USING CONTINUOUS HELICAL FLOW ELECTRIC HEAT EXCHANGERS TO REDUCE FOULING

***Dennis P. Long[1], Jacob Wilson[1]**
[1] 12001 Lackland Road, St. Louis, Missouri, USA

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ABSTRACT

A variety of devices and technologies are used inside non-electric shell and tube heat exchangers to provide the highest heat transfer rate, lowest pressure drop and lowest fouling rate, while considering the capital expenditure and operating cost. The same devices and technologies have generally also been available in electric heat exchangers, also known as electric process heaters.

Continuous helical flow for heat exchangers has been developed as an alternative to segmental baffles to prevent the observed condition of reverse flow or eddy currents. Helical flow has long been available in the market in the form of triangular or quadrant plates installed at an angle to produce a helical type flow. There are breaks between the installed triangular or quadrant plates. Continuous helical does not have any breaks and takes the geometric form of a helicoid. The absence of breaks prevents the sudden changes in fluid flow cross sectional area to assure the fluid dynamics maintain the intended values.

INTRODUCTION

This study of helical flow compared to segmental baffles was undertaken to explore the expected fouling rates between the two technologies. Industry and commerce will benefit from any heat exchanger technologies that increase the time between maintenance intervals necessary to clean fouled heat exchangers. The cost of fouling varies with the application. Losses due to fouling in the distillation unit for crude oil reached US $ 4.2-10 billion per year in the United States [1]. This study is about a fouling mitigation technique based on a more efficient design of the heat exchanger. This study utilizes electric heat exchanger technology with constant heat flux, but the results could be applied to non-electric heat exchanger technologies such as shell and tube heat exchangers.

FOULING RATE

Various fouling rate equations have been introduced over years of study to approximate and predict fouling rates. One equation resulted from studies performed by W. A. Ebert and C. B. Panchal [2].

$$\frac{dR_f}{dt} = \text{deposition} - \text{suppression}$$

$$= \alpha Re^{\beta} Pr^{\delta} \exp[-E/RT_{film}] - \gamma \tau_w \quad (1)$$

Here α, β, γ and δ are parameters determined by regression.

Key factors in the equation that can help to mitigate the fouling rate are the tube film temperature and the tube wall shear stress. The tube wall shear stress is a function of the dynamic viscosity and the flow velocity parallel to the tube wall. The viscosity varies with temperature, and the flow velocity parallel to the tube wall is affected by the fluid dynamics through the heat exchanger. Heat exchanger geometries that help to maintain uniform fluid velocities and uniform temperatures should help to reduce fouling resulting from unintended eddy currents in the flow pattern.

An equation for tube wall shear stress is shown:

$$\tau_w = \mu \, (dU/dY)_{Y=0} \quad (2)$$

Helical Flow Compared to Segmental Baffles

True continuous helical flow in a heat exchanger can be achieved if the principal device controlling fluid dynamics is in the form of a helicoid. The helicoid geometry is shown in Figure 1.

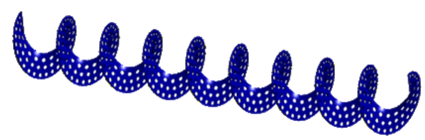

Figure 1 Depiction of a helicoid as used within a continuous helical flow heat exchanger

Various heat exchanger mixing technologies are available in the heat exchanger industry that are referred to as helical flow. Those devices develop helical like flow using non-continuous triangular and quadrant plates installed at varying angles designed to induce helical like flow.

Segmental baffles have long been used in the industry and are designed to produce crossflows through a series of 180 degree turns within the heat exchanger. A geometric illustration comparison of helical and segmental technologies is shown in Figure 2. Segmental baffles are shown on the top while a continuous helical baffle is shown at the bottom of the illustration.

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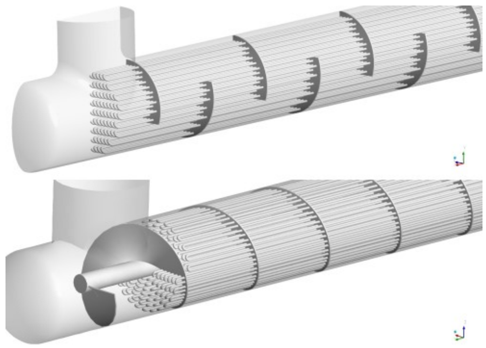

Figure 2 Illustrations of a segmental style heat exchanger and a continuous helical flow style heat exchanger

A Comparison of Technologies

A numerical study was undertaken to compare the predicted tube wall temperature and fluid velocity and various points within comparable continuous helical and segmental baffle heat exchangers. The hypothesis is that a lower variation in the tube wall temperature and the fluid velocity will provide more predictable fouling rates. Further, technology that results in lower tube wall temperature and prevents eddy currents should result in lower fouling rates.

