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Enhanced Heat Transfer Surface Development for Exterior Tube Surfaces

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Enhanced heat transfer surfaces are produced by modifying a process surface. New tube and process designs are necessary in order to increase heat transfer, minimize operating costs and save energy. In a comparison of first generation Vipertex enhanced heat transfer tubes with smooth tubes, an increase of performance in excess of sixty percent was determined for the enhanced tubes. This study was undertaken to further enhance heat transfer on the outer surface of these heat transfer tubes. Through the use of computational fluid dynamic (CFD) methods, a flow optimization study of the characters that are used to build the enhanced surface was performed. This study evaluates the effect of character pattern and character geometry on the fluid flow and heat transfer of the process surface. As a result, new process surface designs were developed that produce performance enhancement on the outside of a tube for Reynolds numbers to 215,000. For this range, the minimum increase in heat transfer was experimentally determined at low flows to be 125 %; an increase of heat transfer in excess of 200 % was found for high flows. Modest increases of the friction factor accompany these increases in heat transfer.
Heat transfer enhancement is important in the development of high performance thermal systems. Many industrial processes involve the transfer of heat energy and most employ old technology; if improved process performance is desired, these processes should be considered for redesign using enhanced surfaces. Enhanced heat transfer performance is the result of a combination of surface variations that are a result from this detailed surface study. Enhanced performance characteristics include: increased fluid turbulence, secondary fluid flow patterns enhancement, disruption of the thermal boundary layer and increased process surface area. These enhanced factors lead to an increase in the heat transfer coefficient; the ability to produce a unit with a smaller unit footprint; systems that are more economic to operate and have a prolonged product life. This provides a very important and exciting advancement in the design of processes that utilize heat transfer tubes and surfaces.

1. Introduction

Agra et al. (2011) numerically investigated the heat transfer and pressure drop characteristics of smooth, corrugated and helically finned tubes using CFD analysis. Analysis was carried out for Reynolds numbers ranging from 12,000 to 57,000 for various tubes. Water was used as a fluid and a constant temperature boundary condition was applied to the tube wall. The effects of the helix angle or ridge height on the temperature between the fluid and the inner tube wall, pressure drop penalty and convective heat transfer coefficient were investigated as a function of temperature, mass flux and Reynolds number. Kumar et al. (2012) summarizes several CFD investigations detailing the effect of roughness geometries on the heat transfer and friction factor used in solar air heating ducts. Kukulka and Smith (2012) detail the development process and results for performance on the inside of an enhanced heat transfer tube. Kukulka et. al (2011) presents performance of enhanced heat transfer tubes under fouling conditions.
A modified form of Dittus-Boelter's (1930) classic correlation was used in the present study to compare the heat transfer coefficient on the outside to that of a smooth tube as a function of the annulus Reynolds number. No other comparison can be made since peak performance range considered in the current study did not fall into the range considered in Agra et al. (2011) or Kumar et al. (2012).

In general the objective of this study is to optimize the surface pattern on an enhanced heat transfer surface in order to maximize heat transfer while minimizing pumping power and the rate of fouling for a certain range of flows. Enhancement characters used in the first generation Vipertex tubes were evaluated and modified. For the conditions considered, the optimized enhanced surface was then compared to an unenhanced surface. Various models of the surfaces were identified and the characters used in the development of the enhancement surfaces analyzed using CFD analysis. Pattern results were visualized and effects combined to achieve the desired results. Several patterns were modelled and the desired objectives evaluated (heat transfer, fouling, pumping power, low flow, turbulent flow, single phase, two phase, etc). Enhancement characters can be combined into patterns, and then multiple patterns can be combined to produce the desired results. These designs were then used to produce the second generation Vipertex 1EHT enhanced surface. Heat transfer tubes were then produced and these tubes were experimentally evaluated.

2. Model

In order to simplify the model, several assumptions have been adopted in this study including: 1) Gravity and buoyancy is negligible; 2) Thermophysical fluid properties are constant; 3) Local thermodynamic equilibrium is satisfied; 4) Ambient temperature, T_∞ , is constant; 5) Flow is uniform with a constant velocity, U_∞ ; 6) Tube surface for the smooth surface has no-slip velocity boundary conditions.

