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Comparison of Heat Exchanger Designs Using Vipertex 1EHT Enhanced Heat Transfer Tubes

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A numeric study was performed that compares the performance of heat exchangers using the Vipertex 1EHT enhanced heat transfer tubes to the performance of heat exchangers that use smooth surface tubes. Heat transfer enhancement is an important factor in obtaining energy efficiency improvements in all heat transfer applications. Surface enhancement of the 1EHT tube is accomplished through the use of the primary dimple enhancement and the secondary background pattern made up of petal arrays. Utilization of enhanced heat transfer tubes is an effective method that is utilized in the development of high performance thermal systems. Vipertex™ enhanced surfaces, have been designed and produced through material surface modifications that produce flow optimized heat transfer tubes that increase heat transfer. Current energy demands and the desire to increase efficiencies of systems have prompted the development of enhanced heat transfer surfaces. Enhanced heat transfer tubes are widely used in many areas (refrigeration, air-conditioning, petro-chemical, chemical, etc.) in order to reduce cost and create a smaller application footprint. A new type of enhanced heat transfer tube has been created; therefore it is important to investigate relevant heat exchanger designs using the Vipertex 1EHT enhanced surface tube in industrial applications and compare that performance to other tubes. Results include design characteristics and performance predictions using the design simulations produced using HTRI Exchanger Suite (2016). Performance for all cases considered using the 1EHT tube predicted over performance when compared to a smooth tube design. Vipertex 1EHT tubes produced higher performance and more efficient designs.

1. Introduction

Enhanced heat transfer surfaces increase performance through a combination of: increased turbulence; boundary layer disruption; secondary flow generation and increased heat transfer surface area. These factors lead to an increase in the heat transfer coefficient; smaller unit footprint; more economic operation costs and a prolonged product life. There are a few different scenarios to be considered in heat exchanger optimization. In the case of a one-for-one replacement of smooth tubes with enhanced tubes of equal length; there is an increase in heat transfer for a constant fluid flow rate. Typically this is accomplished with an increase to the pumping power of the enhanced tube heat exchanger since there is increased friction. Another scenario to consider is constant pumping power designs; in this case the tube length could be reduced. Finally for the case of constant heat transfer, the use of enhanced tubes will reduce the pumping power requirements. Gough (2012) discusses the increased demand on the performance of heat exchangers and the need to enhance their performance. Many industrial processes that involve the transfer of heat energy employ old technology; making them ideal candidates for a redesign utilizing enhanced surfaces that improve process performance.

Vipertex™ optimized several enhanced heat transfer tubes. Heat transfer enhancement using the Vipertex EHT series of tubes provides a means to significantly advance many heat exchange processes; with the greatest enhancements seen at low flows with approximately a 100 % increase in heat transfer shown for other regions. Utilization of enhanced heat transfer tubes is necessary in the development of high performance thermal systems. Their use will allow a reduction in the cooling fluid mass flow rate required to

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obtain the designed heat transfer. Vipertex enhanced surfaces allow heat exchangers to operate in the laminar or transitional flow regime, at flowrates not previously considered, saving both energy and cooling fluid. In many geographical regions, cooling water design criteria for heat transfer devices require operations in the low flow region; in or near the traditional laminar flow regime (an area where performance of the 1EHT tube is best). Vipertex EHT enhanced tubes create an earlier transition, producing more heat transfer at lower flow rates. These EHT tubes can be employed to design more efficient heat exchangers while at the same time decreasing the required mass flow rate and allowing the heat exchangers to operate at lower flows; and if needed, they also can reduce the footprint of the heat exchange device. Vipertex™ enhanced surfaces, have been designed and produced through material surface modifications, creating flow optimized heat transfer tubes. This study details the use of these tubes in various heat exchanger designs and compares those results to heat exchangers designed using smooth surface tubes and low fin tubes.