The study can be understood better by first understanding the variation in convective coefficients. In the study and segmental baffle and continuous helical baffle were compared using identical fluids and identical inlet flow rates within identical vessel diameters. The two designs are illustrated in Figure 3. The segmental baffle is shown on the top. The fluid flow is from left to right within the illustrations. The darker portions within the illustrations equate to lower convective coefficient numbers. The segmental baffle design has the highest convective coefficient numbers, but the technology also creates some eddy current areas, aka dead zones, that have very low convective coefficients. When the coefficients are averaged for the technology, the continuous helical technology, tradename HELIMAX®, has an overall higher average. In table 1 the maximum achieved convective coefficient as well as the average is provided.

Many thermal engineering calculation tools tend to use the best case convective coefficient when designing segmental baffle heat exchangers, and do not account for the worst-case tube wall temperature that will result from low flow areas.

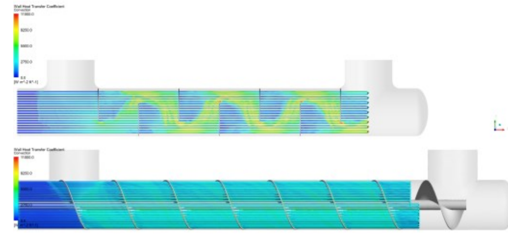

Figure 3 Illustrations of flow rate variations within a segmental style heat exchanger and continuous helical flow style heat exchanger

Table 1. A comparison of average and maximum convective coefficients by heat exchanger technology type

Technology Type	h_{sheath}, avg (W/m^2-K)	h_{sheath}, max (W/m^2-K)
Segmental	2518	19440
Continuous Helical	2657	7162

A Comparison of Velocity

A further study of the same two heat exchangers looks at the velocity profiles within the heat exchangers. Since shear wall stress is a function of mean velocity, it is proposed that technologies that provide consistent velocities within the calculated intent are likely to have lower fouling rates, as compared to technologies that result in very low velocity regions, such as segmental baffles. To analyze this the two technologies shown in Figure 3 were effectively sliced perpendicular to the axis at three different points. The segmental slices are shown in Figure 4, while the continuous helical slices are shown in Figure 5.

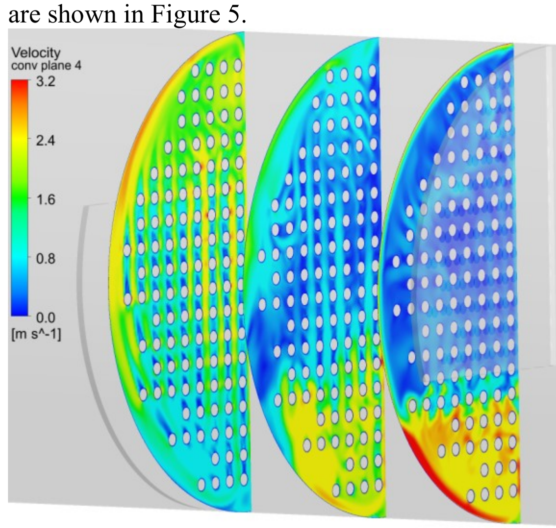

Figure 4 Segmental baffle plane sections to analyze velocity distribution

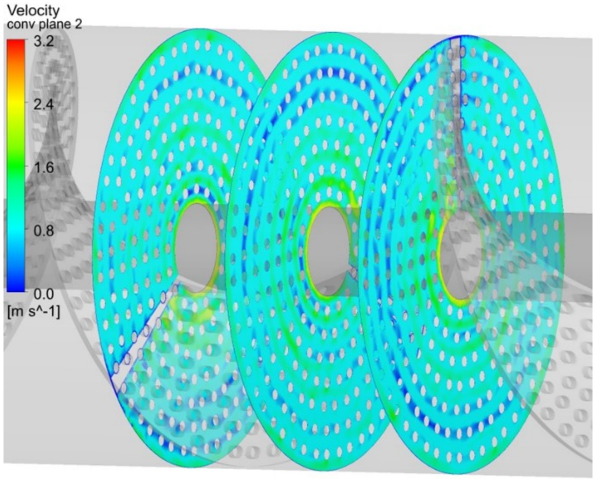

Figure 5 Continuous helical baffle (flight) plane sections to analyze velocity distribution

The sectioned analysis notes a very wide velocity distribution for the segmental baffle technology, while a much tighter velocity is noted for the continuous helical technology. The results are shown in Table 2.

