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RETROFITTING DESIGN OF HEAT EXCHANGER NETWORKS USING ASPEN-HYSYS: A CASE STUDY OF CRUDE OIL REFINING PROCESS

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ABSTRACT

Energy integration is an important request in many chemical industries, particularly in petroleum refinery, because the cost of energy used in operation represents a significant percentage of the total energy. Retrofit of heat exchanger networks (HENs) is a magical solution for energy saving and minimizing external consumption of cold and hot facilities through several mathematical and graphical methods in recent years, but many of these methods are complementary complex and uneconomic. Redesign approach is developed for the existing heat exchanger network using the ASPEN-HYSYS. Simulation of Middle East Petroleum Refinery has been done then, linked to energy analyzer program to make the necessary retrofit which shows reduction of 28.46 (MW) 29.55%, 14.23 (MW) 37.6% and 14.23 (MW) 24.34% in total utilities, hot utility and cold utility, respectively with 29.55% reduction of CO_2 emissions.

Keywords: *Oil refinery, Heat exchangers network, Retrofit, Heat recovery.*

1. INTRODUCTION

Crude oil distillation systems are the most energy-consuming in chemical plants; it was evaluated that the energy required for such industries is equivalent to 2% of total crude oil processed, which configured in a complex manner that interacts strongly with the associated heat recovery systems [1]. To be specific, first the preheated crude oil must be heated from ambient temperature to approximately 360°C or higher, at that point oil partially vaporizes to let subsequent components, where large fraction of this heat (~60–70%) is recovered from product cooling and heat removing pump-around circuits among the streams of the distillation columns using heat exchangers (HEXs) [2, 3]. Then, the crude oil is fed to a furnace to reach the required processing temperature. The operating cost is increased as the fuel consumed in the furnace increases.

Any recovered energy from the distillation process reduces the consumed utility in the furnace. The energy efficiency of the distillation process can be improved by designing the column to provide opportunities for heat recovery and designing the heat exchanger network to exploit these opportunities. Objectives of retrofit projects in refineries include

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reducing energy consumption (operating cost), increasing production capacity and minimizing heat exchanger area (fixed cost), in order to increase profit [4]. Many graphical and mathematical techniques have been developed for retrofit. Ref. [5] used pinch analysis to retrofit. A new approach for predicting the ΔT_{min} prior to design in retrofit situations was presented and the scope of using the existing area more efficiently was investigated, where the targeting procedure was continued. Ref. [6] provided the synthesis procedure of the targeted network.

A new graphical representation was proposed by [7] to simulate existing preheat trains with all energy equipment to describe typical heat exchanger networks and retrofit the current installations for better energy efficiency where energy recovery is increased by 14% beyond the maximum level achieved for the existing process conditions. Ref. [8] described the development of a knowledge-based system for the selection and preliminary design of equipment for low-grade waste energy recovery in the process industries. Ref. [9] proposed a systematic methodology to reduce utility consumption that is able to tackle the key issues posed using enhancement techniques in HEN retrofit. Ref. [10] presented a new analysis method to retrofit heat exchanger networks which appear savings of approximately 10.5% in the energy demand with minor structural modifications and 60% of the potential energy savings with respect to Pinch Analysis benchmarks. In [11], the authors proposed a new conceptual diagram for super-ambient and sub-ambient temperature process using a diagram, it can be achieved to the concepts such as 1- retrofit of the HEN for energy saving, 2- the best location of hot and cold utility, 3- The actual amount of required hot and cold utility. Ref. [12] introduced a new stepwise approach for the optimal retrofit of heat exchanger networks involving superstructures that embed retrofit alternatives as well as numerical optimization to minimize the project's total annualized cost.

