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Improving Energy Efficiency for Refinery through Bottleneck Elimination

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The improvement of the energy efficiency of existing industrial plants using a minimum investment is a very important task. The structural bottleneck check and elimination can play a key role in the retrofit. The heat transfer area of exchangers less than the required area have high probability of becoming the structural bottleneck of the existing network. The methodology of bottleneck identification jointly with Pinch Technology is described. With bottleneck identification and elimination the plant energy efficiency improved. For the case study, through operation parameters change and one additional heat exchanger added to the heat exchanger network (HEN) the final entrance temperature before being heated in the furnace was increased by 8 ºC and heat transfer cross Pinch decreased 28.6 % compared with the original HEN.

1. Introduction

The petroleum refining industry in China is the second largest nation's industry in the world (Liu et al., 2013) and provides products to many other sectors. Typically 60 % of a refinery operating cost is spent on energy. Enhanced energy efficiency helps refineries reduce cost as well as environmental pollution and greenhouse gas emissions (Liu et al., 2013). From 2000 to 2010, the CNPC (China National Petroleum Company) has decreased their unit energy consumption by 28 % (CPCIA, 2010). CNPC (2014) - China National Petroleum Company - reduced energy use by 1.26 Mt of standard coal and fresh water use by 24.62 Mm^3/y. The use of energy-efficient technology meets the challenges posed by modern refineries that consist of more complex and integrated systems. Various technologies can be used to improve the energy efficiency of refinery: Using Process Integration based Pinch Analysis (Klemeš, 2013), a major reductions are possible to be achieved by Total Site Integration (Klemeš and Kravanja, 2014), low grade heat source recovery and utilisation (Tchanche et al., 2011), combined heat and power system optimisation (Mitra, 2013). Wang and Chen (2012) applied Pinch Analysis to the refinery hydrogen distribution system. Recent papers demonstrated the advantage of using a novel Shifted Retrofit Thermodynamic Diagram (Yong et al., 2014) supported by a successful implementation of HEN retrofit by Extended Grid Diagram and Heat Path Development (Yong et al., 2014). Retrofit Tracing Grid Diagram (Nemet et al., 2015) has been successfully implemented for a Heat Integration retrofit analysis of an Italian oil refinery case study. Chen et al. (2013) proposed a steam and power system optimisation model for analysis of existing steam power plant in a refinery. Jian et al (2014) investigated the ORC technology on the recovery of waste heat sources in petroleum refining industry. In this paper, the methodology of based on the Network Pinch (Yong, et al., 2015) combines heat exchanger area optimisation finding and removing bottleneck check and elimination technology is presented based on a 1,500 kt/y refinery plant. The bottleneck of the existing network configuration is first identified by redistributing the heat loads of existing exchangers, which is referred to as Pinching the existing network. The identified heat exchanger bottleneck of the original network is retrofitted according the optimisation.

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2. Back process and base case

The back refinery process consists of three columns, a flash, an atmospheric distillation unit (ADU) and a vacuum distillation unit (VDU) column. Figure 1 shows the HEN before desalination which is named as HEN1 in this paper. Figure 2 is the second HEN between the desalination and the flash column named HEN2. Figure 3 is the third HEN between the flash column and the furnace of the ADU named HEN3 and the ADU column.