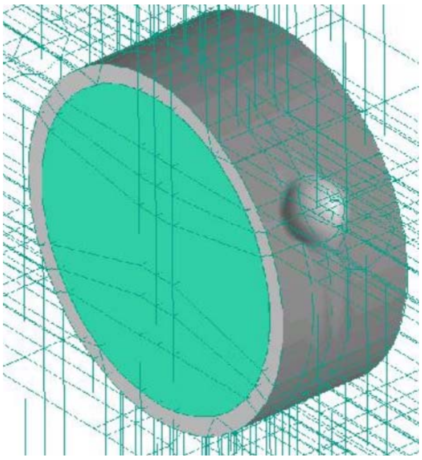

Figure 1: Sample mesh for CFD analysis of an enhancement character

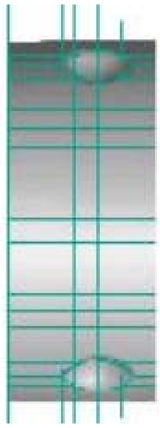

Figure 2: Location of the CFD analysis on an enhancement character

The conservation equations with the appropriate boundary conditions are solved numerically by CFD2000, a commercial CFD code. An initial study of various enhancement characters was performed in order to determine the enhancement to be considered. In order to minimize the effect of the far-field boundary conditions, the outer boundary of the computational domain must be placed sufficiently far away from the tube. A rectangular domain was chosen to simulate the unbounded flow past the tube section in order to insure that the outer boundaries do not have any noticeable effect on the CFD simulation flow parameters. The model utilized a rectangular mesh, and the area around the cylinder wall was carefully meshed using a boundary layer technique that allowed the grid to be refined and minimized. This is necessary in order to observe the flow near the tubes. Figure 1 shows a representation of the mesh for a sample enhancement character. Uniform incoming fluid velocity is set for the entry computation region; with an inlet velocity, U_∞, of 1 ft/sec (0.3048 m/s); fluid inlet temperature, T_∞, was set at 70 ^oF (21.1 ^oC); and outer boundaries are set as adiabatic. A standard wall function processing method is adopted near the wall.
Generally, the accuracy of a numerical solution increases as the number of cells increase. However, the use of a larger number of cells is restricted by the sophistication of the computer hardware and the computing time. Several meshes, with increasing refinement, were tested to ensure that the solution was independent of the mesh. The results showed that the variation of the pressure coefficient, p, for different grid schemes, is very small with a minimum relative error. Verification of mesh independence for a circular

tube was obtained. A grid scheme was chosen for use by optimizing the minimization of computation time and maximizing the accuracy of solution; verifying mesh independence for use in the analysis of the enhanced tubes and verifying the method of the CFD simulation presented in this study. Figure 2 shows the enhancement character centerline, used for the centerline analysis.

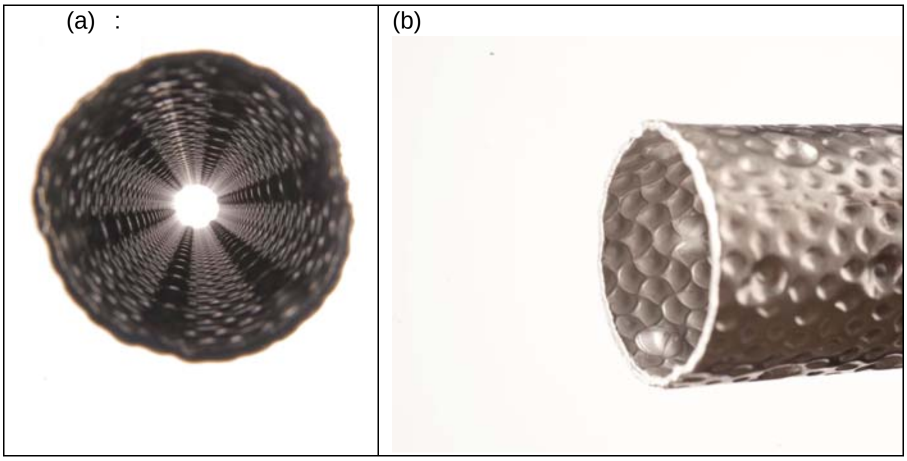

Figure 3 Details of the Vipertex 1EHT (Type 304 L stainless steel) Enhanced Tube (a) Cross sectional inner view (b) Outer surface

