Spiral Tube Heat Exchanger: Enhancing Energy Efficiency in Hydroprocessing

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Abstract

This article describes the use of Spiral Tube Heat Exchanger (STHE) fabricated by Zhenhai Petrochemical Jianan Engineering Co., Ltd (ZPJE) within the Hydroprocessing unit of Sinopec Guangzhou. The integration of this technology was a key element in the implementation of Sinopec Hydroprocessing technology, allowing the shutdown of the furnace during normal operation, thus achieving enhanced operational efficiency and allowing dramatic energy savings on the unit. In the 2MMTA DHT unit, this innovative design has reduced the equipment investment by 23 million RMB (US$3 million) and the energy consumption by 3kg standard oil / T feed oil. The annual profits have been increased by almost US$3.5 million and the annual CO_2 emission reduced by 14 000 tons. By using STHE from ZPJE, Sinopec Guangzhou achieved considerable economic and social benefits.

Introduction

The Company

Zhenhai Petrochemical Jianan Engineering Co., Ltd., is a former subsidiary of Sinopec Zhenhai Refining & Chemical Company. Since 2008, ZPJE is an independent joint-stock company established in the Ningbo region in the eastern coast of China. The company has more than 700 employees specialized in pressure vessel and tube manufacturing, thermal and hydraulic calculation, R&D and project management. ZPJE owns Production License for design and manufacture of Special Equipment in China and ASME authorization certificates of U & U2. ZPJE to date has delivered more than 1800 heat exchangers to its domestic and international customers.

Meanwhile, it has obtained ISO 9001:2015 Quality Management System Certification, ISO 14001:2015 Environmental Management System Certification and ISO 45001:2018 Occupational Health and Safety Management System Certification.

The Product

Spiral tube heat exchangers have been used for many years, in fact, since the beginning of cryogenic liquefaction industry. For more than 30 years, ZPJE has developed a unique state of the art know how of heat exchange calculation, hydraulic simulation and mechanical modeling of spiral tubes design to enable this technology to be used in refinery, petrochemical and Oil & Gas businesses [1].

The result of this intense R&D development is the publication of more than 150 national and international patents, and 25 software copyrights for the calculation program used to simulate the heat exchange, the pressure drop and the mechanical strength of this type of exchanger.

The design of spiral tube heat exchangers consists of many tubes arranged in multiple layers of helical coils, around a center pipe. This tube bundle is enclosed in a cylindrical pressure vessel. The fluid on the tube side and on the shell side flows in opposite directions, making the equipment a true counter-current heat exchanger (see figure 1)

On the Shell Side: The high turbulence flow is created by the patented design of the tube coils. The variation of the fluid velocity between the tubes creates a pulse-surge collision flow regime increasing subsequently the heat exchange coefficient outside the tubes. The possibility of fouling is greatly limited by the non-baffle design, the turbulence of the fluid and the very low surface roughness of the tubes.

On the Tube Side: The Helix-pattern flow in the tubes creates, thanks to the centrifugal forces, a secondary flow consisting of a pair of vortices enhancing the heat transfer coefficient at the peripheral of the tubes. Spiral tubes are coiled layer by layer in opposite direction to have a homogeneous heat transfer all along the exchanger.

The Project

Diesel Hydrotreating

The products derived from Crude and Vacuum distillation columns often contain impurities such as sulfur, nitrogen, oxygen, or metals that must be removed before further processing or use. While Hydrocracking serves to convert heavy oil into lighter fractions, Hydrotreating units play a critical role in converting undesirable aromatics, olefins, nitrogen, metals, and organosulfur compounds into stabilized products . Refineries encounter escalating challenges in processing increasingly complex feedstocks while upholding stringent product quality standards, including adherence to regulations such as the Euro V norm.

Addressing these challenges demands the utilization of high-efficiency equipment, such as ZPJE Spiral Tube Heat Exchangers (STHE), to significantly enhance the economic viability of these units. The integration of such advanced equipment can bring substantial annual savings running into millions of dollars.

The robustness and maintainability are key to ensure prolonged and trouble-free operations during successive production runs. These factors show the necessity for reliable equipments and low maintenance in the face of evolving refinery demands and regulatory compliance.

