and provide a very important and exciting advancement in tube design. The patented Rigidized surfaces enhance heat transfer, minimize cost and saves energy. Further studies of these tubes and surfaces are currently under way. Additional surfaces are being developed to address specific flow conditions.

Table 1: Increases in Heat Transfer for Rigidized 2EHT series Enhanced Heat Transfer Tubes

2EHT1		**117 % increase in Overall** Heat Transfer Coefficient
2EHT2		**138 % increase in Overall** Heat Transfer Coefficient
2EHT3		**106 % increase in Overall** Heat Transfer Coefficient
2EHT4		**123% increase in Overall** Heat Transfer Coefficient

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