Figure 3 provides inner and outer surface views of the 0.75 inch (19.05 mm) outer diameter Vipertex 1EHT enhanced stainless steel tube that was evaluated in this study. Heat transfer and hydraulic characteristics of the enhanced Vipertex 1EHT heat transfer tubes were evaluated and then verified with an experimental study at the Heat Transfer Research, Inc. (HTRI) Research and Technology Center. The heat transfer experimental setup was a horizontal double-pipe heat exchanger with propylene glycol used for the inside test fluid (for Re between 250 and 18,000 for heating; and between 50 and 20,000 for cooling) and covered a wide range of annulus Reynolds numbers. Saturated steam was used as the heating medium and water was used as the cooling medium in the test apparatus. The temperature of the cooling water could be varied between ambient and 250 °F (121.1 °C). For all tests, the heated/cooled length of the tested tube was 15 ft. (4.572 m). Data measurements were performed using multi-point calibrated instruments that when possible have been calibrated to NIST-traceable standards, while other instruments (flow meters, weight scale and pressure transmitters) were factory calibrated, with calibration certificates; multipoint calibration checks are used for verification.

3. Results

The present analysis considers a 0.75 inch (1.905 cm) OD smooth tube and variations of an enhanced heat transfer tube. Heat transfer tubes had a circular-shaped cross section and a 0.037 inch (0.094 cm) wall. Various enhancements were considered, with the final primary enhancements presented being a dimple shape with a diameter of 0.2 inch (0.508 cm) and a smaller dimple with a diameter of 0.138 inch (0.351 cm). Other shapes were considered, but due to manufacturing considerations, the circular shapes were pursued. An enhancement character of a dimple on the inside produces the inverse on the outside surface.

Heat transfer and flow enhancement is desired for various conditions. Several new enhancements were considered for the new surface, and modeled in a CFD analysis. The velocity distribution and other heat transfer/flow parameters were evaluated in order to determine the character enhancement that would provide the best performance. Figure 4 provides a sample comparison between an enhanced tube and a smooth tube. It can be seen from these figures that the 0.2 inch (0.508 cm) diameter dimple enhancement provides the best velocity distribution of the enhancements considered. As can be seen there is an early onset of turbulent flow with violent mixing occurring within the micro-flows near the wall; this leading to enhanced heat transfer performance when compared to a smooth tube.

Figure 5 shows the velocity distribution of the Vipertex 1EHT enhanced tube (with an optimized enhancement character) that was designed to maximize heat transfer, minimize pumping power and