Figure 1: *STHE single stream design*

Sinopec Guangzhou Petrochemical Unit

The primary focus of Sinopec Guangzhou Petrochemical Company lies in the domains of oil refining and ethylene production, boasting an extensive crude oil processing capacity of 12.75 million metric tons per annum (MMTA) and an ethylene production capacity of 0.22 MMTA. Its 2.0 MMTA diesel hydrotreating unit was equipped with ZPJE's Spiral Tube Heat Exchanger. The adoption of this high efficiency technology enabled the use of the furnace only for start-up, leading to notable reductions in engineering investment, operational expenses, and overall energy consumption.

A total of three Spiral Tube Heat Exchangers (STHEs) were incorporated into this unit , becoming operational in April 2012. Leveraging this cutting-edge technology in constructing the diesel hydrotreating unit has resulted in a 4.5% decrease in engineering investment and a 45% reduction in fuel consumption for the all unit. This accomplishment aligns with the objective of exclusively using the furnace during the start-up phase, eliminating its necessity during regular operations.

The Offer

In this newly-built diesel hydrotreating unit, the feedstock is mixed diesel made of FCC light cycle oil, Coker gasoil and Straight Run gasoil. The Design parameters of these 3 STHEs are given in table 1

In this specific unit configuration, the conventional technology used is Breach Lock Shell & Tubes Heat Exchanger. However, This technology has the following inherent limitations :

1. **Design:** The design used is as per TEMA type with girth flange sealing. Several exchangers in parallel or series are required to handle large duties, leading to multiple piping, flanges, gaskets and instrumentation.
2. **Thermal Efficiency:** The "U" tube exchanger technology can only offer poor thermal efficiency, leading to high Hot Approach Temperature (temperature difference between the outlet of the cold stream and the inlet of the hot stream).
3. **Pressure Drop:** The necessity to have baffles, support plates and piping connection contributes to a notably high total pressure drop across the train of exchangers.

Table 1: *Design Parameters of STHEs*

Service		Fluid	Operation Temperature (°C)	Operation Pressure (MPa g)
Hot Combined Feed/Effluent Exchanger(E-9101)	Tube Side	Hot Combined Feed	154/358	12.59
	Shell Side	Reactor Effluent	405/240	11.71
HHPS Gas/Cold Combined Feed Exchanger (E-9103)	Tube Side	HHPS Gas	170/103	11.22
	Shell Side	Cold Combined Feed	93/160	12.4
HDF Diesel/LPS Oil Exchanger (E-9206)	Tube Side	HDF Diesel	235/191	1.4
	Shell Side	LPS Oil	170/210	1.15

4. **Fouling:** The differences in flow velocity caused by the baffle create zones of low flow and stagnant region where fouling deposits tend to occur.
5. **Cleaning:** Due to the high fouling, frequent cleaning of the equipment becomes imperative. The design with shell and baffle complicates the cleaning process, often resulting in partially efficient results. Cleaning procedures are required after each operational run.
6. **Main Risks of Failures:** The primary failure points associated with breach lock design are : tube to tubesheet joint leaking, tube leakage or rupture, girth flange leakage.

In comparison to the Breach Lock Shell and Tube technology, the STHE brings several advantageous characteristics such as a compact structure, large size, high thermal efficiency, minimal pressure drop, exceptional mechanical resistance, low fouling, reduced weight, and a smaller footprint. The benefits associated with STHE are as follows:

1. **Consolidated design:** The use of a single shell significantly reduces the required plot area and simplifies the piping system. For instance, within this unit, the use of 3 spiral tube heat exchangers replaced the need for 9 Breach Lock S&T units, resulting in space and piping work savings.
2. **Enhanced thermal efficiency:** The STHE technology notably improves fuel savings by achieving the exclusive use of the furnace during start-up, eliminating its need during regular operations. This leads to a substantial 45% reduction in fuel consumption, thereby reducing dramatically the operating costs.
3. **Minimal pressure drop:** The STHE's design gives a low pressure drop, which consequently reduces the requirements for the pumps and compressors, lowering the overhaul project capital cost as well as operating costs.
4. **Reduced maintenance costs:** The 3 STHE units, operational since 2012, have performed flawlessly without any malfunctions. During shutdowns and overhauls, their maintenance necessitated only nitrogen blanketing, significantly minimizing maintenance expenses and downtime.