Different methods for achieving cost-effective retrofit were explored by [13]. First, they presented a novel methodology for the application of heat transfer enhancement in HEN retrofit with a fixed network structure considering pressure drop constraints. Heat transfer enhancement is a low-cost option. However, heat transfer enhancement on its own without changes to the network structure provides a limited scope for energy reduction. Second, they presented a new pinch retrofit method that identifies network structural change sequentially to meet the retrofit target. However, the high capital cost associated with installing new heat exchangers, relocating existing exchangers, and increasing the heat transfer area of existing heat exchangers most often leads to uneconomic retrofits. A structured retrofitting approach (SRA) to the near-optimal design of natural gas (NG) pressure reduction stations (PRSs) was presented by [14]. Ref. [15] developed a novel method for the retrofit of Heat Exchanger Networks based on Bridge Retrofit analysis. The method used two new proposed tools: The Heat Surplus-Deficit Table and the Modified Energy Transfer Diagram, which results from the retrofit method. A new procedure for practical retrofit and operational optimization of existing heat exchanger networks, with particular focus on crude oil preheat trains was presented by [16] which, able to consider features particularly relevant to crude oil preheat trains, where achieved a reduction in the furnace duty of 5%, compared to a 2% reduction achieved by the benchmark study.In [17] developed a process simulation model for a modern crude distillation unit with pre-flash in an oil refinery with energy-saving of heating utility about 7.2% and cooling utility saving of 11.1%, with 23.5% CO_2 emissions reduction over the existing design. A new graphical method was presented for the retrofitting design of HENs using a single diagram called Supply-Target Diagram (ST-D) by [18]. This paper presents a new approach based on using ASPEN-HYSYS for energy integration and retrofit design with an illustrative case study to explain the application of the new method for retrofitting design of HEN.

2. MATERIALS AND METHODS

ASPEN-HYSYS version 10.1 has been used; necessary data of temperature, pressure, flow rate and composition of the crude oil are required to simulate an oil refining plant. Crude oil is fed to a variety of ten heat exchangers, where heat is exchanged between the hot streams, that produce from the tower and cold stream (crude oil) then, hot products used in heat exchange are kerosene from side stripper, Gas oil from side stripper, fuel oil from the bottom of the tower, top pump-around and bottom pump-around as demonstrated in Figure 1.

Data extraction in heat integration is the first step carried out, and then the column will be converged. Process data streams are extracted for Pinch Analysis from material and heat balances of the operating crude distillation unit (CDU), which used as input to the Aspen Energy Analyser software platform, where hot and cold streams matches depend on specific heat flow rates for hot and cold streams as displayed in Figure 2. Maximum energy recovery in hot streams and minimum total operating cost (hot utility and cold utility) are obtained through connected streams.

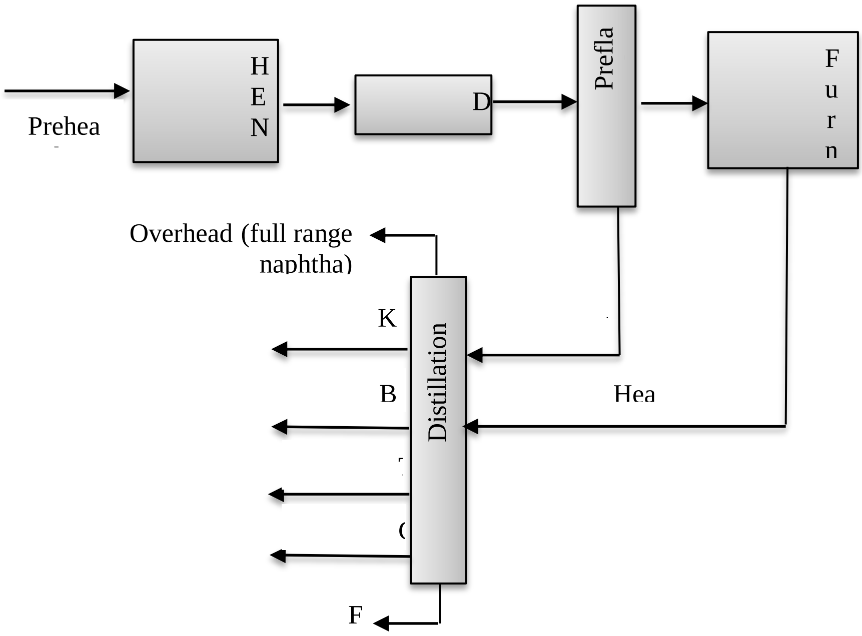

Fig.1. Schematic flow diagram for a refinery unit.

