New Applications for Spiral-Tube Heat Exchangers

A decades-old, yet less well-known type of heat exchanger offers advantages for new and emerging applications

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Spiral-tube or helically-coiled heat exchangers have been around for decades addressing sample cooling, mechanical seal cooling, vent condensers, vaporization and general heating or cooling requirements. They serve niche or unique applications and are not as well known or understood as are ubiquitous shell-and-tube or gasketed-plate heat exchangers. With turnover in engineering departments and entrance of younger engineers, a loss of familiarity with, or awareness of, spiral-tube heat exchangers is inevitable.

The last several years ushered in new heat-transfer requirements that fit spiral-tube heat exchangers perfectly. The energy transition, applications involving supercritical-fluid heat transfer [*1*] and a focus on removing or reclaiming volatile organic compound (VOC) emissions [*2*], to name a few drivers, have increased demand and expanded the applications where spiral-tube heat exchangers are used.

This article introduces — or for some, reintroduces — spiral-tube heat exchangers and provides an overview of new applications where they are being used or are specified for emerging or developing markets, such as the hydrogen economy, botanical extraction, compressed natural-gas systems, cryogenic vaporization and vent-emission reduction.

Spiral-tube heat exchanger

A spiral-tube heat exchanger consists of a number of tubes stacked and helically coiled (Figure 1). The coiled tubes at each end are welded, soldered or brazed into manifolds or piping that permit fluid to enter and exit the coil. In heat-exchanger parlance, this is referred to as the tube side of the heat exchanger. The coil is placed inside a casing or housing where a baseplate provides for a sealed enclosure, creating the shell side, or casing side, that permits fluid to enter and flow along a pathway exposed to the exterior of the coil and then exit the heat exchange area.

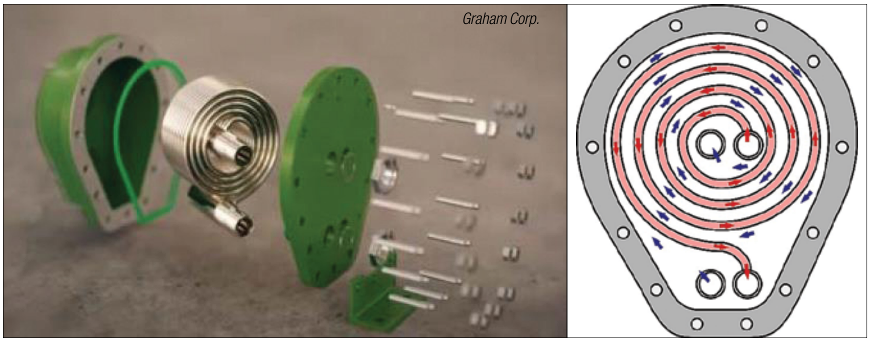
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FIGURE 1. On the left is an exploded view of a spiral-tube heat exchanger. The flow path of the heat-transfer fluid is shown on the right

A number of advantages are present with such a configuration [*3*]:

Compactness. The straight length of tubing, which can be 45 ft long, is coiled, resulting in a smaller footprint as compared to a corresponding shell-and-tube heat exchanger. This attribute is ideal for heat-exchanger integration within a packaged system. For example, a spiral-tube heat exchanger with 380 ft^2 of heat-exchange area addressing a 3,000 psig operating pressure occupies a volume of 5 ft × 4 ft × 4 ft. In contrast, a shell-and-tube heat exchanger with high pressure on the tube side occupies a volume of 15 ft × 3 ft × 2 ft. The 15-ft tube length for a shell-and-tube exchanger causes integration complexity and an increase in floor space needed for the overall packaged system by approximately 10 ft.

High pressure capability. The coil is comprised of cylindrical parts, specifically, the tubes and manifolds, which can withstand high operating pressures. Pressures of 5,000 psi (345 bars) are rather routine, and for hydrogen service, pressures of 15,000 psi (1,000 bars) are economically possible. This attribute is an ideal fit for supercritical-fluid service, where operating pressure is high, or for hydrogen fueling systems.

