Applied Thermal Engineering 30 (2010) 2300–2305

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Advanced energy saving in the reaction section of the hydro-desulfurization process with self-heat recuperation technology

Kazuo Matsuda [a,*], Kenichi Kawazuishi [a], Yoshiichi Hirochi [a], Rei Sato [a], Yasuki Kansha [b], Chihiro Fushimi [b], Yutaka Shikatani [c], Hiroshi Kunikiyo [c], Atsushi Tsutsumi [b]

[a] Chiyoda Corporation, 2-12-1, Tsurumichuo, Tsurumi-ku, Yokohama 230-8601, Japan
[b] Collaborative Research Center for Energy Engineering, Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
[c] Nippon Oil Corporation, 1-3-12 Nishi Shimbashi, Minato-ku, Tokyo 105-8412, Japan

ARTICLE INFO

Article history:
Received 26 August 2009
Accepted 4 May 2010
Available online 8 May 2010

Keywords:
Self-heat recuperation technology
Energy saving
Compressor
Heat pump
Pinch technology

ABSTRACT

The reaction section of the naphtha hydro-desulfurization (HDS) process is a heating and cooling thermal process consisting of a feed/effluent heat exchanger and a fired heater. Energy savings are fundamentally made as a result of the maximized heat recovery in the heat exchanger and the reduced heat duty of the fired heater. To achieve further energy saving in the process, "self-heat recuperation technology" (SHRT) was adopted. In this technology, a compressor was introduced. The suction side of the compressor needed a lower pressure and the feed stream evaporated much easily. The discharged side of the compressor satisfied the operating conditions of both pressure and temperature at the inlet of the reactor. And the reactor effluent stream was able to be used completely to preheat and vaporize the feed stream. All the heat in the process stream was re-circulated without using a fired heater. SHRT was applied to the naphtha HDS process of 18,000 barrel per stream day (BPSD) in the refinery and the mass and energy balance of the process was calculated using commercially available simulation software, Invensys PROII version 8.1. This process-simulation case study confirmed that despite there being no more energy saving potential in the conventional process that makes use of a fired heater, the advanced process with SHRT can reduce the energy consumption significantly by using the recuperated heat of the feed stream.

1. Introduction

The naphtha HDS process, a well-known process adopted by refineries, uses a fired heater in the reaction section to heat the process streams. The fired heater consumes not only a large amount of energy but also a large amount of exergy during combustion due to the large temperature difference in the fired heater between fuel combustion (over 800 °C) and process condition (around 300 °C) for the reactor. In order to reduce energy consumption in the fired heater, pinch technology has been widely applied for heat recovery to save energy in a plant or a complex of plants. In the 1980s, Linnhoff et al. [1] introduced the concept of "target before design" using pinch technology for the design of individual processes. Pinch technology for Heat Exchanger Network (HEN) design was developed by Linnhoff and Hindmarsh [2]. Methodologies were evolved by Linnhoff and Ahmad [3] and Ahmad et al. [4] based on HEN synthesis to incorporate total cost targeting and block-decomposition. Later a HEN retrofit framework was established, based on the "process pinch" (Tjoe and Linnhoff [5]), "network pinch" (Asante and Zhu [6]), and "multiple utilities" (Salama [7]) concepts. Pinch technology, which improves heat exchange between the hot and cold streams in a process, has been applied to thermal processes. However, a conventional heat recovery approach based on pinch technology has fundamental limitations: 1) The minimum temperature difference (ΔT_{min}) for heat exchange between hot and cold streams is required to heat the process stream to the operation condition by using an additional fired heater and 2) a large amount of low-grade heat from a hot stream cannot be recovered and is eventually exhausted.

To resolve these problems, Kansha et al. [8] and Tsuru et al. [9] have recently proposed "self-heat recuperation technology" (SHRT) for heating and cooling in thermal processes. They demonstrated that the self-heat recuperation technology, in which the heat of the reactor effluent stream is recuperated by gas and/or vapor recompression and reused for the reactor feed stream heating in a heat exchanger, can drastically reduce energy consumption.

* Corresponding author. Tel.: +81 45 506 7182; fax: +81 45 506 7376.
E-mail address: kmatsuda@ykh.chiyoda.co.jp (K. Matsuda).

1359-4311/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2010.05.003

Nomenclature

BPSD	barrel per stream day
CW	cooling water
HDS	hydro-desulfurization
HE	heat exchanger
ΔT_{min}	minimum temperature difference, °C
SHRT	self-heat recuperation technology

Following these studies, we initially undertook a feasibility study by applying this technology in the heavy chemical industrial field. We developed an advanced naphtha HDS process in which the recuperated heat comes from the reactor effluent stream. We compared its energy saving effect with the conventional naphtha HDS process using a fired heater.

