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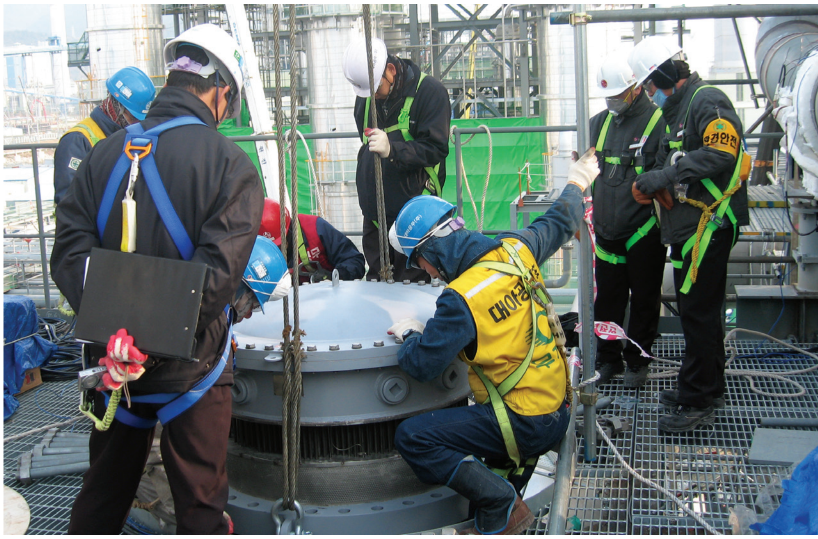
Using Continuous Helical Flow to Reduce Fouling



Summary:

It would not be an understatement to say that fouling is one of the most costly recurring problems in hydrocarbon processing, and that it hits process heaters and heat exchangers the hardest. Fouling can have a significant impact on heat transfer across the heat exchanger surface, and so likewise on both overall operational performance and total cost of maintenance.

There is good evidence that preventing build-up is both safer and more cost-effective than detection and removal. While there are many ideas for preventing fouling build-up, it appears a major decrease in the fouling rate can be achieved by using continuous helical flow baffles (CHFs). While these have been around for some time, they have never been available in an electric heat exchanger/process heater. We now have new research showing that such baffles really do help maintain temperatures in a much tighter range, eliminating the dead zones and "hotspots" that produce fouling.

Two Problems Brought on by Fouling in Hydrocarbon Processing

When it comes to operational performance, fouling build-up reduces the cross-sectional area of flow channels, increases the resistance of the fluid passing over the surface and lowers the overall heat transfer coefficient. (The thermal conductivity of these deposits is much lower than most metals, and so even a thin layer can cause significant thermal resistance.)

These effects in turn combine to increase the pressure drop across the heater, reducing flow rates and aggravating the problem further. Even worse, fouling can cause heaters to run hotter to accommodate the drop in process temperature, which magnifies the problem as hot spots continue to accumulate coking. The reduced heat transfer rate means more power is required to achieve the desired outlet process temperature. The increase in power will cause the electric heater resistance coil to increase, as well as the heater sheath temperature.

As for the costs associated with process heater fouling, there are both direct and indirect:

- **Production losses due to lowered efficiency**
- **Lost production time during planned (or unplanned) shutdowns to clean or replace elements or entire heaters**
- **Direct costs for the removal and cleaning of fouling deposits**
- **Replacement costs for corrosion of other thermal equipment**

Indeed, cleaning costs alone can range from $40,000 to $50,000 per process heater per cleaning[1]. The cost total to replace a process heater can exceed 10 times that amount, when replacement costs are combined with downtime losses. These additional operating costs increase rapidly the longer the system is down.

The impact of fouling on heat exchangers has been recognized since 1910, and there have been a number of approaches to lessening, detecting and controlling it--everything from neural network models to predictive failure analysis due to fouling, to precisely controlled temperature and flow rates and new process heater designs.