Maximized LMTD. Fluid-flow orientation between hot-side and cold-side fluids is fully countercurrent, thus eliminating logarithmic mean-temperature difference (LMTD) correction factors for multipass shell-and-tube heat exchangers. Such an attribute is ideal when heat transfer requires a temperature cross, more specifically, when the hot side is cooled below the cold-side fluid-outlet temperature.

Large temperature differences. The coiled geometry permits handling large-temperature variation between the hot- and cold-side fluid. It is not uncommon to have a cryogenic temperature on the tube side, such as liquid nitrogen at –280°F, and steam on the casing side at 300°F. This coiled geometry characteristic is well suited when thermal growth issues are challenging in shell-and-tube type heat exchangers

Removable bundle. In most common geometries, the casing or shell side is accessible for cleaning or removal of fouling deposits. Also the coil can be removed and easily replaced.

Materials of construction (MoC). MoC for coiled-tube heat exchangers are comparable to those common for shell-and-tube exchangers, including stainless steel, duplex,


Neuman & Esser USA

FIGURE 2. Three spiral-tube heat exchangers are shown here (arrows) within a Neuman & Esser hydrogen diaphragm-compressor package

copper, copper-nickel, titanium, Hastelloy, Inconel and Incoloy. The casings are commonly in cast iron, cast steel, fabricated steel or stainless steel. Although any material that can be cold worked (rolled) and welded may be used for the casing or shell side.

High-pressure applications

When fluid operating pressure is elevated, above 750 psig, as an example, a spiral-tube heat exchanger is an ideal candidate. New energy applications, such as hydrogen-fueling systems or remote natural-gas delivery systems, create new demand for this type of heat exchanger. Similarly, developing markets, such as supercritical CO_2 for botanical extraction or shelf-stable alternatives to traditionally frozen foods and also mature markets for industrial gases, like helium systems, also require these specialized heat exchangers.

Hydrogen fueling systems. The energy transition and search for non-fossil-based transportation fuels has brought hydrogen to the forefront as a fuel for fuel-cell electric vehicles. The Society of Automotive Engineers Standard SAE J2601 governs fuel-station requirements for light duty vehicles and buses. Dispensing pressure to the vehicle is either 10,000 psi (70 MPa) or 5,000 psi (35 MPa). These are extremely high pressures. Diaphragm compressors are used to increase hydrogen pressure to the required storage pressure. The compressors are multi-stage, where heat exchangers remove heat of compression (Figure 2). Spiral-tube heat exchangers are used for compressor inter- and after-coolers to remove heat caused by compression. At such high operating pressures and for system integration, spiral tube exchangers are chosen. A typical heat removal requirement for a hydrogen compressor inter-stage cooler is 100 lb/h of hydrogen at supercritical pressure of 2,000 psig cooled from 300°F to 100°F. For the final compression stage the heat removal requirement typically is the same 100 lb/h of supercritical hydrogen at 10,000 psig cooled from 250°F to 100°F. Actual mass flowrate will vary from installation to installation as will the inter-stage and final-stage cooling requirement based upon compressor design.

Another use of spiral-tube heat exchangers in hydrogen fueling stations is for precooling the hydrogen before it is dispensed to a vehicle. SAE J2601 refers to T40 or T30, for example, meaning the dispensing system is to deliver hydrogen to the vehicle at –40°C or –30°C, respectively. The temperature is essential for meeting fueling time requirements.

Hydrogen has a unique thermodynamic property that is unlike most other gases, except for helium. Most gases, when passing through a control valve, expand adiabatically to a lower pressure and experience a reduction in temperature. Due to a negative Joule-Thomson coefficient for hydrogen and the operating conditions of the fueling system, when hydrogen flows through a flow control valve and undergoes a pressure loss, the temperature actually rises. If the resultant rise in temperature isn't removed, it affects the vehicle filling time.