Table 2. A comparison of minimum and maximum developed velocity by heat exchanger technology type

Technology Type	Approximate velocity, minimum, m/s	Approximate velocity, maximum, m/s
Segmental	0.1	3.2
Continuous Helical	0.4	2.6

A Comparison of Tube Wall Temperature Profiles

Finally, a study of the same two heat exchangers examines the tube wall (sheath) temperature profiles within the heat exchangers. Since the fouling rate in Equation 1 is a function of the tube film temperature (Tf), it is proposed that technologies that provide consistent and predicable film temperatures within the calculated intent are likely to have lower fouling rates. Conversely, large variations in the film temperature, especially when the worst case film temperature is not calculated are likely to result in fouling beyond what is anticipated. This could result in unplanned downtime and maintenance costs well beyond the original estimates. To analyze this the two technologies shown in Figure 3 were effectively sliced perpendicular to the axis at three different points. The locations of sectioning are identical to the sections shown in Figures 4 and 5.

For purposes of the temperature study the illustrations for temperature are shown as Figures 6 and 7. Table 3 is may be referenced to compare the temperature data in table form. The variation in temperature for both technologies is comparable to the velocity profiles and the convective coefficient.

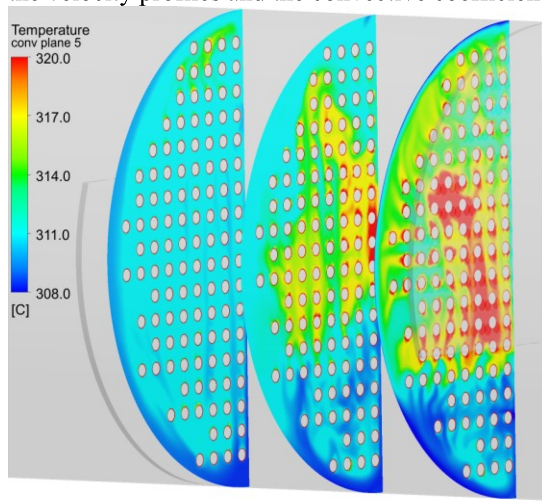

Figure 6 Segmental baffle plane sections to analyze tube wall temperature distribution

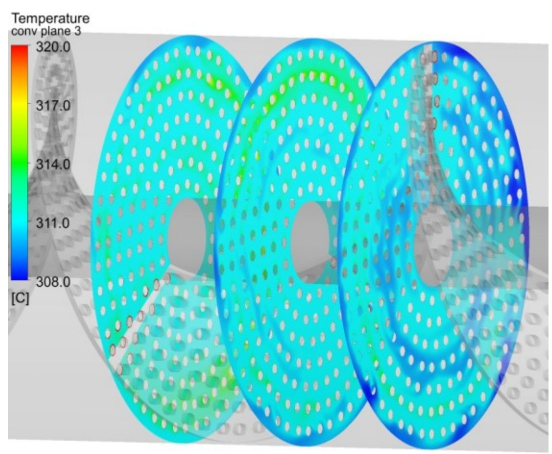

Figure 7 Continuous helical baffle (flight) plane sections to analyze tube wall temperature distribution

Table 3. A comparison of minimum and maximum tube wall temperature by heat exchanger technology type

Technology Type	Approximate, temperature minimum, C	Approximate, temperature maximum, C
Segmental	308	320
Continuous Helical	308	314

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CONCLUSION

The work points out that continuous helical flow technology will result in less variation in the predicted convective coefficient, flow velocity and tube wall temperature. The significance is that fouling rate predictions developed from derived flow velocity and tube wall temperature is only as accurate as the actual values. Further, the continuous helical flow technology results in less variation of these key fouling factor parameters. The result is end users have more confidence in the predicted fouling rate and can more confidently predict maintenance costs and planned downtime for maintenance activities.

NOMENCLATURE

All symbols used within the manuscript, their definitions, and their SI units.

E fouling model activation energy, J/mol
h_{sheath} convective coefficient, (W/m^2-K)
Pr Prandtl number, -
R gas constant, J/mol K
Re Reynolds number, -
Rf fouling resistance, m2K/W
T temperature, K
t time, s
Tf film temperature, K
τw wall shear stress, Pa
μ viscosity, Pa s
U mean velocity, m/s
W power, watts
Y distance to the wall, m

Subscript

f film
sheath sheath
w wall

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