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# Consider spiral heat exchangers for fouling applications

## The inherent 'self-cleaning' action reduces downtime

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Heat exchanger fouling is estimated to account for 0.25% of the gross national product in highly industrialized countries.[1] In the US refining industry alone, a study in the early 1980s estimated the fouling cost to be over $2 billion annually.[2] Every plant operator around the world can testify to the large costs and hassle associated with both scheduled and unscheduled downtime originating from fouled heat transfer equipment.

When selecting heat transfer equipment, reliability is one of the main criterion. The high cost of unscheduled downtime makes the process industry, in general, and the refinery and petrochemical industry, in particular, cautious about using unfamiliar, although not necessarily new, types of equipment.[3] However, in view of the huge costs associated with fouling, it is surprising that most heat exchangers sold and installed are still the traditional shell-and-tube (S&T) type. The number of alternative heat exchangers has increased substantially in the past two decades, as has the diversity of their design and working principles. The spiral heat exchanger (SHE) is not new, but deserves serious attention as a cost-effective alternative to the S&T in fouling duties.

In this context, the term fouling is used in its broadest sense to include scaling, other types of surface deposits, sedimentation, larger particulate matter and growth of organic matter such as algae. This article describes the unique features of the SHE, applications in which the SHE has been successfully used and conclude with some practical design guidelines.

**Mechanical design and operating principles.** The SHE consists of two long metal sheets that are wound as spirals around a common center. Before welding, studs are spotwelded to the sheet to maintain the distance to the next outer turn of the sheet and thereby create two separate flow channels. The channels are normally closed along one side and open along the other side. To retain the internal liquid pressure, the last turn of the spiral body is manufactured with thicker sheets. An alternative design is to place the body inside a pressure-retaining shell.

Covers are placed on the two flat sides of the spiral body with full-faced gaskets in between to prevent bypass flow between the spiral turns (Fig. 1). An alternative design offers channels that are completely free from studs, but at the expense of allowable design pressure. SHEs can be manufactured in carbon steel, stainless steel, duplex, titanium and virtually any other metal that can be cold formed, rolled and welded.

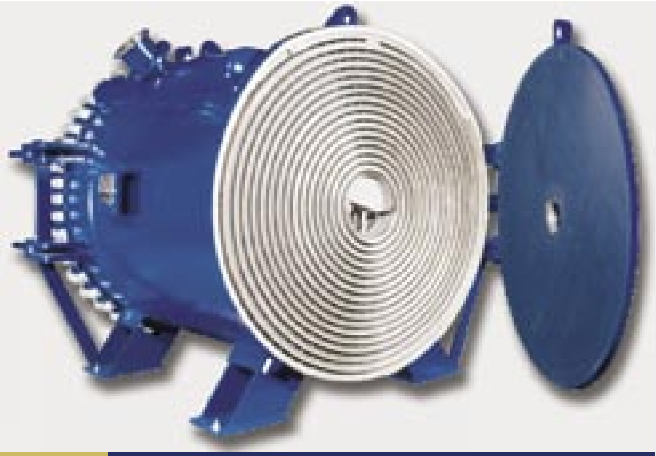

**FIG. 1** Spiral heat exchanger with a hinged cover.

In liquid-liquid duties, one liquid enters the SHE in the center and spirals to the periphery, where it exits through a connection welded to the shell. The other fluid enters through a peripheral connection and exits through a center connection. As shown in Fig. 2, the flow is practically 100% counter-current, which allows a high degree of heat recovery. The studs and the curvature of the single channel help to promote turbulence and thus heat transfer, which gives the SHE up to twice the heat transfer coefficient compared to the S&T.[4]

By using studs of different heights, the two channels can be independently adapted to match the thermal, hydromechanical and fouling requirements for the two liquids (Fig. 3). The high heat transfer rate in combination with the spiralling channel makes the SHE very compact in terms of $m^2/m^3$ and offers a small installed footprint. In addition, the service footprint is significantly smaller than for an S&T, which requires space for removing the bonnets, rodding the tubes or even extracting the tubes.