Operating FeedBack

Long Term Performances

After the implementation of the Hot Combined Feed/Effluent Exchanger (E-9101), the tube-side pressure drop has demonstrated consistent stability without notable upward trends, albeit exhibiting fluctuations associated with varying load, hydrogen flow rates, and secondary line regulation. On the shell-side, pressure drop has only slightly increase by 20 kPa compared to its original design. These variations are attributed to gradual fouling and different stages of the reaction process.

Concerning the Hot Approach Temperature (HAT), as shown in the figure 2, the reactor feed is heated by E-9103 and E-9101 before entering the Reactor, and the reactor inlet temperature is controlled by adjusting the opening of E-9101 bypass valve. In Start Of Run (SOR) case where the catalyst activity is good, the required temperature of reactor feed is low so the valve is open to decrease the feed flow rate entering into E-9101, which will increase the outlet temperature of E-9101, resulting in the decreasing of HAT. When it comes to End Of Run (EOR) case, the catalyst activity decreases requiring higher temperature for the reaction. The valve opening will then close to allow the feed to recover more heat from E-9101 which will increase the HAT. E-9101 was designed according to EOR case with maximum feed (100%) for a HAT of 47°C, while SOR case with reduced feed flowrate (60%) will give a HAT of 10°C. The recorded HAT is in line with these design conditions.

E-9103 and E-9206 have exhibited seamless operation since their commissioning, displaying steady HAT and pressure drop patterns without any significant deviations. The three Spiral Tube Heat Exchangers (STHEs) have functioned without malfunction since 2012, undergoing only nitrogen blanketing during shutdowns and overhauls. During a planned shutdown in October 2023, the exchanger E-9101 was mechanically chemically cleaned on the tube-side and shell-side. The performances after the unit restart were in line with the design parameters.