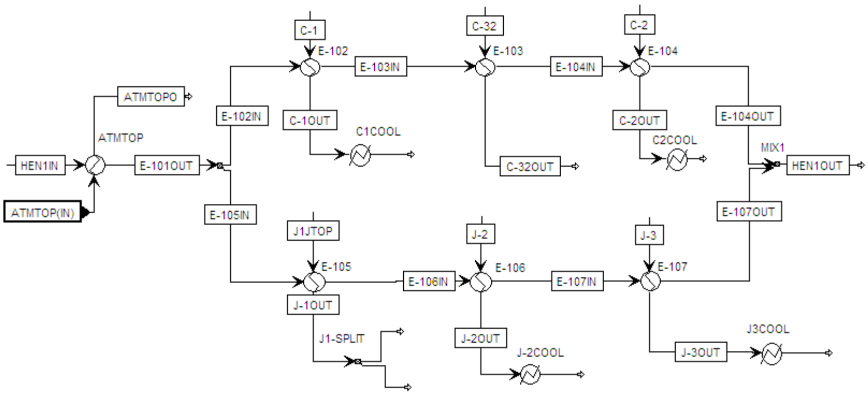

Figure 1: The HEN before desalination (HEN1). CRUDE - Crude Oil, C1, C2, C32 - the first, second and the third side draw of the ADU; J1JTOP, J2, J3 - the first, second and the third side draw of the VDU

In HEN1 (Figure 1), the 50 °C feed crude oil is heated by the top gas of the ADU first before being divided into two streams heated with heat exchangers of E102, E103, E104 and E105, E106, E107 separately, and subsequently mixed again at 130 °C into the desalination unit.

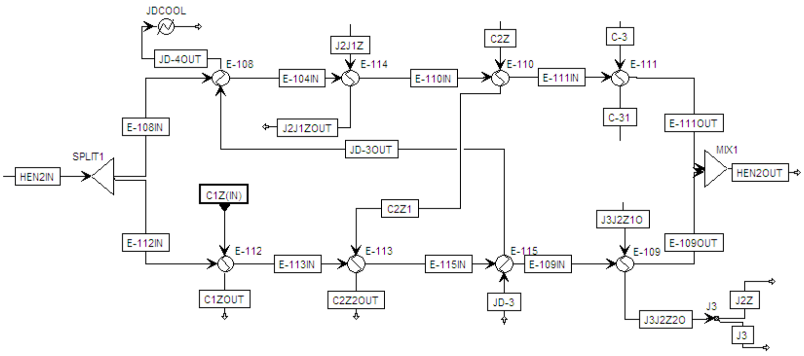

Figure 2: The heat exchanger network between the desalination and the flash column (HEN2). JD-3, JD-4 -The residue of the VDU; J2J1Z, J3J2Z - the first and the second pumparound of the VDU; C1Z, C2Z, C3 - The first, second and the third pumparound of the ADU

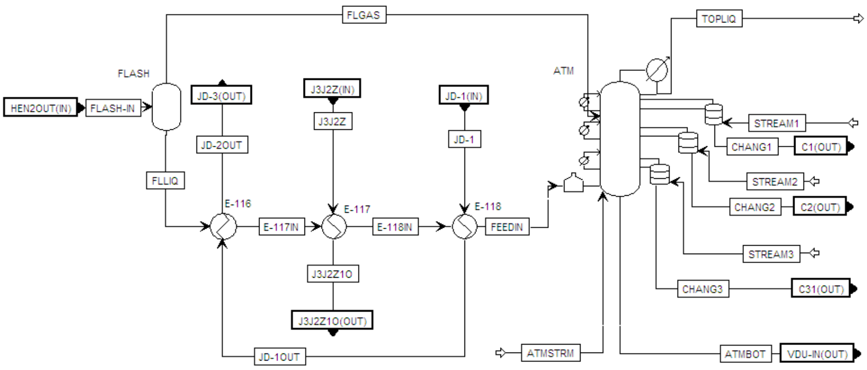

Figure 3: The HEN between the flash and the ADU column (HEN3) and the ADU. JD-1, JD-2 - The residue of the VDU; J3J2Z - The second pumparound of the VDU

In HEN2 (Figure 2), the oil coming out from the desalination unit is divided into two streams heated with heat exchangers of E108, E114, E110, E111 and E112, E113, E115, E109 separately, and then mixed at 220 °C into the flash unit.
In HEN3 (Figure 3), the stream coming out from the bottom of the flash column is heated by the residue of the VDU from the heat exchanger E115, then heated by the second pumparound of the VDU, and then heated by the residue of the bottom of the VDU. The end temperature is 280 °C.