Perhaps the most important feature of the SHE when it comes to combating fouling is the unique concept of a single flow channel. If fouling starts to build up anywhere in the channel, the local cross-sectional area for the flow will be reduced at that position (Fig. 4). As a consequence, the local velocity will be higher than in the rest of the channel. The shear rate between the liquid and the solid fouling will increase in proportion to the velocity squared and will cause a

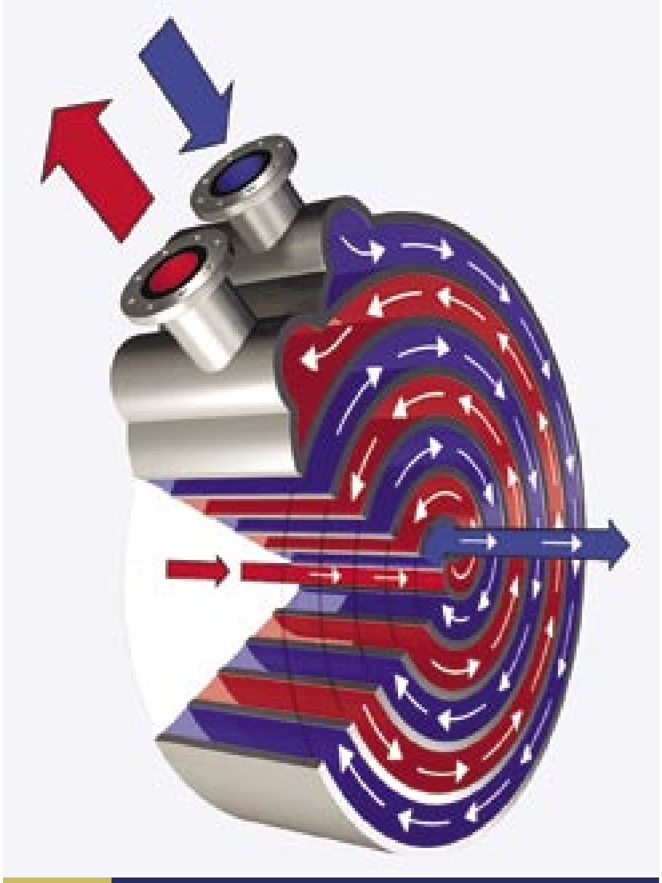

**FIG. 2** The flow is practically 100% counter-current, which allows a high degree of heat recovery.

scrubbing effect that helps to remove the fouling. This phenomenon is often referred to as the "self-cleaning effect."

In a multiple channel heat exchanger such as an S&T, partial plugging of one tube will, due to the law of least resistance, lead to higher flow in the other tubes. The plugged tube will see a smaller flow that may not be sufficient to scrub it clean. A snowballing effect will result as more and more tubes become plugged, and the effective heat transfer area decreases rapidly.

In applications involving heat exchange between two fouling liquids, a conventional S&T will encounter problems. Although the tube side can be designed to stay clean for a reasonable time, the shell side presents a major problem for fouling liquids. In contrast, the SHE offers a single channel per liquid, each having the self-cleaning effect. In this respect, the SHE can only be matched by the double-pipe heat exchanger. However, the double-pipe heat exchanger offers much less heat transfer efficiency and compactness.

**Application examples.** The SHE is suitable for many duties in the refining and petrochemical industry.[5] One particular application where the SHE has been used with great success is cooling of the bottoms product in fluid catalytic cracking (FCC) units. The bottoms can contain up to 1% catalyst in the form of fine grains. When this is combined with cracked byproducts from the FCC process, fouling is inevitable. At one refinery in Germany, a SHE replaced a double-pipe heat exchanger in the FCC bottoms cooling duty.[6] The double-pipe heat exchanger required a three-

**FIG. 3** Open channel with large studs and closed channel with small studs.

day cleaning operation after 10 days of operation at considerable cost. In contrast, the SHE operated five years without any cleaning. According to the refinery, payback for the capital costs of the SHE as a result of service cost savings was one year.

At a refinery in Central Europe, SHEs replaced S&Ts as visbreaker feed/product interchangers. The feed, which is atmospheric residue, is preheated before going to the furnace for cracking. The product exits the visbreaker at 370°C (700°F) and poses a severe fouling problem in the S&Ts when it is cooled. The main problem is formation of coke and ashphaltenes on the tube side. The tubular heat exchangers had to be opened every two months for extensive cleaning, whereas the SHEs have now operated more than three years without any unscheduled or frequent shutdown.

Another common application is extracting oil from tar sands where steam is injected to melt the bitumen. The resulting water-bitumen emulsion is separated. The water is subsequently cooled before it is reinjected to the well. The water contains sand, some bitumen and salts—a mixture that is prone to scale when cooled. SHEs have been operating as coolers of this type of water for more than 20 years of operation without ever being opened for cleaning.