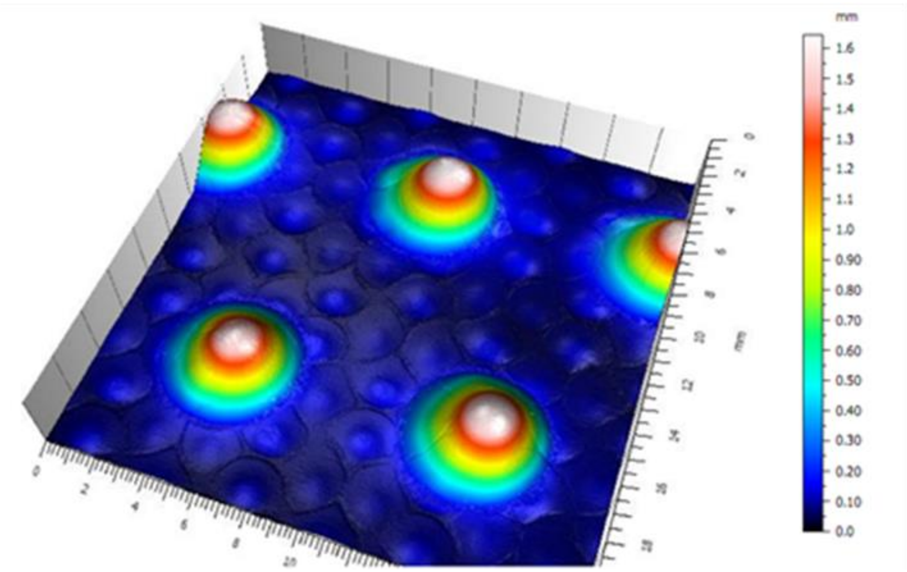

Figure 1 Surface Enhancement of the 1EHT tube produced using a Non-Contact Profilometer producing a false color view of the 1EHT tube (Tube Option 1)

The 1EHT enhanced heat transfer tube developed by Vipertex, is a novel kind of tube that was developed by modifying surface geometries (i.e. creating a modified surface that is a combination of larger dimples and smaller petals) which can enhance the heat transfer coefficient on both the inside and outside surface of the tube; its details are shown in Figure 1. Vipertex 1EHT enhanced heat transfer tubes are neither the classic ‘‘integral roughness’’ (little surface area increase) tube, nor an internally finned tube (surface area increase with no flow separation). It can be considered to be more of a hybrid surface that increases surface area and produces flow separation from the dimpled protrusions on the tube. Enhancement of the heat transfer using the 1EHT tube is produced from a combination of increased turbulence, disruption of the boundary layer, secondary flow generation, increased heat transfer surface area and a large number nucleation sites; all leading to an enhanced heat transfer performance for a wide range of conditions.

Kukulka et al. (2011) studied enhanced heat transfer tubes for single phase heat transfer conditions. Kukulka and Smith (2013) evaluated the relationship of heat transfer enhancement to the surface geometry of 1EHT enhanced tubes. They compared the heat transfer for single phase flows and found that the 1EHT surface can produce heat transfer increases of more than 500 % when compared to smooth tubes. Li et al. (2016) evaluated the 1EHT tube experimentally and numerically. They presented a non-dimensional performance evaluation criteria (PEC) to assess the thermal-hydraulic performance of the 1EHT tube. Nusselt number and friction factor correlations are presented based upon experimental results. Kukulka and Smith (2014) present results for a bundle of 1EHT tubes showing an increase in the overall heat transfer coefficient up to 200 % when compared to the heat transfer performance of a smooth tube bundle using typical fluids (n-Pentane, p-Xylene and water); for midpoint shell-side Reynolds number values in the range of 2,010 to 20,400; with effective mean temperature difference (EMTD) values between 8.6 °C and 65.7 °C. Additional work performed in Kukulka et al. (2012) provides important information for the development of enhanced systems that may be exposed to fouling. They go on to discuss how these enhanced tubes increase heat transfer and also minimize the rate of fouling. Joshi et al. (2014) used performance evaluation criteria (PEC) in order to compare heat exchanger performance of a heat exchanger using smooth mild carbon steel tubes and another using Vipertex 1EHT tubes. The evaluation showed that using Vipertex tubes can produce a heat duty increase of up to 19% under crude fouling conditions. In addition they also demonstrated that in order to achieve the same heat duties, a flow rate reduction of 18−30 % could be utilized. Kukulka et al. (2014) performed an experimental investigation in order to determine the evaporation and condensation heat transfer coefficient of R22 and R410A inside the 1EHT tube. Guo et al. (2015) 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. Kukulka et al. (2015) present evaporation and condensation results for performance on the outside of the 1EHT tube. Overall, maximum performance for the 1EHT tube is shown in the region typically classified as the transitional region. Bergles and Morton (1965) discuss that enhancements in the transitional region can yield the largest gains. This is supported in Kukulka and Smith (2013) and in Li et al. (2016), leading to the overdesign results that are part of this study.