A hydrogen precooler is used to remove the heat caused by pressure drop across a flow-control valve in the supply line to the fuel dispenser admitting hydrogen into a vehicle. Here too, pressure is high and in the range of 10,000 psi for automobiles or 5,000 psi for mass-transportation vehicles. The removal requirement is typically 120°F hydrogen cooled to –40°F (–40°C) for a J2601 T40 fueling system.

Developing heat exchanger designs at pressures of 5,000 psi or greater with hydrogen in supercritical state is not ordinary fare.

Botanicals, shelf-stable foods

Supercritical CO_2, where pressure is above 1,075 psia and temperature in excess of 88°F, serves as an ideal solvent for separating essential oils by varying CO_2 pressure and temperature. To effect precise control of the extraction or separation process, a heat exchanger is used to heat supercritical CO_2 at pressures in the range of 4,000 to 5,000 psig from approximately 32°F to 140°F. Tailoring the solvating properties of supercritical CO_2 is important for separating high-purity plant oils. Spiral-tube heat exchangers handle the high-pressure service economically, provide reliable outlet temperatures and integrate into an extraction system package compactly (Figure 3). Also to bring CO_2 to the 4,000 to 5,000 psig operating pressure diaphragm or reciprocating compressors are utilized. Inter-stage and final-stage compressor coolers apply spiral-tube heat exchangers where heat of compression is removed.

An emerging market involves the


Advanced Extraction Systems

FIGURE 3. A spiral-tube heat exchanger (blue) is integrated into Advance Extraction Systems' supercritical CO_2 botanical extraction system

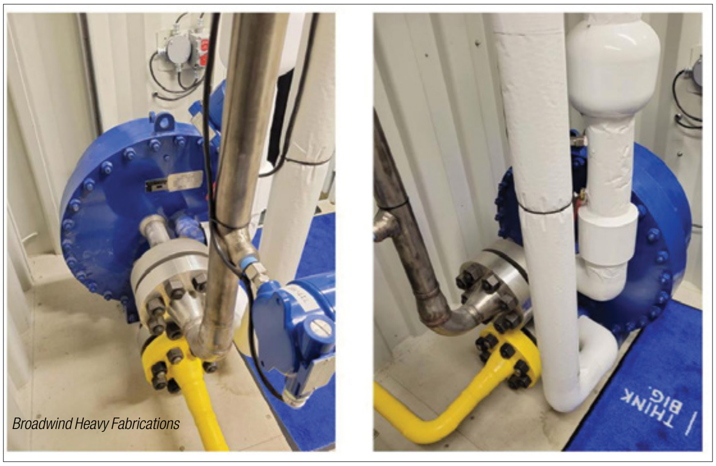
Broadwind Heavy Fabrications

FIGURE 4. Spiral-tube heat exchangers within a Broadwind Heavy Fabrications compressed natural-gas pressure-reduction system

use of supercritical CO_2 to produce quality food products that do not require freezing, refrigeration or cold storage. Supercritical CO_2 is used to sterilize foods that are shelf-stable, thereby eliminating requirements for cold-storage infrastructure, such as refrigerated tractor trailers, cold-storage warehousing or grocery store refrigerated-food displays. In this application, CO_2 is compressed to 4,000 to 5,000 psig and spiral-tube heat exchangers are applied to remove heat of compression.

Compressed natural gas systems

In remote locations, where infrastructure and pipeline-delivery systems for natural gas do not exist, compressed natural gas is trailered to the location. Natural gas with pressures in the range of 4,000 psig is delivered in truck trailers. Then pressure-reducing systems lower the natural-gas operating pressure for use by a remote user. Spiral-tube heat exchangers are applied to heat the high-pressure natural gas prior to pressure reduction to maintain acceptable operating temperatures following adiabatic expansion across the pressure-reducing system. As described previously, this typically results in cooling of the natural gas. For example, Permian Basin hydraulic-fracturing sites can improve drilling rig economics by using dual-fuel engines that can operate with diesel or a diesel and natural-gas mixture. During times of high diesel fuel prices, diesel/natural-gas mixture dual-fuel, where natural gas displaces 60–70% of the diesel, greatly improves drilling rig operating cost. Fracking sites often do not have natural-gas distribution systems, thus “virtual pipelines” are employed, where compressed natural gas at high pressure is trucked to a remote location where decompression systems lower the pressure for use in an industrial application (Figure 4), such as a dual-fuel engine. Additionally, this type of “virtual pipeline” may be used as a fuel source for peak shaving on limited pipeline capacity and pipeline outages or for another industrial application where natural-gas pipeline infrastructure is not present.