3. Bottleneck identification and elimination

3.1 Process simulation

The refinery process is simulated in Aspen Plus (Aspen Tech, 2011) The Pinch Point is located by Aspen Energy Analyser. Then the structural bottleneck of existing network configuration is indentified, which is the existing exchangers referred to as Pinching the existing network. With Aspen Exchanger Design and Rating (EDR), the performance of each heat exchanger can be rated. With Aspen Plus, the total flowsheet model was built composed of five parts: the mixer of crude oil, HEN1, HEN2, ADU and VDU, as seen in Figure 4. The real boiling point data of the feed crude oil is listed in Table 1. Its gravity is 0.9.

Table 1: The real boiling point data of the feed crude oil

Distillate ratio, V/V	0	5	10	30	50	70	90	95	100
Temperature, °C	59	134	174	299	388	476	588	606	618

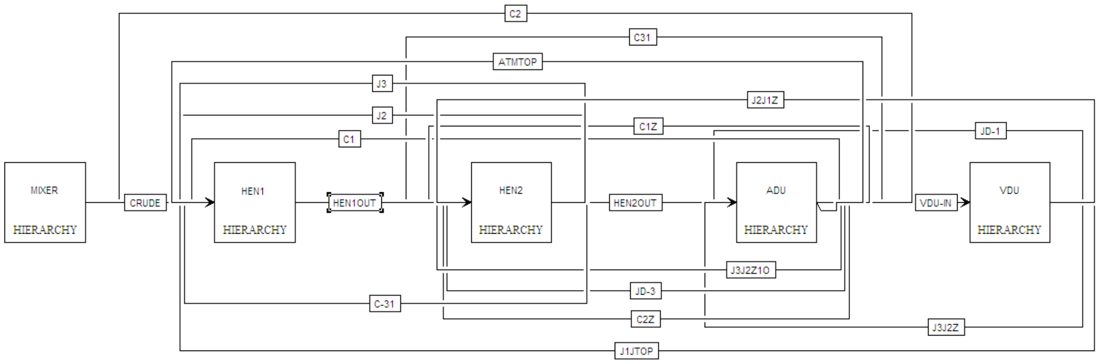

Figure 4: The flowsheet of the total process simulation model

Table 2: The comparison of simulation and operation data

Temperature	Operation (°C)	Simulation(°C)	Difference (%)
HEN1 end	130	133	2.3
HEN2 end	225	220	-2.2
HEN3 end	280	280	0
Top of ADU	112.5	110	-2.3
First side draw of ADU	190	205	7.9
Second side draw of ADU	302.5	319	5.5
Third side draw of ADU	345	360	4.3
Bottom of ADU	365	364	-0.3
Top of VDU	65	60	-7.7
First side draw of VDU	170	163	-4.1
Second side draw of VDU	285	286	0.4
Third side draw of VDU	330	334	1.2
Bottom of VDU	375	374	-0.3

The key results of the simulation are compared with the operation data in Table 2. As a result, the simulation fits well with the operation data.

3.2 Pinch Analysis

Since oil product is on high value viscosity and presents poor heat transfer performance, the ΔT_{min} is set 30 °C. Pinch Analysis was conducted with Aspen Energy Analyzer (Aspen-Tech, 2015) see Figure. 5. The

Pinch temperatures for hot and cold streams are 282 °C and 252 °C. Based on the total flowsheet model, steam information for Pinch Analysis can be extracted. As an example, the streams information in HEN1 is listed in Table 3.

