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Comparison of condensation and evaporation heat transfer on the outside of smooth and enhanced 1EHT tubes

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HIGHLIGHTS

- Evaporation heat transfer performance on the outside of the 1EHT tube is greater than a smooth tube.
- Surface enhancement creates more nucleation sites and excellent evaporation performance.
- Condensation heat transfer on the 1EHT tube is less than a smooth tube for low flowrates.

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ABSTRACT

Results are presented here from an experimental investigation that evaluated the outside condensation and evaporation heat transfer that took place on a 12.7 mm (0.5 in.) OD horizontal copper tube. Evaporation conditions include a mass flux that ranged from 10 to 40 kg/m^2 s; with an inlet quality of 0.1 (±0.05); outlet quality of 0.8 (±0.05); and a nominal evaporation temperature of 279 K. Condensation conditions considered here include mass flux values that varied from 5 to 50 kg/m^2 s; at a saturation temperature of 318 K; with an inlet quality of 0.8 (±0.05); and outlet quality of 0.1 (±0.05). For enhanced tubes, there are limited heat transfer predicting procedures available (within the degree of confidence necessary to perform analysis) since any work that has been done is limited to specific geometry and operating conditions that have been based upon tests from which the predicting procedures have been derived. Therefore, in this study, smooth tubes were compared to the newly developed Vipertex™ 1EHT enhanced surface tube. Average evaporation heat transfer coefficients for R22 and R410A on the 1EHT tube are in the range of one to four times greater than those of a smooth tube. Condensation heat transfer performance on the outside of a 1EHT tube is less than a smooth tube due to the pattern/drainage characteristics of that model of tube for the flow conditions considered.

Three dimensional enhanced surfaces can be incorporated on the surface of tubes in order to enhance heat transfer performance. Under many conditions, enhanced surface tubes can recover more energy and provide the opportunity to advance the design of many heat transfer products. Enhanced heat transfer tubes are widely used in a variety of industries in order to reduce cost and create applications that use a smaller footprint. Vipertex 1EHT tubes are a new type of enhanced heat transfer tube that uses multiple enhancement patterns; a primary pattern made up of dimples/protrusions with a secondary pattern that is an array of petals. Since this design is unique and unlike other tubes it is important to investigate the heat transfer characteristics of this novel enhanced heat transfer tube and compare it to other tubes.

1. Introduction

Enhanced heat transfer has received a good deal of attention due to increased demands by industry to conserve energy; produce heat exchange equipment that is less expensive to build and operate; or produce equipment with a smaller footprint. Designs that utilize enhanced tubes will require fewer tubes to produce the same heat transfer and can lower the initial cost/size of the process units. Alternatively, for the same size (physical unit size), the use of enhanced tubes can also increase energy production/recovery; all this provides a strong motivation for their use in the development of new heat transfer equipment. Tubeside heat transfer enhancement is often considered when trying to obtain

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energy efficiency improvements for many applications. This new tube is enhanced on both the inside and outside surface, providing shell side enhancement in addition to tube side enhancement.

This study evaluated the heat transfer performance of the Vipertex 1EHT enhanced tubes for outside tube condensation and evaporation conditions. The enhanced 1EHT tube surface is neither a classic "integral roughness" (little surface area increase) tube, nor an internally finned tube with a surface area increase and no flow separation. This surface is more of a hybrid surface that produces both separation of flow (produced by the primary dimple enhancement) and a surface area increase (produced by the primary dimple enhancement and secondary background enhancement). This enhanced heat transfer surface creates increased performance through a combination of: increased turbulence; high density of nucleation sites; boundary layer disruption; secondary flow generation; and increased heat transfer surface area. For most conditions these factors can lead to an increase in the heat transfer coefficient resulting in: a smaller unit footprint; savings in operational costs and a prolonged product life. Heat transfer enhancement using the 1EHT series of tubes provides a means to significantly advance the design of many heating and cooling processes.

Additional support regarding the use of enhanced heat transfer surfaces and their use in energy efficient projects is discussed by Reay [1] where he states that "between 1900 and 1955 the average rate of global energy use rose from about 1 TW to 2 TW. From 1955 to 1999 energy use rose from 2 TW to about 12 TW." In 2011 energy use rose to an estimated value of 17 TW; and it is currently above 20 TW; with future demand expected to increase at a similar rate. Government legislation and specific energy conservation targets have been set for overall energy reduction on a national basis by many countries. Some governments even provide incentives to reduce energy usage and environmental impact. Gough [2] points out that the nuclear disaster that occurred several years ago in Japan has prompted the Japanese government to take a more active role in its serious drive to reduce energy use. Additional countries have started to adopt the same approach, making the conservation of waste energy and the development of enhanced heat transfer even more important. Reay [1] also notes "that there is a need to reduce CO_2 emissions by over 50% in order to stabilize their impact on global warming. One way in which we can address this is by judicious use of process intensification technology." He goes on to define process intensification as: "Any engineering development that leads to a substantially smaller, cleaner, safer and more energy-efficient technology." This encompasses a large number of processes and is most often characterized by a large reduction in plant volume; in addition "its contribution in reducing greenhouse gas emissions may also be significant." Heat transfer enhancement plays an important part in process intensification.