Figure 1:
Examples of fouling in process heaters

We contend that one of the best ways to solve a problem is to prevent it from happening in the first place. Preventing or reducing fouling will always be a cheaper and more effective alternative to the detection, removal and cleaning of fouling deposits. Prevention is, in effect, the only way to avoid all of the costs listed above, and so will almost always be the most economical solution as well.

[1] Hassan Al-Haj Ibrahim (2012), "Fouling in Heat Exchangers." *MATLAB – A Fundamental Tool for Scientific Computing and Engineering Applications – Volume 3*, Intech.

Process Heater Baffles and Fluid Velocity

In a series of papers and conference presentations in the 1990s, Ebert and Panchal presented what is now considered the classical model for expressing the average fouling rate for a process under given conditions. They saw the rate of fouling as a balance between deposition and mitigation (or anti-deposition), given by the equation:

$$\frac{dR_f}{dt} = \alpha \mathrm{Re}^{\beta} \mathrm{Pr}^{\delta} \exp\left[\frac{-E}{RT_{film}}\right] - \gamma\tau_{\omega}$$

Here α, β, γ and δ are parameters determined by regression, $\tau\omega$ is the shear stress at the tube wall and T_{film} is the fluid film temperature. The aim of developing and using such an equation was to find temperature and velocity combinations below which the fouling rates will be negligible. But this focus did two things in industry. First, it placed an emphasis on predicting when fouling would occur so it could be anticipated ("threshold fouling"). Second, it suggested that temperature and velocity of the fluid were the main variables involved.

It is true more often than not that fouling is the direct result of a flow-velocity dependent process. In more traditional heaters, segmental baffles force fluid into a zigzag flow. How turbulent this flow ends up being depends on baffle cut and spacing. More turbulent flow will have wakes and eddies where the difference in flow velocity (and thus heat exchange) creates "dead zones" where fouling is most likely to occur. Thus, fouling deposits are always found to be most heavy in the region of low-velocity flow near baffles in the shell side of process heaters.

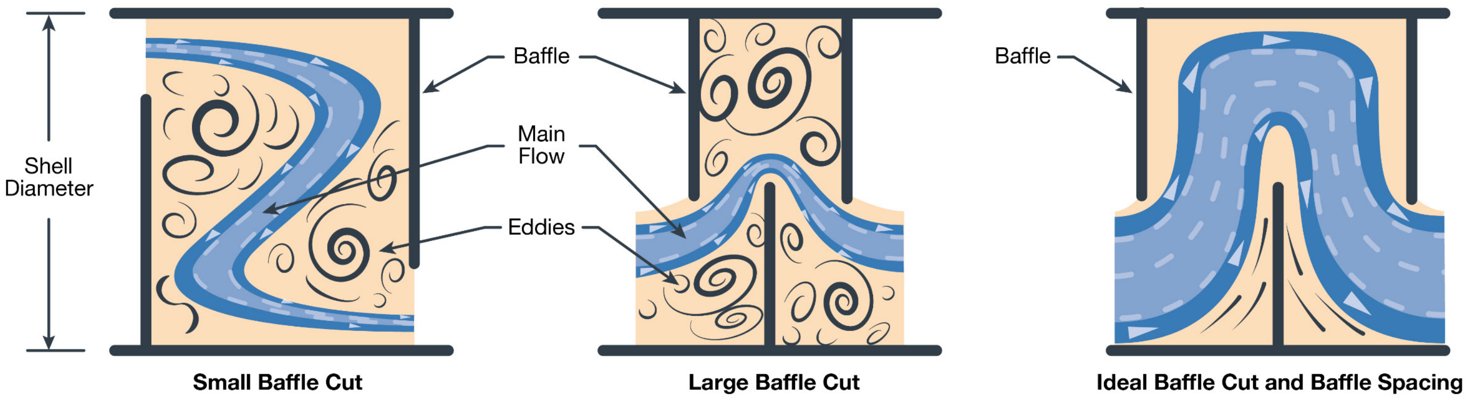


Figure 2:
Fluid flow around and between baffles in a process heater

In some cases, simply increasing fluid velocity increases the fluid shear stress, which causes removal of deposits. Indeed, this is what Ebert and Panchal originally found. But increasing fluid velocity, by itself, is not a reliable solution. For one thing, stronger deposits might not be affected by increased flow velocity. For another, flow velocity does not necessarily address the problem of creating wakes and eddies in the flow, nor addressing the resulting temperature variation. Heater baffle geometry thus comes into play.