Lu et al. (2013) discussed methods of enhancing the shellside performance of a heat exchanger. Stehlik et al. (2013) presents enhancement possibilities in high temperature applications. Jiang et al. (2014) demonstrates a simple but reliable method to model the performance of shell-and-tube heat exchangers using enhancement methods (i.e. inserts, etc.). Wang et al. (2012) presents methods to determine which heat exchangers in a network need to be enhanced and ways to calculate the level of enhancement. No case studies have been published that have evaluated the effect of using 1EHT tubes in practical heat exchanger designs.

2. Analysis

HTRI Xchanger Suite® (2016) is a design/simulation program developed by the Heat Transfer Research Institute (HTRI). HTRI is a leading laboratory in process heat transfer and heat exchanger technology; Xchanger Suite provides the components to perform the necessary calculations in the design of heat exchangers. The calculation and simulation methods are backed by more than fifty years of research and data collected on industrially relevant heat transfer equipment. All Xchanger Suite components are highly flexible, allowing the rigorous specification of the exchanger geometry. This capability makes use of HTRI's proprietary heat transfer and pressure drop correlations; allowing the most accurate performance predictions possible for all heat exchangers. Based on the results produced by the Xchanger Suite simulations, the expected performance of using the 1EHT tube in industrially relevant heat exchangers are produced. Table 1 summarizes the process conditions of the heat exchanger design case studies considered in this study. Note that baffle type 0 refers to no baffle and Baffle type 1 is a single segmental baffle. Cases considered provide a variety of relevant industrial designs. As can be seen in Table 1 there is a variety of conditions considered: single phase and two phase; various fluids (hydrocarbons, water, gas, steam, etc.); a wide range of inlet/ outlet temperature and pressure conditions; heating/cooling, etc.

Table 1: Conditions for sample heat exchanger design case studies used in the comparison of Vipertex 1EHT tubes to smooth tubes and low fin tubes

Cases ► Design Parameters▼	**1 Standard 2**	**2 Design 2**	**3 Shell-side Boil**	**4 Falling Film**	**5 Water Water**	**6 Fuel Oil**	**7 Fuel Gas Heater**
Hot fluid	Shellside	Shellside	Tubeside	Shellside	Shellside	Tubeside	Shellside
Orientation	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Horizontal	Horizontal
Shellside Fluid	Benzene	Oil	Hydrocarbon	Steam	CC Water	Bunker C Fuel Oil	Lube Oil
Tube Side Fluid	Water	Process	Hot	Glycols	Raw Water	Steam	Fuel Gas
Shellside Flow, kg/s	5.8967	2.0259	30.7435	0.9099	17	1.6492	2
Tubeside Flow, kg/s	19.6342	0.5361	37.7994	10.3863	42	0.0787	1.76
Shellside T In/Out, °C	91.67/ 37.78	310.01/ 280.01	76.6/ 101.67	184.2/ 184.19	115.01/ 53.59	54.46/ 107.23	87.31/ 60

