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Advanced Energy Saving in the Reaction Section of Hydro-DeSulfurization Process with Self-Heat Recuperation Technology

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In this paper, an advanced energy saving system in the reaction section of Naphtha Hydro-DeSulfurization (HDS) Process is proposed. The heat of the process stream is recuperated by the compressor and exchanged with itself based on the self-heat recuperation technology, leading to the removal of a fired heat from the reaction section in the process. The result of process simulation shows a drastic reduction in energy consumption of the proposed system from the conventional process that uses a fired heater.

1. Introduction

Naphtha Hydro-DeSulfurization (HDS) process, which is a well-known process in a refinery, has a fired heater in the reaction section. The fired heater consumes not only a large amount of energy but also a large amount of exergy during combustion, because there is a big temperature difference in a fired heater between fuel combustion (over 800 ^{o}C) and process condition (around 300 ^{o}C) for the reactor. Pinch technology (Tjoe and Linnhoff (1986), Asante and Zhu (1996), Dhole et al. (1992), Raisi (1994), Klemes et al. (1997), is a well known technology for a heat-recovery to reduce a plenty of energy in a plant or a complex of plants. However, a conventional heat-recovery system has limits fundamentally: 1) 1) it is necessary to heat the process stream to the operation condition by the additional fired heater due to the minimum temperature difference $\Delta T_{\min}$ for heat exchange between hot and cold stream. 2) a large amount of low-grade heat from a hot stream is not recovered and exhausted.

To solve these problems, Sato et al. (2007) and Kansha et al. (2008a and 2008b) recently have proposed “self-heat recuperation technology” for heating and cooling thermal process.

By following this technology for energy saving in a refinery process, we developed an advanced naphtha HDS process based on the self-heat recuperation technology which utilizes the heat of the process stream itself effectively by a compressor without using a

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fired heater. The result of process simulation showed that the proposed Naphtha HDS process could decrease the required energy input drastically compared with the conventional process which uses a fired heater.

2. Self-heat recuperation technology

Tsuru et al. (2008) reported that the self-heat recuperation technology for heating and cooling thermal processes by pressure change could achieve a perfect internal heat circulation in feed/effluent heat exchanger. Figures 1(a) and (b) show the conventional flow diagram of thermal process and its composite curves, respectively. The liquid feed stream is vaporized partially in a heat exchanger and heated up to the required condition of a fired heater. The effluent stream from a reactor heats the feed stream up to T_b, boiling temperature, with feed/effluent heat exchanger under the condition of minimum temperature difference ΔT_{min}. A part of latent heat in phase change is recovered in heat exchanger. A fired heater (Q_{H}) supplies larger heat duty to the feed stream than a heat exchanger (Q_{HX}).

Figures 2(a) and (b) show the advanced flow diagram with self-heat recuperation technology and its composite curves, respectively. The boiling temperature is shifted T_{b} to $T_{\mathrm{b'}}$ by the pressure change of the feed stream and the latent heat can be exchanged between feed and effluent stream in this flow. All of the heat of the process stream is re-circulated in the process without a fired heater, results in reduction of energy consumption of the process.

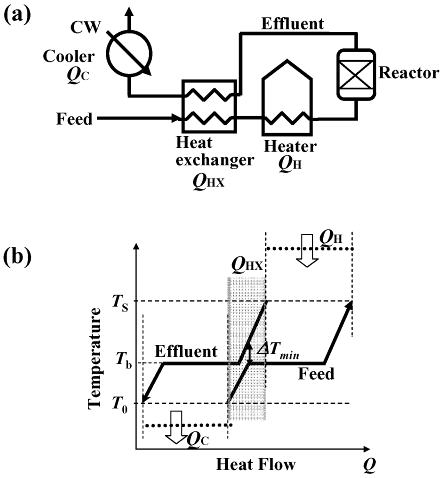

Fig.1 Conventional flow

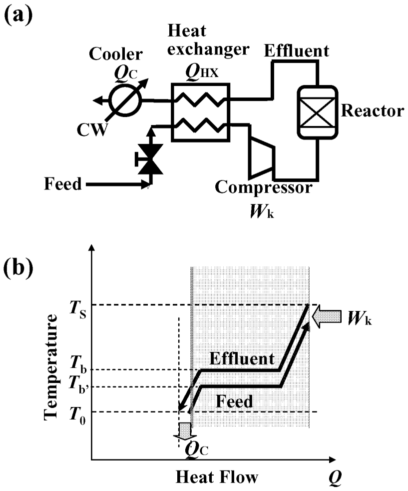

Fig.2 Advanced flow with self-heat recuperation technology

3. Simulation

3.1 Conventional Naphtha HDS flow

Figure 3 shows a conventional Naphtha HDS flow diagram. In this flow, liquid Naphtha is pumped up and mixed with compressed hydrogen, and then the stream of Naphtha and gas, which has a vapor/liquid mixed phase, is heated in a heat exchanger. The stream, which still has a mixed phase, is heated up to the required condition at the inlet of the reactor by a fired heater. A reactor effluent is cooled down by a heat exchanger and a cooling water cooler. In this conventional Naphtha HDS process flow, the fired heater satisfies the operating condition of temperature (300 °C) at the inlet of the reactor. However, fuel combustion in a fired heater generates a very high temperature heat beyond 800 °C. That temperature difference between the operating temperature (300 °C) and the generating temperature (800 °C) causes a large exergy loss. Furthermore, in this flow, the heat duty (3,274kW) of a cooling water cooler is almost same as the heat duty (3,370kW) of a fired heater. This means that this process consumes energy as high-grade heat in a fired heater and exhausts energy in a cooling water cooler.

