Retrofit of Crude Distillation Unit Using Process Simulation and Process Integration
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Retrofit of Crude Distillation Unit Using Process Simulation and Process Integration

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Abstract

Nowadays energy is a fundamental driver of economic growth and hence is essential to our well being and quality of life. Pinch technology and its recent extensions offer an effective and practical method for designing the HEN for new and retrofit projects. Crude distillation unit is the basic processing step in oil refinery and is a highly energy-intensive process and represents one of the most important areas for energy integration in a refinery. Frequently the heat exchanger network (HEN) of this unit, one of the most complex in oil refinery, need retrofit. The HEN of the Distillation unit considered here consists of a crude preheat-exchanger network and flashing section, atmospheric distillation section, and vacuum distillation section. Because some of the heat exchangers in this unit have a relation to the S.R.G. unit we consider this unit, too. The Case Study to be considered is for a reasonably complex refinery of moderate capacity is Esfahan refinery. In the paper the approach is to produce different acceptable scenarios of retrofit using an integrated instrument: process simulator and process integration software. In this case Aspen Plus environment integrated with Aspen Pinch software from Aspen Tech CO. are used to illustrate the pinch methodology. The incremental area efficiency methodology was used for the targeting stage of the design and the design was carried out using the network pinch method consisting of both a diagnosis and optimization stage. In the diagnosis stage promising designs were generated using Aspen pinch software. The generated design was then optimized to trade-off capital cost and energy savings. The design option were compared and evaluated and the retrofit design suggested. The stream data consists of 21 hot and 10 cold streams and cost and economic data required for the analysis were specified. The existing hot utility consumption of the process was 96962.09 kW. The area efficiency of existing design was 0.5895. The targeting stage using incremental area efficiency sets the minimum approach temperature at 33°C, thereby establishing the scope for potential energy savings. To achieve a practical project, the number of modifications is limited. The modifications include resequencing (changing the order of exchangers on a stream), addition of new heat exchanger units, repiping of existing exchanger and split of stream. We search a lot of option for heat recovery, in best option we can save about 9.2464% of overall energy consumption in furnace.

Keywords: heat integration; crude oil; retrofit; heat exchanger network, Aspen Pinch

1. Introduction

Since the early 1970s, energy conservation has been a major area of research in chemical engineering. Distillation unit is an energy-intensive process and has received significant attention for better energy integration in chemical plants. Several researchers (Naka Y.; Terasita M.; Hayashiguchi S.; Takamatsu T., 1980; Pritchard C.; Halfani M., 1980; Ishida M.; Ohno T., 1983) proposed various methods for identifying energy-saving opportunities in different applications. Distillation unit in a petroleum refinery is a major consumer of energy, of the order of several MJ/s, and represents one of the most important areas for energy integration by revamping existing plants and generating improved designs. Kesler (1988) described several ways of recovering useful energy which include alternative arrangements for top product removal, elimination of intermediate product cooling, and improvement of heat exchange between existing process units and concluded that it is worthwhile to find better opportunities for heat exchange through "process analysis" instead of only optimizing the "exchange of that heat". Dhole and Linhoff (1993) proposed the application of pinch technology to binary distillation column targeting for reducing the overall "utility" demand by generating grand composite curves (GCCs). The GCC helps in identifying the "best" locations for, and the amounts of, heat addition and removal. In conventional oil refining, Crude Distillation Unit (CDU) is the first step of processing enabling separate the crude oil into different fractions depending on the difference of boiling temperatures (gases, naphtha, kerosene, diesel, gasoline, heavy products). The products of the crude oil distillation unit can be either final products or feedstock to other plants for further processing. Depending on the quality of crude oil, different quantities of product streams are obtained. In the middle decades of XXth century, when some of oil refineries operating today where designed, each refinery was considered to process a certain type of product and certain amount of product and heat consumption. In the last two decades, the increase demand for gasoline and other product case to increase capacity of refinery, withal crude oil distillation systems are among the largest energy consumers. This situation is one of the reasons to retrofit oil refineries, to increase CDU flexibility and increase heat recovery. On the other hand, heat and utility consumption and costs should be drastically reduced, the purpose of this paper is to analyze the degree of integration of a CDU and to find retrofit solutions based on process topology modification. The target is to underline opportunities to save energy and to decrease utility consumption. The primary objective of conventional energy analysis of a crude oil distillation unit is to maximize the yield of heat recovery in HEN. In crude oil distillation, the crude oil is preheated in two stages before entering the distillation column (figure 1). The first stage is a heat exchanger network (HEN), where the oil is heated to an intermediate temperature by cooling distillation process streams and recovering the heat from condensers. After words, the crude oil enters a furnace to reach the required processing temperature. The more fuel consumed in the furnace, the large the operating cost. Any heat recovered from the distillation process reduced the utility consumption in the furnace (Gadalla M., Jobson M. and Smith R., 2003). All petroleum distillation processes are fundamentally the same. The process engineer can make no headway in initiating new processes or in truly understanding the flow diagrams of processes until this fact is clearly understood.