Table 1 (Contnued)

Cases ► Design Parameters ▼	1 Standard 2	2 Design 2	3 Shell-side Boil	4 Falling Film	5 Water Water	6 Fuel Oil	7 Fuel Gas Heater
Tubeside T In/Out, °C	31.67/ 37.78	25.01/ 205.01	153.39/ 101.04	167.46/ 177.28	25.01/ 50.0	204.46/ 134.38	3/ 28.96
Shellside Vapor (In/Out, kg/kg)	0/0	0/0	0/0.2884	1/0	0/0	0/0	0/0
TubeSide Vapor (In/Out, kg/kg)	0/0	0/0	0/0	0/0.5	0/0	1/0	1/1
Shellside Inlet Pressure, kPa	446.09	500	1459.96	1103.16	344.74	997.67	1820
Tubeside Inlet Pressure, kPa	549.51	1600	1302.76	16.89	206.84	308.2	3200
Shellside ΔP Allow, kPa	0.3550/ 68.95	1.9044/ 5	4.99/ 5.17	0.1983/ 0	11.1418/ 0	52.64/ 68.95	9.5178/ 69
Tubeside ΔP Drop Allow, kPa	57.3762/ 68.95	2.4933/ 2	84.10/ 103.42	0.9208/ 0	30.5709/ 0	0.5986/ 172.37	26.7218/ 50
Fouling Resistance (min) Shell/Tube, m^2-K/W	0.0002 / 0	.0004/ .00026	.0003/ .00044	.0001/ .000176	0.0002/ 0.0004	.0011/ 8.81e-05	.0002/ 9.0e-05
Heat Exchanged, Mega Watts	0.5438	0.1897	4.3839	1.8182	4.39	0.1822	0.1120
Design Pressure Shell, kPaG	689.48	517.11	1585.79	1103.16	1000	2068.43	1930.53
Design Pressure Tube, kPaG	689.48	1654.74	1378.95	517.11	1000	2068.43	3447.38
Design Temperature Shell, deg C	121.11	343.33	129.44	260	150	204.46	93.33
Design Temperature Tube, deg C	71.11	237.78	190.56	198.89	100	232.23	32.22
No Passes per Shell, Shell/Tube	1/ 4	1 /4	4/ 8	1 /1	1 /2	1 /2	1 /2
Tube Number	286	30	1508	296	326	156	60
Tube OD, mm	19.05	19	19.05	50.8	19.05	19.05	19.05
Tube Thickness (avg), mm	2.1082	1.6	2.159	2.7686	1.6510	2.4638	1.651
Tube Length, m	4.88	1.8	4.88	4.88	7.32	2.20	2.85
Pitch, mm	25.4	25.4	25.4	63.5	23.8125	23.8126	25.4
Tube Material	Carbon	SS304	Carbon	Carbon	SS304	Carbon	SS316
Tube Pattern	45	30	45	30	30	30	30
Shell ID size, mm	584.2	230.175	1219.2	1219.20	508	355.6	260
Baffle type *	1	1	0	1	1	1	1
% Cut	28.836	25	--	25	28.137	25	22
Spacing (c/c)	584.2	143.523	1177.93	508	519.91	76.2	112
Crosspasses	8	11	0	9	15	25	25

Simulations of designs were performed initially for the base case using smooth tubes. Capability exists in Xchanger Suite to analyze designs for smooth and low fin tubes. Low fin tubes were considered in several heat exchanger cases (see Table 2 for the details of the low fin tubes considered; Cases 3, 4a, 5c, 6 and 7). Tubes utilized were typical of low fin products produced by High Performance Tube, Wieland and Wolverine. As can be seen in Table 2, the low fin tubes considered covered a variety of fin geometries (fin density, root dimeter, height, thickness, wall thickness, etc.). Also considered in the case studies was the Vipertex 1EHT tube (see Figure 1 for the surface structure).