Likewise, spiral-tube heat exchangers are used on the compression side of the natural gas value chain. In the Marcellus Shale Play, natural gas is co-produced along with shale oil during the hydraulic fracturing process. Natural gas can be compressed to 4,000 to 5,000 psig for use in compressed natural gas fueling stations, where trailer trucks are filled with the high-pressure natural gas. When the gas is compressed, the heat of compression must be removed. Spiral-tube heat exchangers are applied as compressor inter-stage and aftercoolers to lower the temperature of the 4,000–5,000 psig gas subsequent to compression.

VOC or product recovery

Reducing harmful or valuable emissions from chemicals processes is always a top priority for environmental stewardship and to improve unit economics. Owing to compactness and effectiveness of condensation with minimal pressure loss, spiral-tube heat exchangers can be considered. Spiral-tube exchangers have three common configurations for vent or process condensing (Figure 5). A low-cost option is where the coil or bundle fits inside the process vessel such that process vapors and gases flow around the outside of the coil and condensable vapors are condensed for reflux back into the vessel. A similar, but more expensive option is where the condenser is mounted on a vessel discharge flange. In this case, process vapors and gases flow around the outside of the coil condensing condensable vapors. In either case, the coolant flows inside the tubes. A desirable aspect of these types of condensers is that they mount directly onto a process vessel to avoid piping and associated hydraulic losses.

Figure 6 shows a cryogenically cooled storage-tank-vent condenser installed to eliminate 98% of methylene chloride (CH_2Cl_2) vapors vented or released from the storage tank

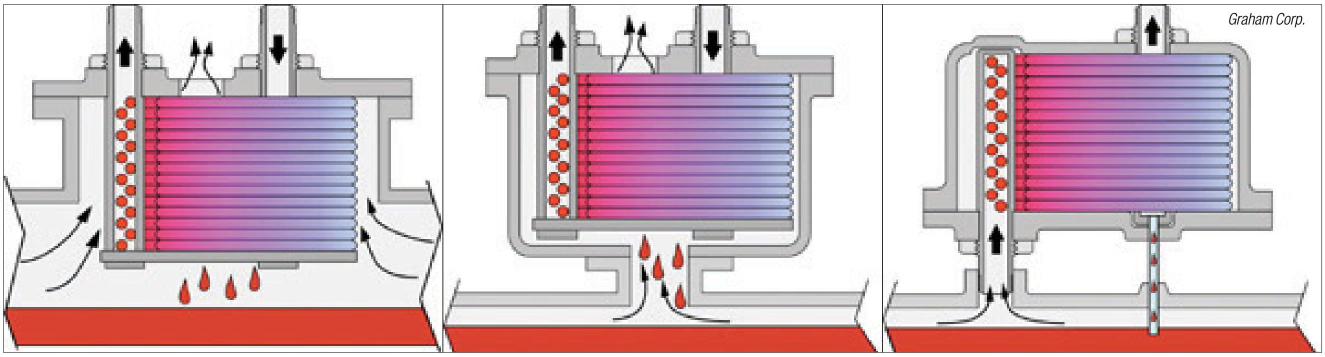
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FIGURE 5. Spiral-tube heat exchangers can help lower environmental impact with VOC or product recovery. Three different configurations are shown here