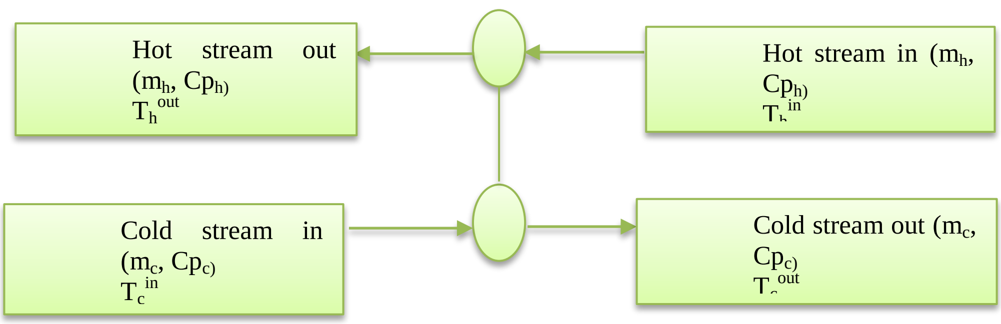

Fig.2. Variables required for the heat exchanger match.

Limitations of this method are that it needs concentration, more accuracy, and some technical skills.

3. ILLUSTRATIVE CASE STUDY

The case studying Middle East Petroleum Refinery. Crude oil is pumped to heat exchangers network at a temperature of 25 ºC and a pressure of 15 atm, the crude temperature is raised to 220 ºC through the HEN, then fed to the furnace to reach a temperature of 343 ºC, and finally pumped to the fractionator which consists of 36 trays then, the product streams are pumped from the tower such as (kerosene, gas oil, fuel oil, top pump-around, and bottom pump-around). Kerosene is drawn from tray 16; top pump-around reflux is drawn from the kerosene draw off to the heat exchanger network above tray 17. Gas oil is drawn from the 23 and 27 trays to feed kerosene side stripper. Bottom pump-around reflux is drawn from the gas oil draw off to the heat exchanger network then returned to the tower above stage number 28. Fuel oil is drawn from the bottom to the heat exchanger section.

The heat exchanger section consists of ten exchangers where the heating side of products are (kerosene, gas oil, and fuel oil) are used to preheat the crude oil as well as the intermediate circulating refluxes of top pump-around which used to preheat crude before desalting, as well as pre-flash and bottom pump-around before pre-flash.

1. Preheating of the crude before desalting is as follows:
    a. Against kerosene in 10E-101
    b. Against fuel oil in 10E-102, 10E-107, 10E-108 and 10E-110
    c. Against top pump-around in 10E103
    d. Against gas oil in 10E-104 and 10E-109

The crude temperature raised in the above section from 25 ºC to 125 ºC, while the temperatures of kerosene, gas oil and fuel oil decreased to 102.5 ºC, 134 ºC, and 130 ºC respectively, then cooled in water coolers to a temperature of 38 ºC, 55 ºC and 93 ºC respectively.

2. Preheating of the crude before pre-flash is as follows:
    a. Against bottom pump-around in 10E-106 and 10E-105

The crude temperature before entering the pre-flash is reached to 150 ºC.

Simulation needs some necessary information such as crude assay and must be aware of the tower details as pump-around and side strippers, where ASPEN HYSYS represents the assay data given to a set of hypothetical pseudo-components plus water and light ends (C5-). The thermodynamic property model is Peng Robinson as a fluid package for the simulation basis. The network is optimized based on minimal energy consumption in the existing process and energy consumption is defined by energy targets by adjusting the network via increasing the area of heat exchangers and the splitting of streams using energy analyzer software to accomplish this task after manual calculations. Data extraction is the first step to be implemented in energy integration, and process data streams are extracted from the material and energy balances of the tower and used as inputs to the Aspen Energy Analyzer software.