3. Results

Table 3 details the performance results of the overdesign which is produced using the various tubes. Vipertex 1EHT, High Performance, Weiland, Wolverine and Weiland GEWA) tubes have been considered and the predicted overdesign calculated. Overdesign details the overcapacity (negative values indicate under design) that is produced for the design conditions given in Table 1. In some of the cases changes to the number of tubes was considered in order to determine the effect of reducing tube count, while maintaining design requirements. This will reduce the overcapacity of the enhanced tubes and create an under design condition for the base case. Through the use of 1EHT tubes, a reduction of 26 % of the required number of tubes necessary to satisfy the design requirements is shown in Cases 1a and 1b. In addition, Case 1c also considered a reduction in the physical size of the heat exchanger. Cases 2a-2c demonstrates that you can reduce the length of the tube and the number of tubes and still satisfy the design requirements. Cases 4a and 4b detail expected performance when the number of tubes is reduced by 32 % and replaced with 1EHT tubes. Other simulations (Cases 3, 4a, 5c, 6 and 7) are included in order to compare 1EHT performance to smooth tube and low fin tube performance.

Table 2: Geometric data of the low fin tubes considered in heat exchanger design case studies

Tube Details	Option 2 High Performance Low Fin	Option 3 Wieland Low Fin	Option 4 Wolverine Low Fin	Option 5 Wieland GEWA
Fins per unit length, fin/meter	1023.6	452.8	748	748
Fin Root Diameter, mm	13.386	13.691	6.401	15.799
Fin Height, mm	1.245	1.001	1.422	1.501
Fin Thickness, mm	0.33	1.079	0.279	0.3
Outside area/Length, m^2/m	0.14996	0.07462	0.06858	0.1584
Wall thickness under fins, mm	0.711	1.245	0.94	1.092

Table 3: Detailed operating performance produced using HTRI Xchanger Suite (2016) to evaluate the designs of the various case studies. Various (Base (Smooth)

HTRI Case Study	Base Smooth Tubes	Option 1 Vipertex 1EHT	Option 2 High Performance Low Fin	Option 3 Weiland Low Fin	Option 4 Wolverine Low Fin	Option 5 Weiland GEWA
Case 1a Standard Case 2 286 tubes 23 in shell	-7.36	37.1	27.5	-21.6	-31	43.5
Case1b Standard Case 2 210 tubes 23 in shell	-29.9	1.6				
Case 1c Standard Case 2 210 tubes 18 in shell	-15.4	21.9				
Case 2a Design 2 44 tubes 2.2 m length	13.1	64				
Case 2b Design 2 3 30 tubes 2.0 m length	-11.9	26.1				
Case 2c Design 2 30 tubes 1.8 m length	-29.1	0.9				
Case 3 Shellside Boiling	45.76	50.3	99.7	57.0	7.7	104
Case 4a Falling Film 296 tubes	-1.67	48.2	-58.8			
Case 4b Falling Film 200 tubes	-29.3	1.6				
Case 5a Water Water 326 tubes	6.68	18.8				
Case 5b Water Water 290 tubes	-3.73	6.6				
Case 5c Water Water 272 tubes	-9	0.4	-6.9	-21.9	-58.7	-2.7
Case 6 Fuel Oil	-22.2	1.7	24.8	-35.6	-54.3	34
Case 7 Fuel Gas Heater	19.53	49.9	49.9	-23.62	--	45.4

4. Conclusions

Enhanced heat transfer tubes are widely used in many areas in order to reduce cost and create a smaller application footprint. A numeric study was performed that predicts performance of industrially relevant heat exchangers using the Vipertex 1EHT enhanced heat transfer tubes and compares them to the performance of heat exchangers that use smooth surface tubes. The 1EHT tubes can be employed to design more efficient heat exchangers while at the same time decreasing the required mass flow rate and allowing the heat exchangers to operate at lower flows; and if needed, they also can reduce the footprint of the heat exchange device. In addition several cases also compared performance to other enhanced tubes. Some of the low fin options performed better for some cases; while for other cases the 1EHT tube performed better. Vipertex 1EHT tubes produced the most consistent performing option for all the cases considered and demonstrate that it is a good overall tube choice for a wide range of conditions. Through the use of 1EHT tubes, optimized design can reduce the number of tubes while maintaining design requirements. In some designs, the physical size of the heat exchanger can be reduced while maintaining design requirements. Additional case studies for a wider range of conditions will be the subject of future studies.