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FIGURE 6. **Shown here is a cryogenically cooled storage-tank-vent condenser, which prevents the release of vapors into the atmosphere**

during filling operations or as a result of changes in ambient temperature leading to release of CH_2Cl_2 as the storage tank breathes. In order to meet the high reclamation rate of 98% recovery of CH_2Cl_2, liquid nitrogen at –275°F is used as the coolant in order to cool vent vapors to –60°F. Such cold temperatures provided the desired elimination of CH_2Cl_2 from the vent while not freezing the vapors onto the tubing. Due to the importance of eliminating the majority of the vented vapors performance of the vent condenser was verified using U.S. Environmental Protection Agency Method 25A “Determination of Total Gaseous Organic Concentrations using a Flame Ionization Analyzer”. It was confirmed that, during tank-filling operations where the venting is at its greatest, the spiral-tube vent condenser recovered 98.8% of the CH_2Cl_2 by cooling the vent stream to –65°F.

Another variation, often considered for corrosive process vapors or where miscibility of condensates is an important design element, is for condensation to occur within the tubes while a coolant is on the shell side.

Vent or reflux spiral-tube condensers use coolants such as liquid nitrogen, chilled methanol, ethylene glycols, brine solutions or low-temperature heat-transfer fluids. The temperature of the coolant is often dependent upon the process vapors, the amount of noncondensable gases and the targeted emission level of process vapors.

Large temperature gradients

Industrial gas applications involving vaporization of cryogenic nitrogen, oxygen or helium, for example, involve large temperature rises on the cryogen side that is flowing within the tube, and also substantial temperature differences between the hot-side fluid and the cryogen [*4*].

The coil-tube-bundle configuration is well suited for large temperature variation and thermal gradients that present mechanical design challenges for shell-and-tube heat exchangers due to thermal expansion. For example, in a lyophilization application (Figure 7), liquid nitrogen at –295°F and 100 psia is sensibly heated to –282.7°F, at which point the nitrogen isothermally absorbs heat and liquid changes state to vapor. After changing phases, the gaseous N_2 is warmed further to –120°F. The Syltherm XLT is cooled to –90°F and returned to freeze dryer for low temperature dehydration of a pharmaceutical.

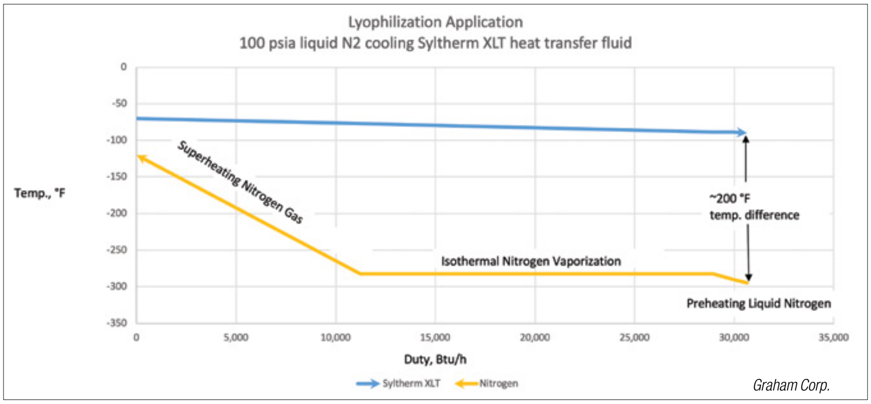

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Figure 7. **Shown here is the temperature-duty graph of a lyophilization application**

In this application, another feature of spiral-tube heat exchangers stands out. Processing of pharmaceuticals is expensive and costly if a batch is subjected to poor temperature control, thus resulting in that batch being discarded due to poor quality. The lyophilization process takes place at low temperatures to permit sublimation of moisture from the pharmaceutical product. With liquid nitrogen as a coolant and a low-temperature heat-transfer fluid as the control fluid for the batch freeze-drying (lyophilization) process, tube wall temperature can be below the freeze point of a heat transfer fluid. Once a heat-transfer fluid begins to freeze, temperature control is lost and pharmaceutical product quality suffers as a result. The curved flow path of a spiral tube heat exchanger induces turbulence and mixing of the boundary layer at the cold tube wall. This turbulence and mixing aids in the mitigation of ice formation or runaway freeze-up, where temperature control is lost. ■

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