4. RESULTS AND DISCUSSIONS

Retrofitting heat exchanger networks using the ASPEN-HYSYS and Energy Analyzer software is presented, the convergence was reached in the simulation model. Figure 3 shows the complete simulation model developed for the current CDU. Figure 4 represents the optimized HEN grid.

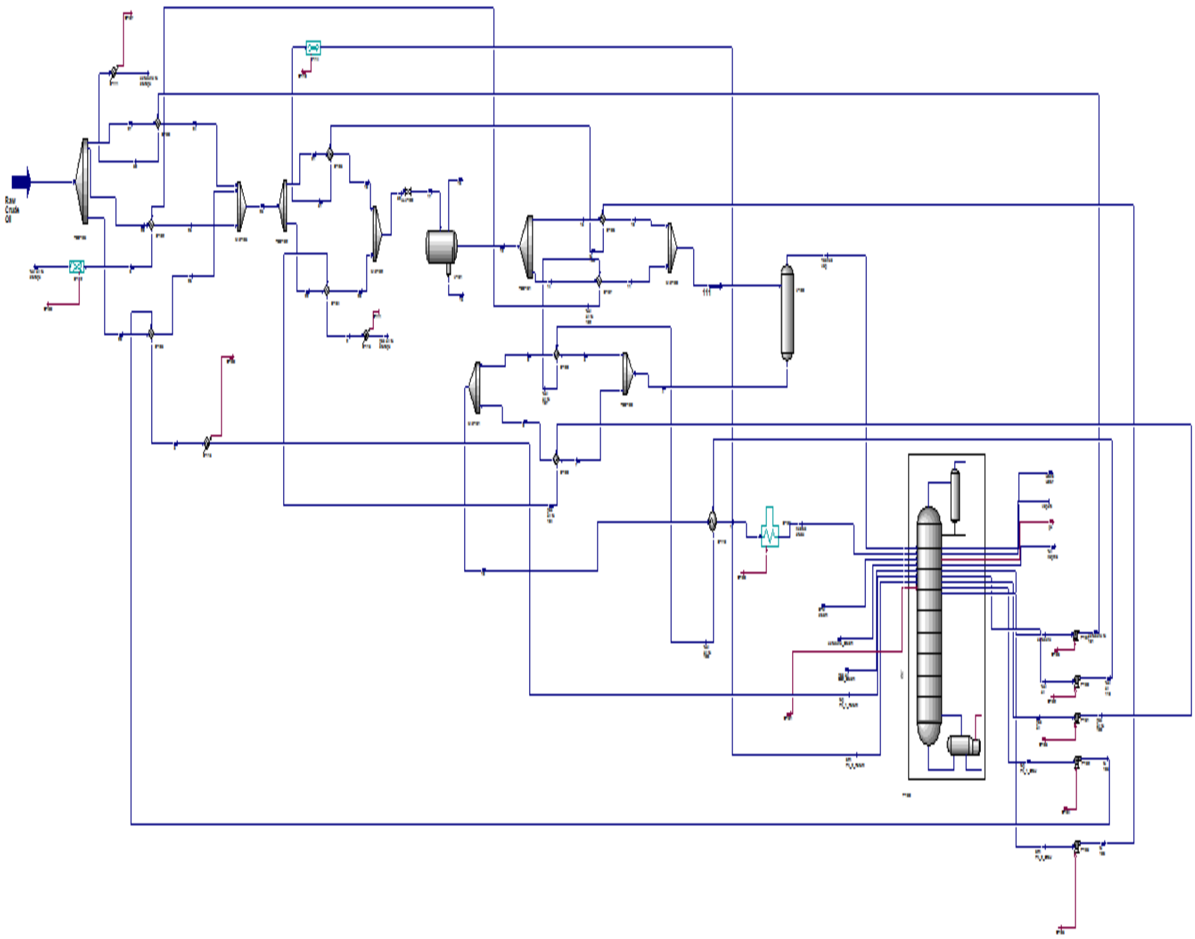

Fig.3. Case study simulation of Middle East CDU.