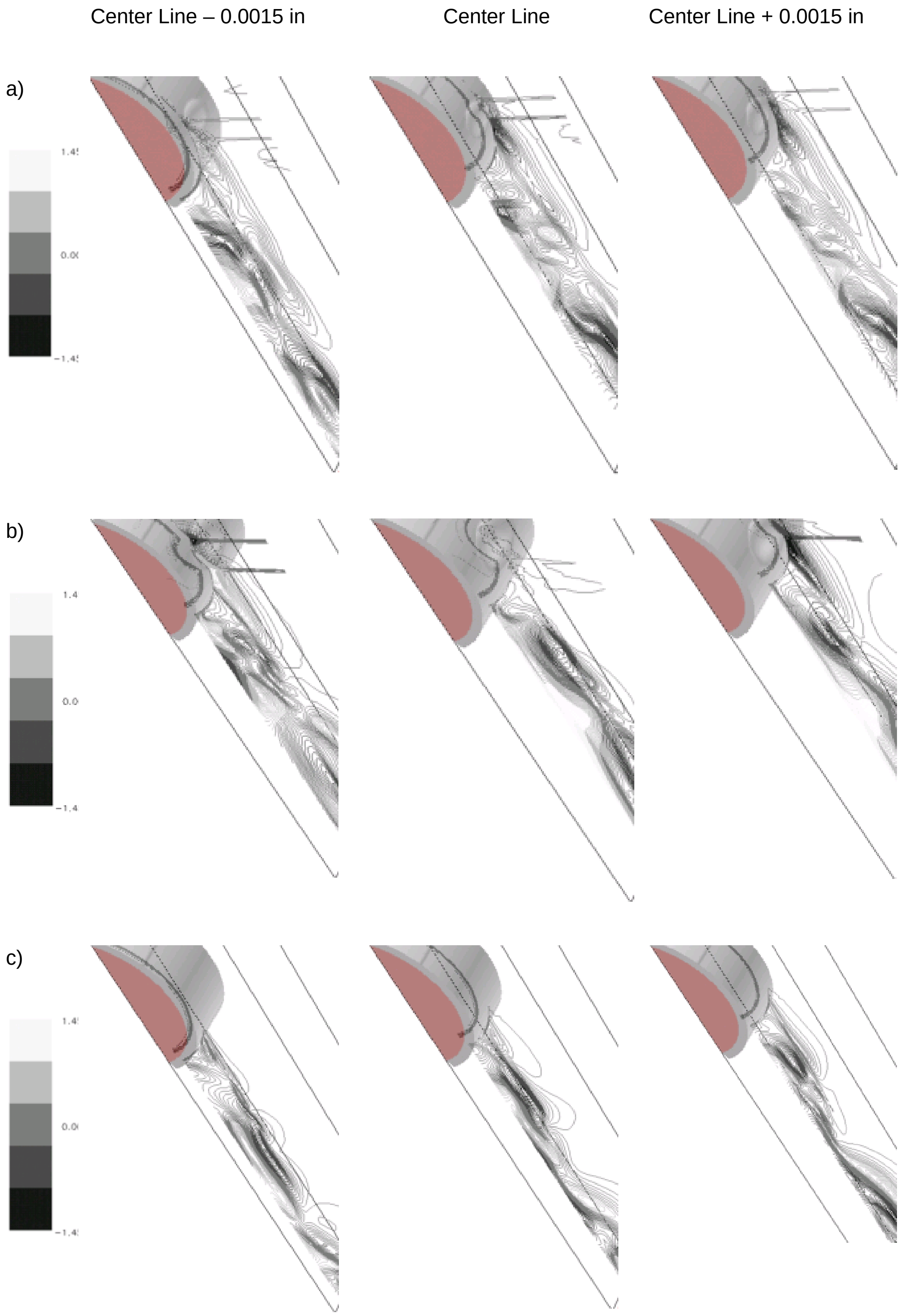

Figure 4: Comparison of the velocity distribution for (a) 0.138 in (0.351 cm) dimple enhancement, (b) 0.2 in (0.508 cm) dimple enhancement, (c) smooth tube, at various locations for the same time period.

minimize the rate of fouling. Vortex formation and distribution is studied in this manner. Vortex movement and their location near the tube surface produces better heat transfer in this 1EHT tube.

Single phase, experimental heat transfer evaluations were then carried out in a horizontal tube, for inner fluid heating and cooling, over a range of annulus Reynolds Numbers to ~250,000. In all tests, the enhanced tubes outperformed smooth tubes under similar conditions. Performance was evaluated using the enhancement ratio which compares overall performance of the enhanced tube to that of a smooth tube. Figure 6 shows a comparison of the outside heat transfer for Vipertex 1EHT tubes compared to smooth tubes. When compared to a smooth tube, there was an increase in excess of 200 % in the overall heat transfer coefficient for Reynolds number flows near 250000. Additional designs provide higher heat transfer values at the expense of increased pumping power and/or an increased expected fouling rate. Vipertex 1EHT enhanced heat transfer tubes provide an unusual combination of surface characteristics that produce heat transfer increases of almost 250 % for a small friction factor penalty. Replacing smooth tubes with 1EHT tubes provides the opportunity to cut operating costs and the ability to obtain more heat transfer out of the same equipment footprint.