Baffle Geometry:

Helical Baffled Heat Exchangers (HBHE) vs. Continuous Helical Flow Technology (CHF)

Helical baffled heat exchangers (HBHE), which are quadrant, sextant or trisection shaped baffles arranged in a spiral at a given angle and pitch, lend a similar spiral flow to fluid passing through the heater. According to one experimental study by Wang and colleagues, this has the effect of lowering the overall pressure drop by about 13%, keeping flow rate constant, or of raising the overall heat transfer rate by 5.6% under the same overall pressure drop.[2] In a comprehensive review of baffle geometry, Salahuddin, Bilal and Ejaz (2015) found that helical baffles did indeed help to eliminate dead zones and thus cause a decrease in fouling.[3]

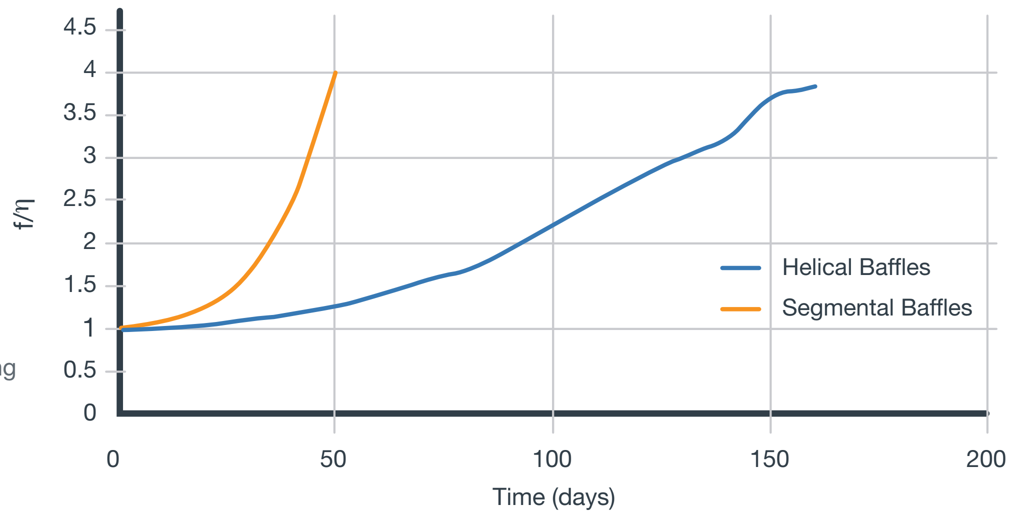


Figure 3: Approximate fouling rates for heaters using helical vs. segmental baffles

Many of these earlier helical baffles were still "segmented," or discontinuous, however. Engineers experimented with variables such as the number and size of segments, the pitch in their spiral arrangements, the tilt of the baffles compared to the axis of flow, etc.

Another approach emerged, however, looking at continuous helical flow baffles (CHF). With CHFs, baffles do not exist as discrete elements, but rather as a single continuous spiral winding around the interior of the shell side of the heater. This further forces the flow to be rotational and helical, resulting in an even better heat transfer coefficient per unit pressure drop. Work by Peng et. al. found this to be true experimentally, showing that CHFs had a nearly 10% increase in heat transfer coefficient compared with that of conventional segmental baffles for the same shell-side pressure drop.[4] Similar results were found in a study by Jian et. al. a few years later: Heat transfer coefficient per unit pressure drop was found to be much larger with traditional discontinuous helical baffles than with CHF.[5] In fact, these and more recent studies are showing that dead zones are practically eliminated with CHFs, eliminating this as a potential source of fouling.