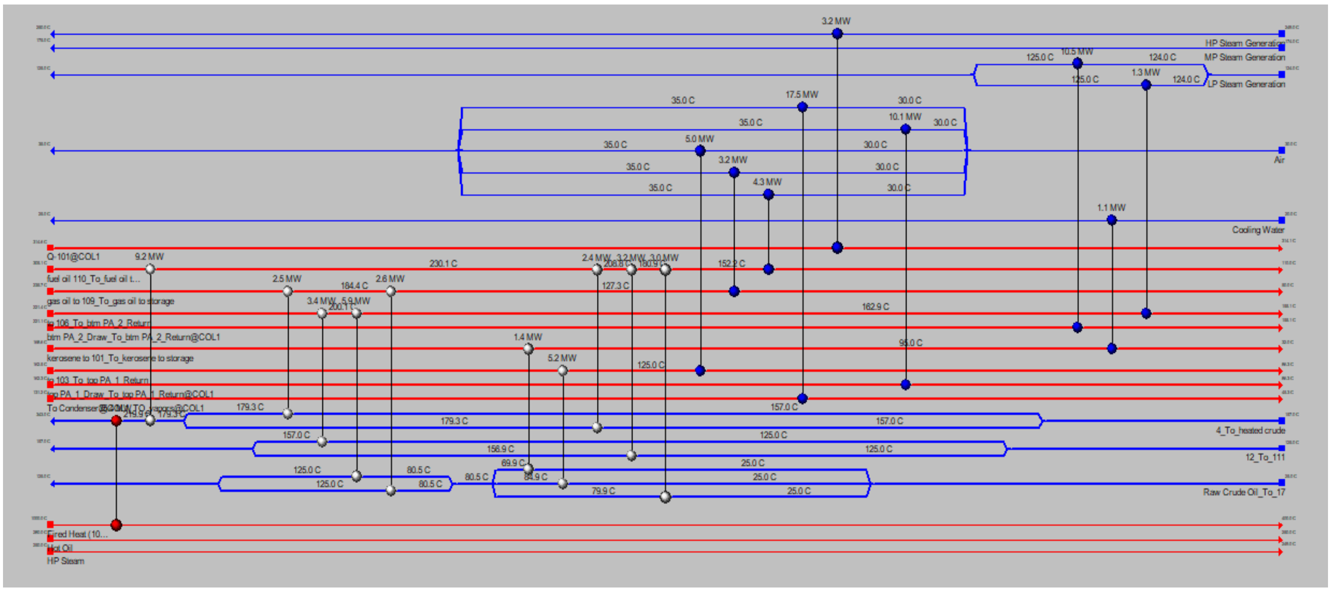

Fig.4. Grid diagram for the retrofit existing case study.

The results summary of activated energy analysis provides energy savings in hot and cold utilities also carbon emissions reduction at minimum temperature approach (ΔT_m) = 10 ºC shown in Table 1 and Figure 4.

Finally, numerous advantageous cost-effective goals could be achieved by this approach, for the sake of the global energy conservation target together with environmental benefits.

Table 1. Available energy savings in hot and cold utilities.