References

Bergles A.E., Morton H.L., 1965, Survey and Evaluation of Techniques to Augment Convective Heat Transfer, MIT Department of Mechanical Engineering, Cambridge, Mass., USA.

Gough M.J., 2012, Process heat transfer enhancement to upgrade performance, throughput and reduced energy use, Chemical Engineering Transactions, 29, 1-6.

Guo S., Wu Z., Li W., Kukulka D., Sundén B., Zhou X., Simon T., 2015, Condensation and evaporation heat transfer characteristics in horizontal smooth, herringbone and enhanced surface EHT tubes, International Journal of Heat and Mass Transfer, 85, , 281–291.

HTRI Xchanger Suite. Version 7.2.1, 2016, Heat Transfer Reseach Institute, Inc, Navasota, Texas, USA.

Jiang N., Shelley J.D., Smith R., 2014, New models for conventional and heat exchangers enhanced with tube inserts for heat exchanger network retrofit, Applied Thermal Engineering, 70, 944-956.

Joshi H.M., Kukulka D.J., Kummari S., 2014, Heat Transfer Performance Evaluation Criteria Applied to a Textured Tube Surface for Crude Oil, Journal of Enhanced Heat Transfer, DOI: 10.1615/JEnhHeatTransf.2015012277, 21(4-5), 397-405.

Kukulka D.J., Smith R., Fuller K., 2011, Development and evaluation of enhanced heat transfer tubes, Applied Thermal Engineering, 31(13), 2141–2145.

Kukulka D.J., Smith R., Zaepfel J., 2012, Development and evaluation of vipertex enhanced heat transfer tubes for use in fouling conditions, Theoretical Foundations of Chemical Engineering, 25(6), 627-633.

Kukulka D.J., Smith R., 2013, Thermal-hydraulic performance of Vipertex 1EHT enhanced heat transfer tubes. Applied Thermal Engineering, 61(1), 60-66.

Kukulka D.J., Smith R., 2014, Heat transfer evaluation of an enhanced heat transfer tube bundle. Energy, 75, 97-103.

Kukulka D.J., Smith R., Li W., 2014, Condensation and Evaporation Characteristics of Vipertex 1EHT Enhanced Heat Transfer Tubes, Chemical Engineering Transactions, 39, 727-732.

Kukulka D.J., Smith R., Li W., 2015, Experimental Investigation to Evaluate the Evaporation and Condensation Heat Transfer Coefficients on the Outside of Vipertex Enhanced Performance 1EHT Tubes, Chemical Engineering Transactions, 45, 799-804, DOI: 10.3303/CET1545134.

Li M., Khan T.S., Al-Hajri E., Ayub Z.H., 2016, Single phase heat transfer and pressure drop analysis of a dimpled enhanced tube, Applied Thermal Engineering, 101, 38–46.

Lu X., Du X., Zhang S., Zeng M., Wang Q., 2013, Experimental and Numerical Investigation on Shell-side Performance of Multilayer Spiral-Wound Heat Exchangers, Chemical Engineering Transactions, 35, 445-450.

Stehlík P., Jegla Z., Kilkovský B., 2013, Possibilities of Intensifying Heat Transfer in Heat Exchangers for High Temperature Applications, Chemical Engineering Transactions, 35, 439-444.

Wang Y., Smith R., Kim J., 2012, Heat exchanger network retrofit optimization involving heat transfer enhancement, Applied Thermal Engineering, 43, 7-13.