[2] Qiuwang Wang, Qiuyang Chen, Guidong Chen, Min Zeng. (2009), "Numerical investigation on combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles" *International Journal of Heat and Mass Transfer, Volume 52,* Issues 5–6. https://doi.org/10.1016/j.ijheatmasstransfer.2008.09.009

[3] Salahuddin, Usman & Bilal, Muhammad & Ejaz, Haider. (2015), A review of the advancements made in helical baffles used in shell and tube heat exchangers. International Communications in Heat and Mass Transfer. 67. 104-108. 10.1016/j.icheatmasstransfer.2015.07.005.

[4] Peng, B., Wang, Q. W., Zhang, C., Xie, G. N., Luo, L. Q., Chen, Q. Y., and Zeng, M. (January 23, 2007), "An Experimental Study of Shell-and-Tube Heat Exchangers With Continuous Helical Baffles." ASME. J. Heat Transfer. October 2007; 129(10): 1425–1431. https://doi.org/10.1115/1.2754878

[5] Jian-Fei Zhang, Ya-Ling He, Wen-Quan Tao. (2009), "3D numerical simulation on shell-and-tube heat exchangers with middle-overlapped helical baffles and continuous baffles – Part II: Simulation results of periodic model and comparison between continuous and noncontinuous helical baffles" *International Journal of Heat and Mass Transfer, Volume 52, Issues 23–24, Pages 5381-5389*. https://doi.org/10.1016/j.ijheatmasstransfer.2009.07.007