3.2 Advanced Naphtha HDS flow with self-heat recuperation technology

In order to reduce the above-mentioned large exergy loss in the process, it would be better to use the heat in the process stream itself. Figure 4 shows the advanced energy saving flow diagram of the reaction section in a Naphtha HDS process. A reactor charge compressor is installed instead of the fired heater and the heat exchanger is revamped to increase a surface area. In the advanced Naphtha HDS flow, liquid Naphtha is pumped up and mixed with hydrogen without any compressor, and then the stream of Naphtha and gas is heated and vaporized totally in a heat exchanger. Finally the feed stream is compressed by a reactor charge compressor to satisfy the operating conditions of not only pressure but also temperature in front of the reactor.

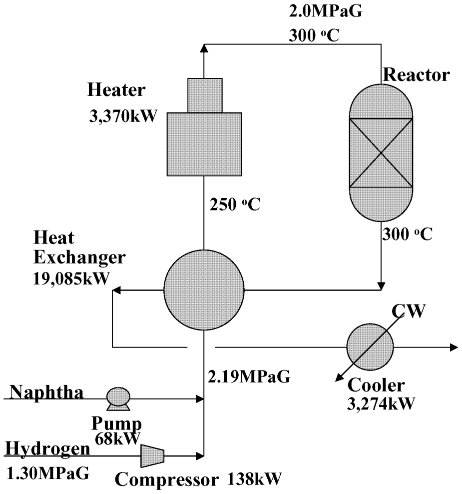

Fig.3 Conventional Naphtha HDS flow

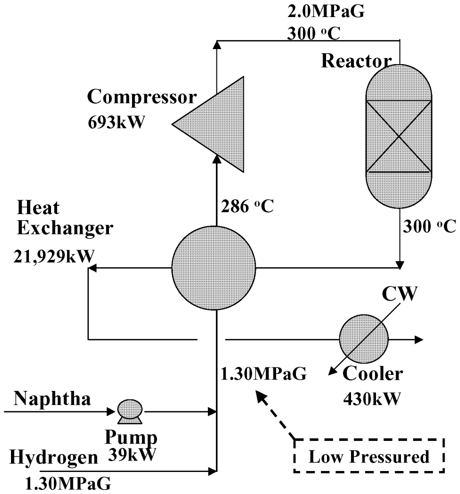

Fig.4 Advanced Naphtha HDS flow with self-heat recuperation technology

4. Results

The required energy of the Naphtha HDS processes were calculated by the commercial simulator, PRO/II^{TM} (Invensys). The Soave-Redlich-Kwong equation of state (SRK) was applied. The throughput of Naphtha HDS process is 18,000 BPSD (barrel per stream day), the inlet condition of the reactor is 2.0 MPaG and 300 ^{o}C. Figures 3 and 4 show the results of the simulation study, respectively. The duty of the equipments, the operating conditions are shown in the figures, where net heat duty is shown at the fired heater, the power is shown at pump and compressors, and exchanged heat duty is shown at heat exchanger. Table 1 summarizes the exergy and energy input to the conventional flow and the advanced flow. As shown in Table 1, the sum of exergy input to the conventional flow with a fired heater, a naphtha pump and a hydrogen compressor is 3,576 kW. On the other hand, in the advanced Naphtha HDS flow, the sum of exergy input with a naphtha pump and a reactor charge compressor is 732 kW. In this process, a hydrogen compressor is removed because installing reactor charge compressor leads to set the lower pressure from 2.19 to 1.3 MPaG in the heat exchanger. 1.3 MPaG of hydrogen stream is supplied from outside process and can be directly fed to the advanced flow without any hydrogen compressor. The required energy of this proposed advanced process (732 kW) is only 20% of that of the conventional process. Considering equipment efficiency and power generation efficiency (36.6% in the Japanese energy saving law), the sum of energy (enthalpy) input is 4,729 kW for the conventional flow and 2,186 kW for the advanced flow. The energy consumption in the advanced flow is 46% of that in the conventional flow. Eventually the energy saving amount equivalent to annual crude oil conversions is calculated 1,900 kL/y (7.4x10^{4}GJ/y).