Property	Actual	Target	Available Savings	% of Actual
Total Utilities [MW]	96.29	67.83	28.46	29.55
Heating Utilities [MW]	37.84	23.61	14.23	37.59
Cooling Utilities [MW]	58.45	44.22	14.23	24.34
Carbon Emissions [kg/h]	19370	13650	5724	29.55

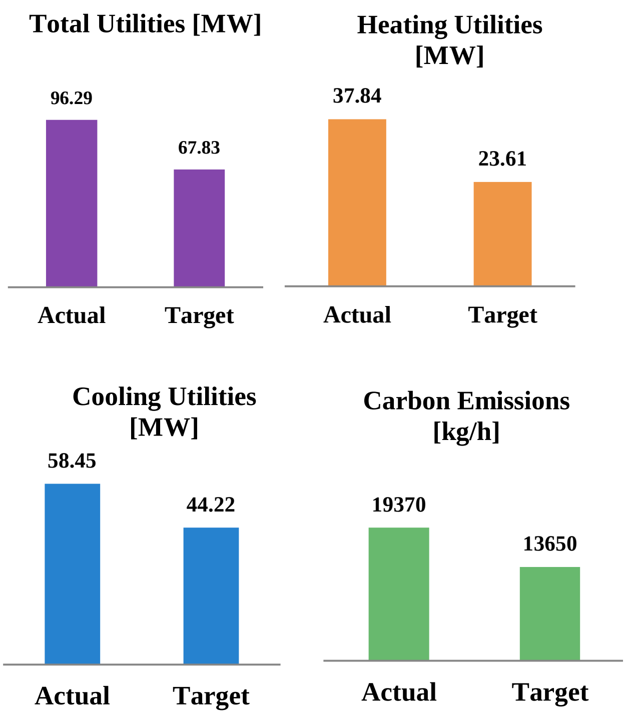

Fig.5. Graphical representation of available energy savings and carbon emissions reduction**.**

5. CONCLUSIONS

This paper presents a new software method for retrofitting heat exchanger networks using the ASPEN-HYSYS program and Energy-Analyzer software. After extracting data from the process flow sheet of the refining plant and applying the previous steps, retrofitting can be explained and achieved, a case study is used to illustrate the applicability of the new software method used for retrofitting design of HENs. Implementation of the new method shows energy savings of 37.59% and 24.34% for the hot and cold utilities, respectively, with a 29.55% reduction of CO_2 emissions.

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Nomenclature

10E: ten heat exchangers
10E-101: heat exchanger no.1
10E-102: heat exchanger no.2
10E-103: heat exchanger no.3
10E-104: heat exchanger no.4
10E-105: heat exchanger no.5
10E-106: heat exchanger no.6
10E-107: heat exchanger no.7
10E-108: heat exchanger no.8
10E-109: heat exchanger no.9
10E-110: heat exchanger no.10

إعادة تصميم شبكات مبادلات الحرارة باستخدام هيسس اسبان: دراسة حالة من عملية إعادة تشكيل زيت الخام

الملخص:

يعتبر تكامل الطاقة مسألة هامة في العديد من الصناعات الكيميائية، ولا سيما في وحدات تقطير النفط الخام بسبب زيادة تكلفة الطاقة وما يرتبط بها من ملوثات. ويركز هذا العمل على اعادة تصميم شبكات المبادل الحراري لانه هو الحل السحري لتوفير الطاقة وتقليل الاستهلاك الخارجي للمرافق الباردة والساخنة إلى أدنى حد من خلال عدة طرق حسابية وبيانية في السنوات الأخيرة، العديد من هذه الأساليب يكمل بعضها الآخر ولكن البعض الاخر معقد وغير اقتصادى. وفي هذا البحث، سنستخدم طريقة برمجية لإعادة تصميم شبكة المبادلات الحرارية الموجودة حيث يستخدم التعديل الجديد برنامج Aspen−HYSYS لمحاكاة محطة تكرير بترول بالشرق الاوسط ثم ربطها ببرنامج Energy−Analyser وتظهر النتائج انخفاض في إجمالي المرافق على النحو التالي:

فى المرافق الساخنة بمقدار 37.6% (14.23 MW)، والباردة بمقدار 24.34% (14.23 MW) كذلك انخفاض في كمية ثاني اكسيد الكربون المنبعثة بمقدار 29.55%(4829 kg/h)