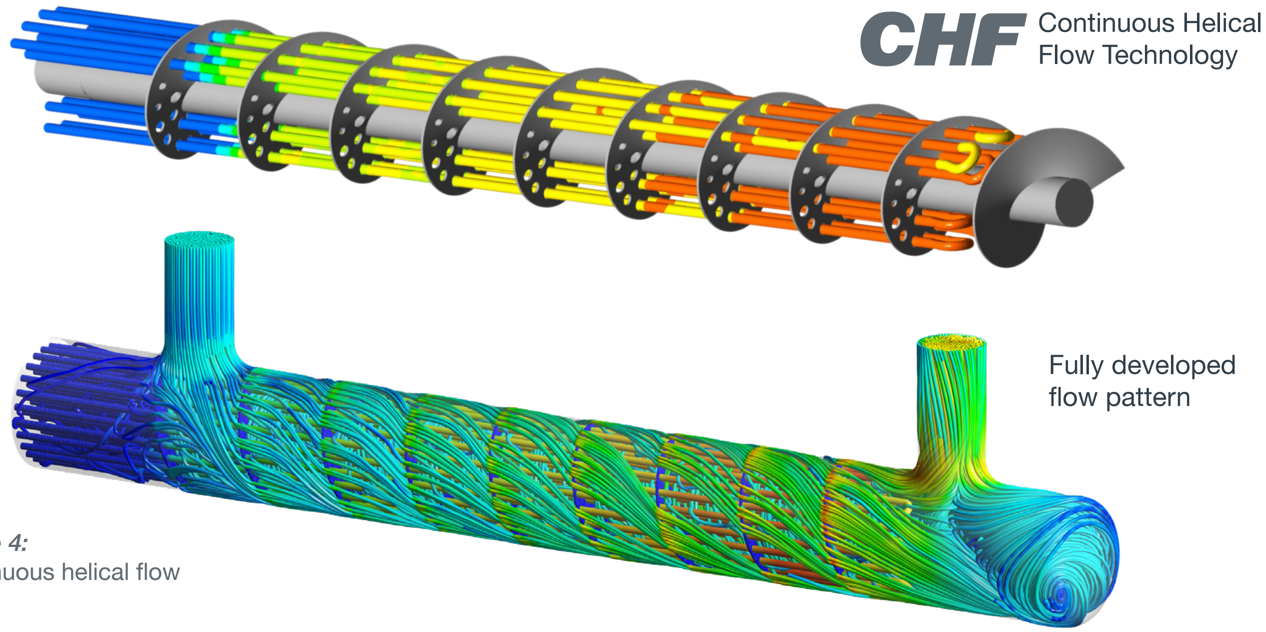


Figure 4:
Continuous helical flow

Testing Heat Transfer and Temperature Variation

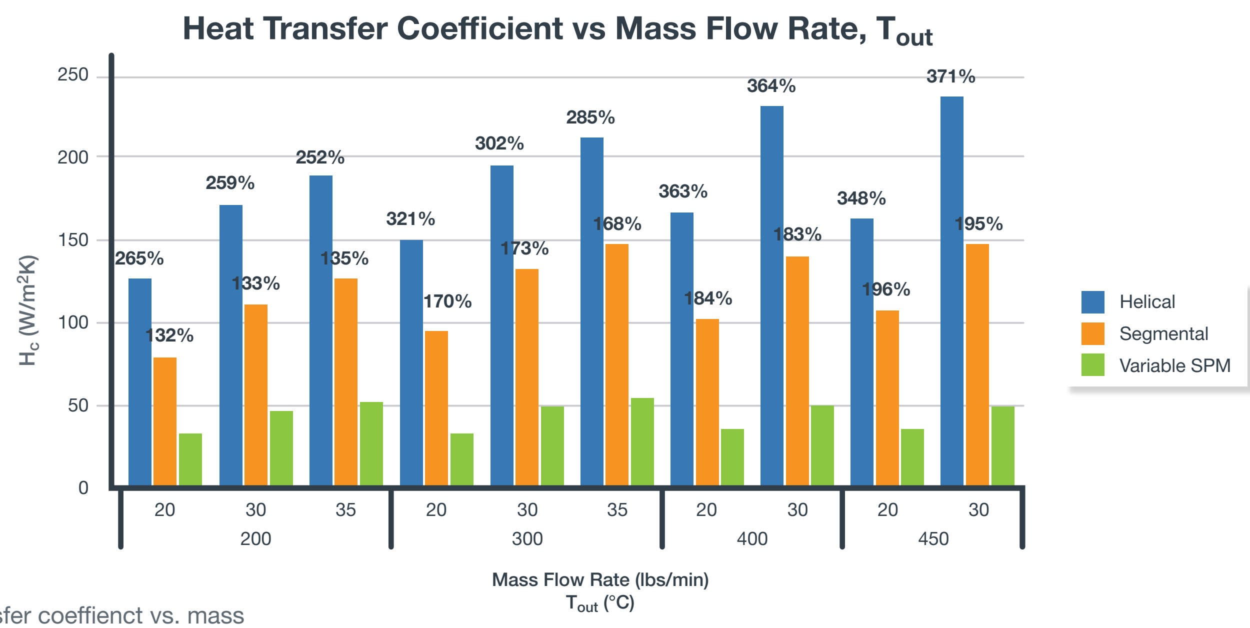
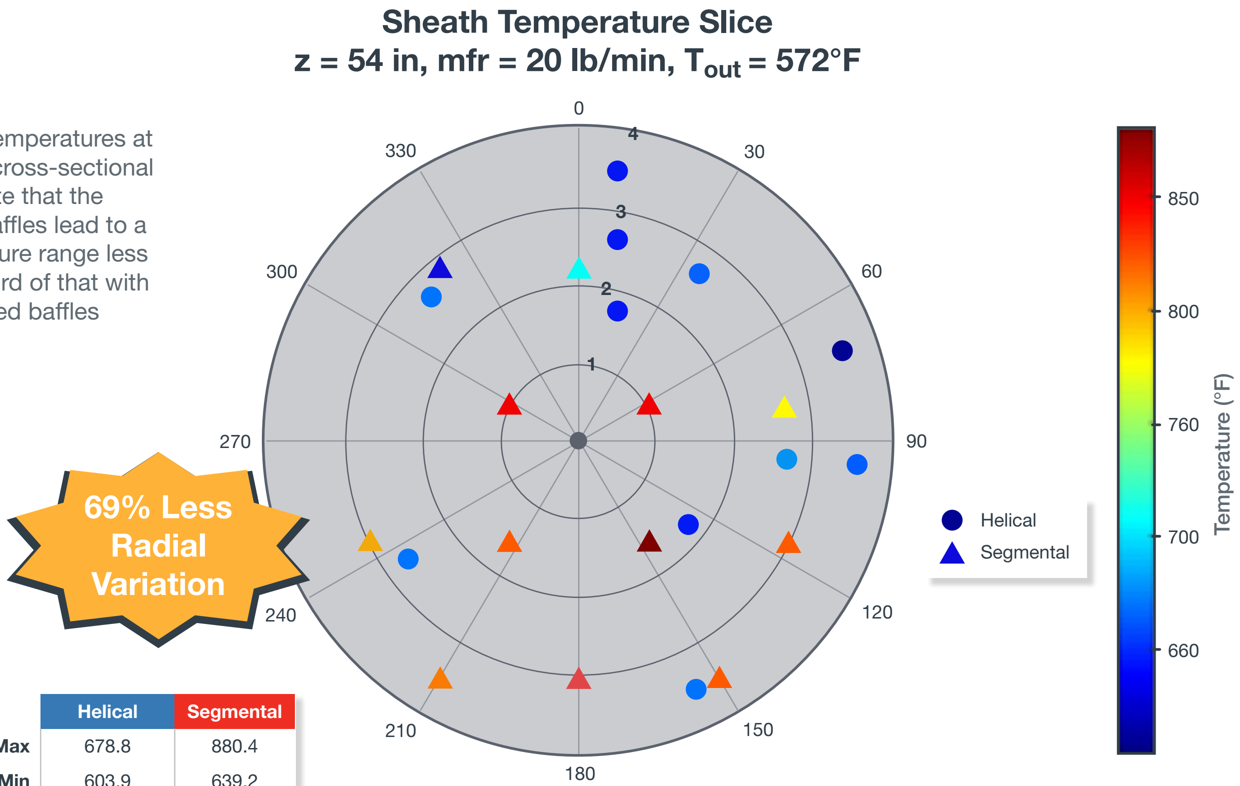