Table 1 Summary of Exergy and Energy Input in Conventional and Advanced flow

	Conventional flow	**Advanced flow**	**Remarks**
Minimum temperature difference in heat exchanger, ^{o}C	**16.2**	**11.5**	
1. Exergy input, kW			
1) Fired heater	**3,370**	**--**	
2) Naphtha pump	**68**	**39**	
3) Hydrogen compressor	**138**	**--**	
4) Reactor charge compressor	**--**	**693**	
Total	**3,576 (100%)**	**732 (20%)**	
2. Energy input, kW			
1) Fired heater	**3,965**	**--**	**1) Efficiency=85%**
2) Naphtha pump	**310 a**	**172 b**	**2) Efficiency=60%a, 62%b**
3) Hydrogen compressor	**454**	**--**	**3) Efficiency=83%**
4) Reactor charge compressor	**--**	**2,014**	**4) Efficiency=94%**
Total	**4,729 (100%)**	**2,186 (46%)**	**2)-4) Power generation efficiency= 36.6%**

5. Discussion

The big exergy loss caused by temperature difference between the inside of fired heater (800 °C) and process requirement for reactor (300 °C) is significantly reduced in an advanced flow. In exergy input, 3,370 kW by a fired heater is reduced to 693 kW by a reactor charge compressor. A cooler duty, 3,274kW, is almost same as a fired heater duty, 3,370kW. Changing from a fired heater to a reactor charge compressor can reduce the amount of exhausted low-grade heat from 3,274kW to 430kW. Figure 5 shows the composite curves for feed and effluent streams. In Fig. 5 lower three lines are feed streams and the upper one is effluent stream. The lowest thin line of feed stream in the conventional flow has a pinch point with effluent stream as $\Delta T_{\text{min-1}}$ (16.2 °C). Although improving the heat-recovery, ΔT_{min} (11.5°C), by increasing a surface area of heat exchanger in conventional flow, the second broken line shows that a small increase can be expected. Introducing reactor charge compressor can set lower pressure of feed stream for heat exchanger than in conventional flow. This lower pressure of feed stream can change its shape in the composite curves. It enables to come much closer to effluent stream. The third thick line of feed stream from the lowest line is in the advanced flow. The location of a pinch point is changed as $\Delta T_{\text{min-2}}$ (11.5 °C) and the amount of improved heat-recovery in advanced flow becomes much bigger than in case of the second broken feed stream. Indeed the effect of lower pressure by introducing a reactor charge compressor leads to improve 15% of the heat duty of a heat exchanger.

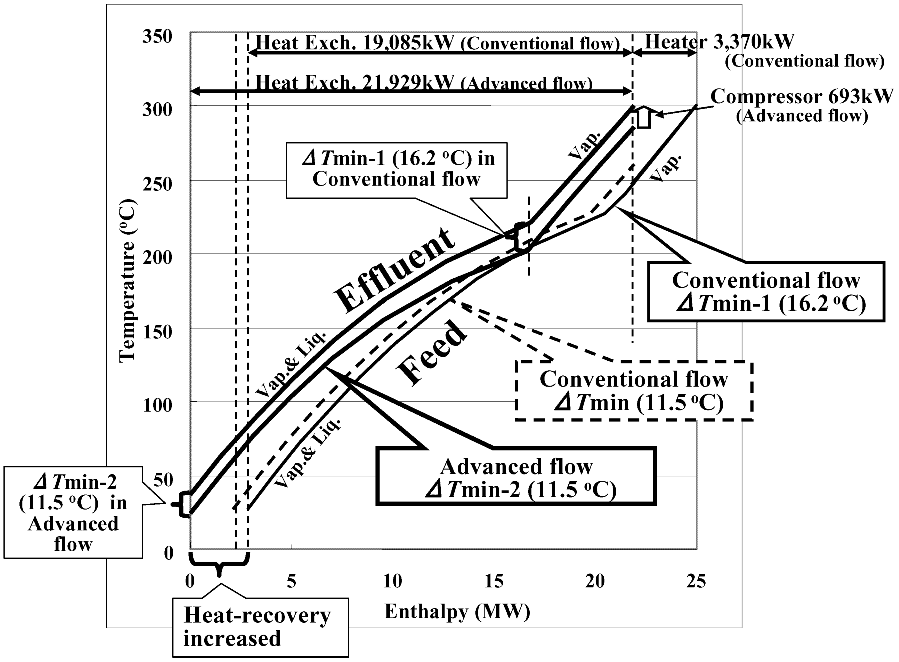

Fig.5 Composite curves

6. Conclusion

The advanced Naphtha HDS process was developed based on "self-heat recuperation technology". We confirmed that this advanced flow could reduce the exergy input to 20% and the energy input to 46% of the conventional flow that uses a fired heater. This advanced flow utilizes the heat of the stream itself effectively by a reactor charge compressor and removes a fired heater. Introducing a reactor charge compressor leads to change the shape of the composite curve of the feed stream and can improve 15% of heat duty of a heat exchanger in the conventional flow.

Acknowledgement

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