2. Conventional and advanced processes

Kansha et al. [8] and Tsuru et al. [9] reported that SHRT, used for heating and cooling in thermal processes by pressure change, could achieve perfect internal heat circulation in a feed/effluent heat exchanger. Fig. 1(a) and (b) show the conventional process and its temperature-heat diagram. The liquid feed stream is partially vaporized in a heat exchanger and heated in a fired heater to the required temperature for the reactor. The effluent stream from the reactor heats the feed stream at boiling temperature (T_b) in the feed/effluent heat exchanger under the condition of minimum temperature difference (ΔT_{min}). A part of the latent heat in the phase-change and the sensible heat are recovered in the heat exchanger. Q_c, the un-recovered latent heat and sensible heat, is discarded in a cooling water (CW) cooler. The fired heater supplies a large amount of heat (Q_H) to the feed stream, which is larger than the heat duty (Q_{HX}) in the heat exchanger.

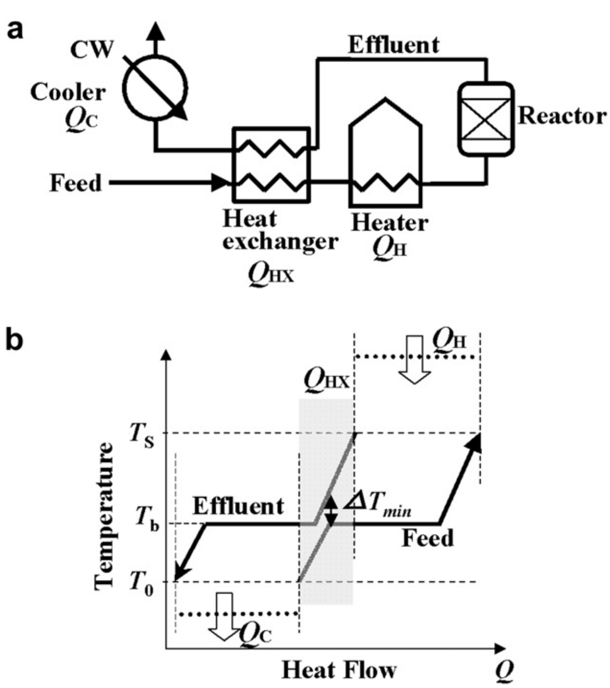

Fig. 1. Conventional process with a fired heater and its temperature-heat diagram.

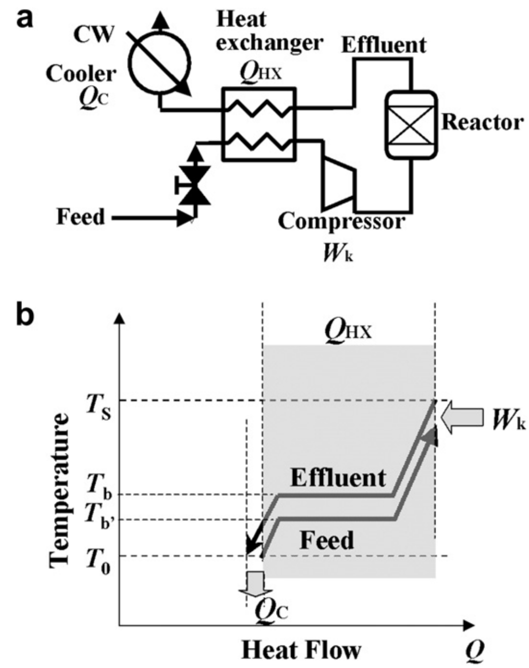

Fig. 2. Advanced process with self-heat recuperation technology and its temperature-heat diagram.

Fig. 2(a) and (b) show the advanced process with self-heat recuperation technology and its temperature-heat diagram. The reactor charge compressor is used in this process. By compressing the stream, the stream pressure and its temperature are both increased simultaneously. The feed stream to the heat exchanger needs to be set at a lower pressure than that in the conventional process, which then allows the reactor inlet pressure in the advanced process to remain the same as in the conventional process. The boiling temperature is shifted from T_b to $T_{b'}$ by the pressure change of the feed stream, which allows the latent heat to be exchanged between the feed and effluent streams. All the heat of the process stream is re-circulated in the process without the need of a fired heater, which means that the heat of the reactor effluent stream can be completely used to preheat and vaporize the feed stream, resulting in a drastic reduction in energy consumption of the process.

Recently, the design strategy of a heat pump with process integration under optimal matching (Fonyo and Benko [10], Wu et al. [11], Smith et al. [12]) was introduced. Energy and exergy analysis of heat pump was applied by Ceylan et al. [13]. Pavlas et al. [14] designed the heat pump system with the aid of Grand Composite Curve. The heat pump was applied to several thermal processes; the liquefaction process of natural gas (Aspelund et al. [15]), the open air-vapor compression refrigeration system (Hou et al. [16]), multi-function heat pump system (Gong et al. [17]), the ground source heat pump system (Tarnawski et al. [18]), and the refrigeration process using moist air and water (Hou and Zhang [19]). The ambient heat or the process waste heat is generally pumped by the heat pump to heat/cool the process stream by the working fluids (steam, CO_2, etc.). Fig. 3 shows the conventional process and its temperature-heat diagram, with a heat pump system supplying the required heat instead of a fired heater. HE-2 in the heat pump system needs to have the same heat duty (Q_H) as a fired heater in the conventional process and requires a heat source (Q_{H0}). Because the temperature difference between Q_{H0} and the feed stream is much larger than that in the heat exchanger in the advanced process, the heat pump system requires more power to improve the quality of the heat from Q_{H0} to Q_H than the power required by the advanced process.