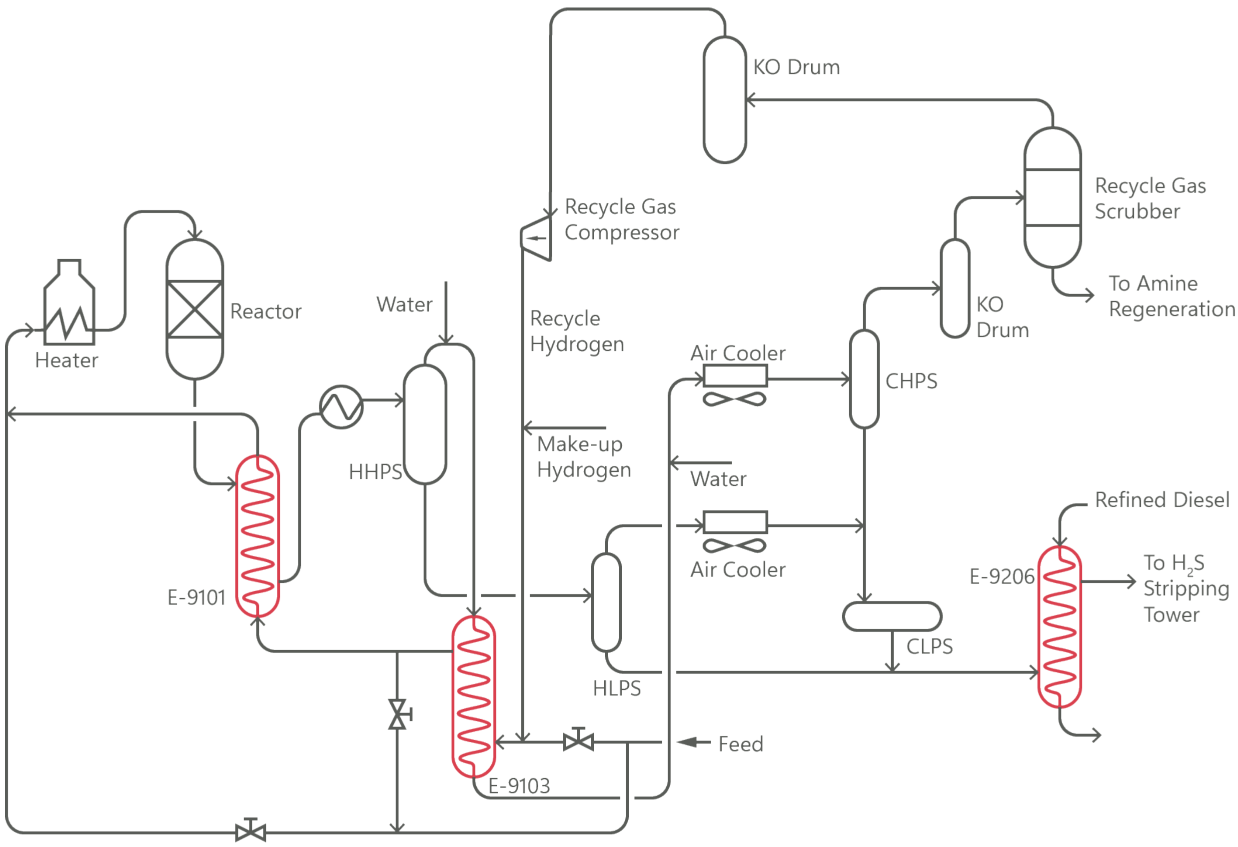

Figure 2: *Unit Process Flow Diagram*

Customer Feedback

Here is what Sinopec Guangzhou Petrochemical Company. says about its experience with ZPJE's STHE technology :

> "The high efficiency STHE technology used in our 2MMTA DHT unit allows us to use the fired heater only during the startup phases. During normal operations, the STHE is so efficient that the furnace can be shut down, saving dramatically the consumption of fuel oil. This innovative design reduces the equipment investment by 23 million RMB (US$3 million) and the energy consumption by 3.03kg standard oil / T feed oil. The annual profits have been increased by almost 25.18 million RMB (US$3.5 million) and the annual CO_2 emission reduced by 14000 tons. By using STHE from ZPJE, we achieved considerable economic and social benefits.
>
> Three STHEs designed and manufactured by ZPJE have been installed on the unit. It includes a reaction effluent/hot mixed feed heat exchanger, a hot high-pressure gas/cold mixed feed heat

exchanger and a refined diesel/low-pressure oil heat exchanger. Since the unit was started in 2012, these three heat exchangers have been running satisfactorily for more than 10 years with good and stable performance without any mechanical issue or cleaning needed.

This hydrotreating unit processes the mixed oil from catalytical, coking and straight run diesel as feed oil to produce naphtha and refined diesel. The successful application of this new STHE technology provides a new design concept for similar hydrotreating process units in the future."

Economics

By implementing STHE technology in its hydroprocessing unit, Sinopec was able to achieve the performances given in table 2

Table 2: *Economics*

Fuel Oil consumption	-45% for the whole unit
Equipment Investment	-US$3 million
CO_2 emission	-14 000 tons/year
Energy consumption	-3.03 kg standard Oil/t feed oil
Annual profits	Increased by US$3.5 million : US$ 1.75/t of feed oil

Conclusion

ZPJE's Spiral Tube Heat Exchanger (STHE) technology, characterized by its compact structure, high efficiency, energy-saving features, low economical investment, and reliable operation, has been successfully implemented in the 2.0 MMTA Diesel Hydrotreating (DHT) Unit at Sinopec Guangzhou Petrochemical.

The use of this technology has enabled significant benefits, including a notable reduction in the initial investment costs associated with heat exchangers and heaters, as well as a decrease in plot area requirements, fuel gas consumption in heaters, and the air cooling load. All these advantages have made a substantial contribution to the overall energy efficiency of the unit.

Since their commissioning in 2012, the three STHEs in operation have consistently met production requirements, demonstrating excellent performances. The STHEs' convenient maintenance and reliable operation have been particularly noteworthy, requiring only nitrogen blanketing during previous shutdowns, earning unanimous praise from the unit's operational staff.

In applications involving high temperatures, high pressures, and hydrogen services with demanding process conditions, the safety and reliability requirements for heat exchangers are heightened. Additionally, there is a pressing need for energy consumption reduction in refining market. The adoption of ZPJE's mature and reliable STHE technology in Hydroprocessing units has become an unavoidable choice in response to these challenges.

For more information, please visit ZPJE website at the following address : `https://www.sthezpje.com/`

References

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