Figure 5:
Heat transfer coeffiecnt vs. mass flow rate for various heaters

We performed our own testing of a process heater with a CHF design, comparing it with a traditional segmental baffle heater and a parallel flow heater. As you can see in Figure 5, heat transfer was much better with the CHF at all flow rates-- a 1.53 times higher average heat transfer rate than the segmental baffles, and a 4.1 times higher average heat transfer rate than parallel flow.

The variation in temperatures within the helical flow stream was also reduced. The more uniform helical flow led to a very tight and predictable distribution of temperatures, with none of the dead zones found with segmental baffles:

Figure 6:
Sheath temperatures at a single cross-sectional slice. Note that the helical baffles lead to a temperature range less than a third of that with segmented baffles



	Helical	Segmental
Max	678.8	880.4
Min	603.9	639.2
Range	74.9	241.2

All that said, pressure drop was higher with the CHF than with segmental baffles, and this difference became more pronounced with rising temperature, suggesting that a CHF might not be appropriate for applications that are more sensitive to pressure drop. The pressure drop can be accurately predicted to see if CHF technology is a good fit.

Summary and Further Directions

Our own research reinforced what previous authors have found: That CHFs provide a superior improvement in heat transfer performance over existing technologies, and that dead zones are practically eliminated. We supplemented the existing research by showing that the flow stream in heaters with CHFs has a much more uniform sheath temperature with none of the tell-tale “hot spots” where fouling occurs.

What might further improvements bring? For one thing, CHFs currently are more costly to manufacture, so the price point for these kinds of heaters could be higher when compared to traditional legacy equipment. Advances in the manufacture of CHF heaters should thus be a priority for vendors within the hydrocarbon processing industry. The pressure drop associated with CHF technology is also something that should be taken into consideration. If the calculated pressure drop is higher than the amount allowed for the application under consideration, other technologies can be considered as a solution. The tradeoff for lower pressure drop through alternative technologies is a reduced heat transfer rate as compared to the CHF technology.