4. Summary and Conclusions

Through the use of computational fluid dynamic methods, optimized three dimensional, enhanced heat transfer surfaces were developed. Vipertex EHT surfaces can be used for a variety of enhanced process applications. This study optimized the outside heat transfer coefficient, pumping requirements and heat transfer under fouling conditions, with the development of a new surface enhancement. Enhanced surfaces, with a peak performance in the range of Reynolds Numbers from 10,000 to 215,000 are presented. Heat transfer enhancements of more than 200 %, with friction losses less than 100 % are discussed. Future plans include the study and development of additional heat transfer tubes that optimize performance using other design conditions; this will be followed with a detailed experimental study of those tubes.

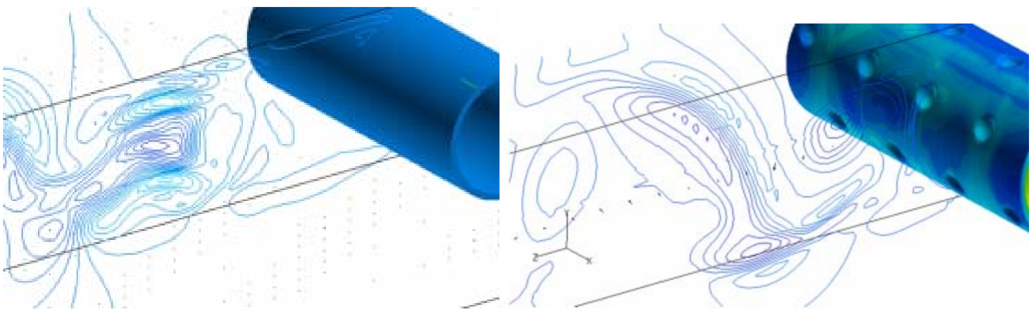

Figure 5: Comparison of the velocity distribution near the outside of a tube for a) Plain unenhanced tube and b) Vipertex 1EHT enhanced tube

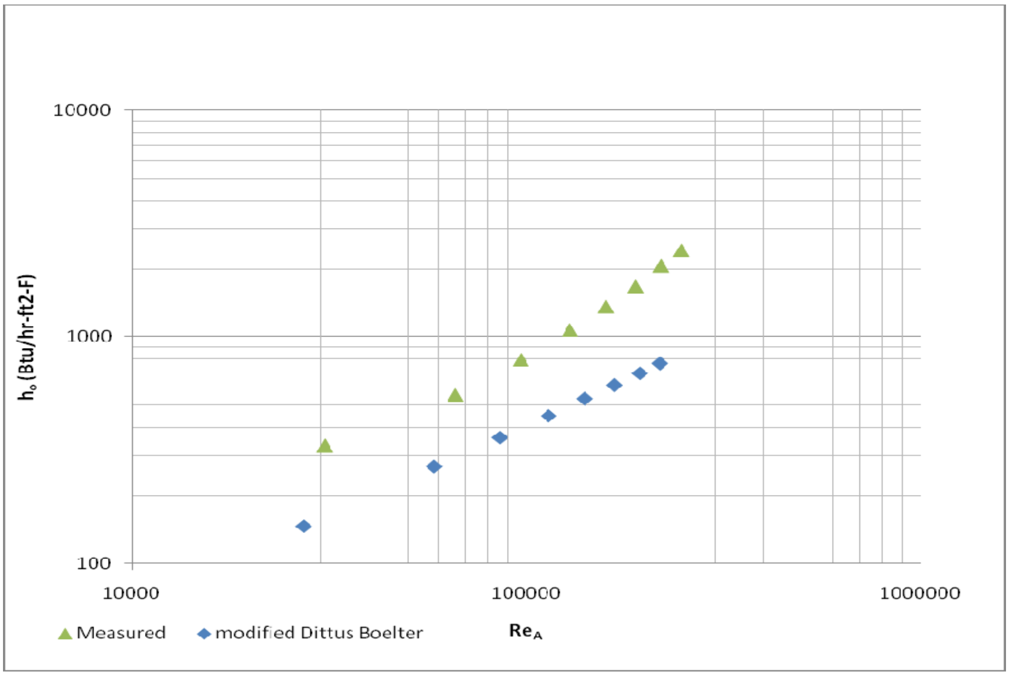

Figure 6: Comparison of the measured outside annulus heat transfer coefficient as a function of the annulus Reynolds Number for the Vipertex 1EHT enhanced tube and a smooth tube.

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