Other examples of applications where the unique features of the SHE play a decisive role are sewage and industrial sludge, coke oven plants, and in PVC and PTA processes.

**Design guidelines to minimize fouling and simplify mechanical cleaning.** The two key parameters for keeping the flow channel clean are velocity and channel height. As a general rule, in fouling applications, the channel velocity should always exceed 1 m/s. In cases of severe fouling, velocities of 2 or even 2.5 m/s (6 to 8 ft/s) are recommended. However, if the liquid contains eroding particles, a balance has to be struck between high velocity for fouling reduction and low velocity for erosion reduction.

Channel height depends not only on the fouling tendency, but also on the maximum particle size and the access for mechanical cleaning. Hence, it is more difficult to generalize, but normally the height should exceed 10 mm (⅜ in.) in fouling applications. A smaller channel height makes mechanical cleaning difficult, whether by water jet or other means. Design rules for specific applications are often the manufacturers' proprietary information.

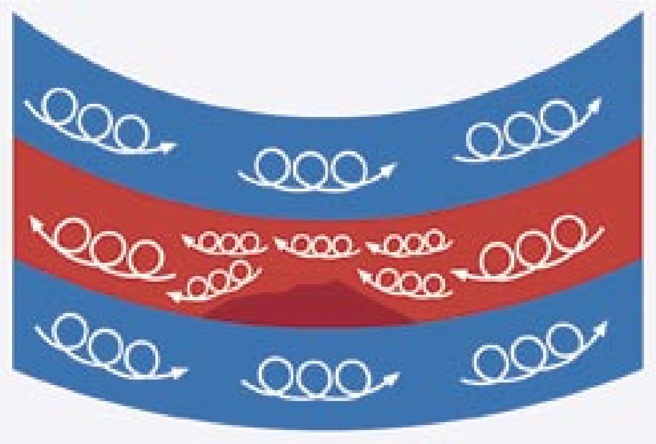

**FIG. 4** The local velocity increase results in a scrubbing effect in a partially fouled channel.

The center of the spiral should have as few pockets and dead spots as possible since these represent potential locations for fouling initiation and clogging. To ensure a smooth transition from pipe to spiral channel and vice versa, the center should be designed so that the fluid has uniform velocity in all cross-sections. These same design guidelines apply to the peripheral connections. Some manufacturers use a tangential connection. This allows the liquid to maintain its velocity and flow direction when moving from pipe to spiral and vice versa.

Flushing with water is always the preferred cleaning method for the SHE. If water cleaning is insufficient, chemical cleaning in place is the next alternative. In tougher applications, mechanical cleaning may have to be used occasionally. To make mechanical cleaning easier and more efficient, some things should be considered when designing a SHE. The cover for the fouling channel should be hinged so that it can be opened without any lifting devices. The channel width should not be too wide since this complicates access to the entire heat transfer surface. Some users prefer a turnable spiral, rotating on its supports, that allows complete drainage of one or both channels.

An automatic backflushing system is often helpful in cases where the fouling consists of fibers and other sediments. Reversing the flow direction helps to flush out loose deposits before they become too compacted. If flow through the SHE varies greatly, even down to zero, care should be taken to either flush the channel with water before a standstill or to keep the fouling liquid circulating without any heat transfer. If the liquid on the nonfouling side is hot, it should be turned off at times where the flow of the fouling liquid is low.

**Cost considerations.** How does the SHE compare with the S&T on lifetime cost? The capital cost for the spiral heat exchanger itself is normally moderately higher than that of a corresponding S&T. However, due to the SHE's higher heat transfer coefficient, it requires a smaller heat transfer surface for an identical thermal duty. This means a lower weight and, hence, lower costs for foundations and civil engineering. Overall, the total capital expenditure (CAPEX) will probably be on the same level or slightly higher for the SHE than for the S&T.

However, if designed correctly, the SHE will in most, if not all, fouling applications have a substantially lower operational expenditure (OPEX). Savings in OPEX will be manifested through more up time. This is due both to longer operating periods between scheduled shutdowns and to easier and faster maintenance during shutdowns. In addition, the risk of unscheduled stops is normally significantly reduced with the SHE. Additional OPEX savings will be realized through a higher degree of heat recovery. Considering both CAPEX and OPEX, the SHE will be the best overall choice for fouling heat exchanger duties. **HP**


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