Cooling system designs used in the transportation and aerospace industries require that the heat exchangers are compact and lightweight. Likewise efficient, compact designs are also important in other industries (i.e. HVAC, power plant, chemical, oil/gas applications, etc.). This has led to the use and development of enhanced heat transfer surfaces on alloys that can be utilized in those industries. In general, enhanced heat transfer surfaces can be used to: (i) reduce the overall volume of the heat exchanger, making the heat exchanger compact and lightweight; (ii) reduce power requirements, making the heat exchanger more economic to operate; (iii) increase the overall UA value of the heat exchanger (where U is the overall heat transfer coefficient and A is the heat transfer area), producing more heat transfer in the same footprint; and (iv) reduce the cost of the heat exchanger; making a smaller, less expensive heat exchanger that also costs less to operate. A higher UA value can obtain an increased heat exchange rate for fixed fluid inlet temperatures; or a reduction of the mean temperature difference can be produced (increasing the thermodynamic process efficiency and saving operating costs).

Enhancement techniques are typically classified as passive or active. Passive methods require no direct application of external power to increase heat transfer and they may employ special surface geometries or fluid additives which produce a heat transfer enhancement; while active methods require external power for operation. The majority of commercial enhancement techniques are passive ones since active commercial techniques are costly and for some arrangements may be difficult to implement. Passive techniques are utilized here to provide enhancement by establishing a higher hA (where h is the heat transfer coefficient and A is the heat transfer surface area) than that which is produced using smooth tubes. These enhancement techniques are implemented by: (i) Increasing the effective heat transfer surface area without appreciably changing the heat transfer coefficient; (ii) Increasing the heat transfer coefficient without appreciably changing the surface area; and (iii) Increasing both the surface area and the heat transfer coefficient.

Enhanced heat transfer surfaces typically produce an increased pressure drop that needs to be considered in the design process. Sometimes, the benefits gained from heat transfer enhancement are not great enough to offset the increase in friction and when considering retrofit designs this is a very important consideration. The desired performance goal for designs using enhancement techniques is to produce the maximum enhancement of heat transfer with a limited increase to the pumping power. Many previous studies have evaluated the enhancement of evaporators/condensers and the use of high performance components in various applications. These enhancement techniques include: twisted tape inserts, internal fins, and the use of enhanced surfaces [3].

A good deal of recent work has been performed to study the effect of enhancement (structured surfaces and inserts) on the tubeside heat transfer coefficient. Li et al. [4] found that rib geometries play only a small role in both average and local heat transfer under forced convection, while for the mixed convection case, rib geometry has a significant effect on heat transfer. Guo et al. [5] evaluated convective condensation and evaporation inside a smooth tube, herringbone tube and the 1EHT enhanced surface tube. Overall the 1EHT tube was found to provide increased tubeside enhancement for both condensation and evaporation. Cheng et al. [6] studied the tubeside condensation heat transfer characteristics of enhanced tubes in a horizontal arrangement using R22. It was determined that the behavior of h for three dimensional tubes is significantly different than low fin surfaces. Kukulka et al. [7] found that the condensation and evaporation heat transfer performance factor (ratio of enhanced h to smooth tube h) is larger than unity for all conditions considered. Ji et al. [8] provides a comprehensive literature survey on the thermal-hydraulic performance of tube side single phase heat transfer. Additional studies have investigated the heat transfer on the inside of various tubes. Cavallini et al. [9] presented a relationship that predicts the condensation heat transfer coefficient in micro-fin tubes and a review of other works. Tube bundles were mainly discussed in the evaluation of external tube performance. Doretti et al. [10] presents a review of the condensation flow patterns inside smooth and micro-fin tubes. Olivier et al. [11] performed an experimental study to compare the heat transfer characteristics on the inside of a: (i) smooth; (ii) micro-fin; and (iii) herringbone tube. Thome et al. [12] studied the development of flow structures in various in-tube flow regimes. Murase et al. [13] evaluated the effect of inundation on banks of enhanced tubes. This study varied position and types of tubes. Zupancic et al. [14] presents the results from the development of biphilic surfaces that are designed to enhance heat transfer during boiling. They present results that demonstrate that the uniform, super-hydrophilic surface produces a heat flux that is