Table 3: The streams information for pinch analysis in HEN1

Streams	Heat exchangers	Inlet temperature, ºC	Outlet temperature, ºC	Heat load, kW
Crude oil	E101/1,2	50	60	628
	E102	60	80	651
	E103	80	91	371
	E104/1,2	91	135	1,569
	E105/1,2	60	95	1,160
	E106	95	109	499
	E107/1,2	109	130	748
Top gas of ADU	E101	110		-628
First side draw of ADU	E102	205	152	-651
Third side draw of ADU	E103	238	112	-371
Second side draw of ADU	E104	319	132	-1,569
First side draw of VDU	E105	163	110	-1,160
Second side draw of VDU	E106	173	120	-499
Third side draw of VDU	E107	246	146	-748

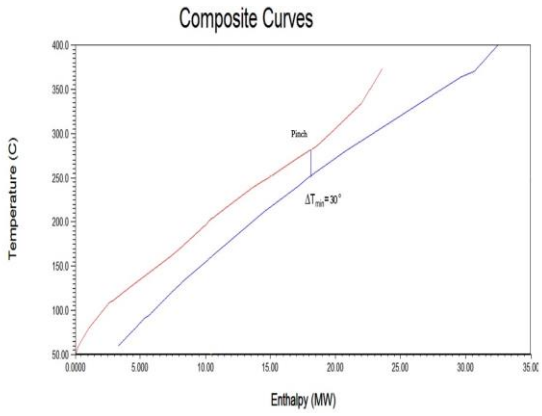

Figure 5: Pinch Analysis

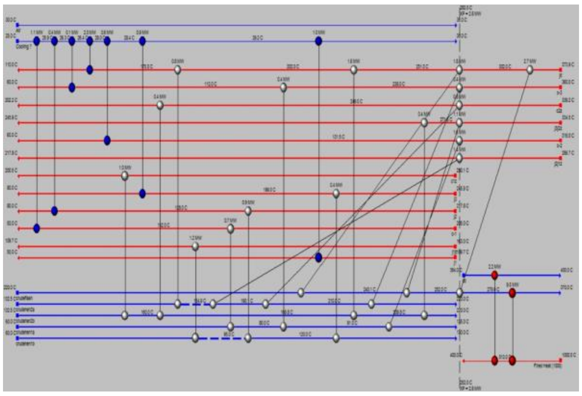

Figure 6: Heat exchanger network

Table 4: Results verification of each heat exchanger

Name of HE	A number of HE	Area ratio (existing/required)	
		63 % load	100 % load
E-102	1	5.13	4.09
E-103	1	1.68	1.21
E-104/1.2	2	1.76	1.41
E-105/1.2	2	1.74	1.49
E-106	1	1.1	0.77
E-107/1.2	2	1.43	1.12
E-108/1.2	2	4.12	3.3
E-109	1	1.75	1.7
E-110/1.2	2	2.23	1.82
E-111	1	1.43	1.43
E-112/1.2	2	6.11	5.21
E-113	1	2.54	2.12
E-114/1.2	2	4.47	3.8
E-115/1.2	2	1.68	1.35

The hot and cold utility targets are 8.945 MW and 3.326 MW. With comparison of the existing usage of hot and cold utilities, 11.730 MW and 6.109 MW, large energy saving potentials are found which are 31.1 % for hot utility and 83.7 % for cold utility. By the simulation of the HEN the Pinch Point is dotted line - Figure 6, it was shown that there are 7 heat exchangers transferring heat cross Pinch and the total amount of heat transfer cross Pinch is 2.8 MW.

Verification of the capacities of the heat exchangers

The Aspen Exchanger Design and Rating (EDR) software (Aspen Tech, 2015) delivers the range of heat exchanger design and rating. With EDR, the performance of each heat exchanger can be verified according the simulated results. As the base process has been presently operated at 63 % load, the simulation at 63 % and 100 % load was made separately. In Table 4, the ratios of real area over required area of each heat exchanger are listed. From these ratios, the bottleneck heat exchanger, i.e. E106, was found because this heat exchanger can satisfy operation only at 63 % load or below.

4. Energy efficiency optimisation

4.1 Rules of optimisation

For the existing process, the optimisation rule should be as bellows.

(1) Use zero or low new investment cost.
(2) Elimination of bottlenecks. Make sure the actual area of heat exchanger satisfy the area requirement–
(3) Joint heat exchanger area optimisation with Pinch Analysis.
(4) Because there is 83.7 % energy saving potential for cold utility, low grade heat would be receiving more attention in optimisation.

4.2 Diagnosis of energy saving opportunities

From the analysis in section 3, some energy saving opportunities were found as below.

(1) The outlet temperature of the VDU residue was 175 ºC, then was cooled down by cooling water. The waste energy in this stream should be considered to utilize in some way.
(2) The temperatures of the third side draw of the ADU (360 °C), the second pumparoud of the ADU (339 °C) and the second side draw of the ADU were high but they were used to heat the heat sinks streams of low temperatures (the cold streams inlet temperatures are 210, 190, 91 °C). A lot of heat was transferred cross Pinch.
(3) The bottom stream of the flash in Figure 3 should be heated with different hot streams.

4.3 Solutions of optimisation

(1) Based on the bottleneck check, the ratio of flow split in Figure 1 was adjusted from 0.5:0.5 to 0.55:0.45, so the E106’s capacity was released first.
(2) Using the outlet stream of the VDU residue (175 °C) to replace the top gas to heat the feed crude oil in Figure 1.
(3) In HEN3, splitting the bottom stream of the flash into two streams with the split ratio as 0.33:0.67, then, using the second side draw of the ADU and the second pumparound of the VDU to heat the 0.33 stream, and using the residue of the VDU to heat the 0.67 stream. Afterwards, the streams were mixed again. The end temperature increased to 288 °C.

The overall optimisation effect is that the end temperature of HEN was increased by/to 8 °C, the amount of Cross Pinch heat transfer was decreased to 2.0 MW (28.6 % of the original amount).

4.4 Verification again of each heat exchanger performance

The optimised process was first simulated with Aspen Plus, and simulation was performed as each heat exchanger’s was rated under 100 % load. The simulated results are listed in Table 5.

5. Results and discussion

Based on process simulation Pinch Analysis and heat exchanger performance verification, the bottleneck of heat exchanger area was diagnosed in refinery plant. By adjusting the ratio of flow split, the bottleneck problem was eliminated and the potential capacity of other related heat exchangers was released as well.

With only one new heat exchanger added and less process adjustment, the end temperature of HEN was increase by 8 °C, the Cross Pinch heat transfer amount was decreased by 28.6 %. The energy efficiency of this process was improved significantly.

According to the Pinch Analysis, there still exists some high energy saving potential in the refinery plant. In future work, the retrofit and energy saving potential still need to be improved supporting potential increased plant capacity and minimising high retrofit capital investment.

Table 5: Heat exchanger verification results after optimisation under 100 % load

Heat exchanger	Amount	Area ratio(real/required)	Note
E-101/1.2	2	1.48	Using the heat exchangers in series instead in parallel before
E-102	1	1.05	Unchanged
E-103	1	2.27	Unchanged
E-104/1.2	2	2.43	Unchanged
E-105/1.2	2	1.06	Unchanged
E-106	1	1.44	Unchanged
E-107/1.2	2	1.48	Unchanged
E-108/1.2	2	3.05	Unchanged
E-109	1	1.1	Unchanged
E-110/1.2	2	1.78	Unchanged
E-111	1	1.44	Unchanged
E-112/1.2	2	3.78	Unchanged
E-113	1	1.1	Unchanged
E-114/1.2	2	4.75	Unchanged
E-115/1.2	2	1.01	Unchanged
E-116/1.2	2	1.99	Unchanged
E-117/1.2	2	2.46	Unchanged
E-118/1.2.3	3	1.3	A new same heat exchanger added

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