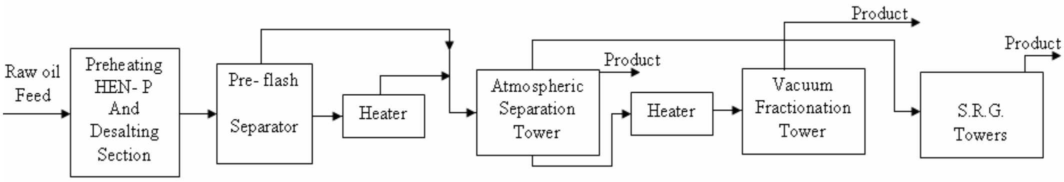

Figure 1 Block diagram of Distillation unit

For economical and environmental reasons and the limited resources of energy, we have to maximize utilization of those energy resources. The distillation unit analyzed in this work is part of refinery complex in Esfahan. The heat exchanger network (HEN) includes the atmospheric and vacuum distillation and S.R.G. unit. Pinch technology analysis and its recent extensions were applied (Shanazari M. M., 2006).
Restrictions concerning different operation parameters are numbers of plates on each zone. The systematic general approach involves three main steps:
Simulation of unit using Aspen PLUS and Aspen B-Jac, analysis and targeting retrofit and finally heat exchanger network retrofit and harmonization with unit.

2. Computer simulation

First stage in simulation is specified the crude oil in assay and blending component. Second stage is defining the thermodynamic property model. A general correlation of the vapor–liquid equilibrium in hydrocarbon mixtures, the thermodynamic model Peng-Robinson with was used in the simulation. The process was simulated using the data supplied by the plant, which included the temperature, pressure and the flow rate of streams. Process simulation of CDU was performed with Aspen Plus simulation environment. All CDU components where considered : HEN, separation columns (pre-flash, atmospheric tower with 3 side strippers and 2 pump-arounds, vacuum distillation tower with 3 pump-arounds, gasoline stabilizer) and two tower in S.R.G. unit and auxiliary equipment and number of trays and other parameters for column units were got from technical data sheet. The simulation was carried out in four stages. First the main column and HEN of pre-heat was simulated followed by the Atmospheric calculation. In this stage and other stage we use a simple heat exchanger. The simulation of the main column converged successfully. For the vacuum section the convergence was more difficult. Thirty, we simulated two column in S.R.G. unit. Finally we connect all stream and place the heat exchanger with details and simulated all stream and equipment. We use Aspen B-jac to simulation details of heat exchanger. The result of simulation have good agreement with available plant data was obtained

3. Data extraction and existing heat exchanger network

The first step in energy integration is data extraction in which stream data is extracted from the process flow sheet simulated. Stream data consists of source and target temperatures, flow rates and enthalpies of cold and hot process streams. We import stream data, heat exchanger network and information of heat exchanger from Aspen Plus and Aspen B-jac in to Aspen Pinch. Stream data extracted for the current case study consists of 21 hot streams that require cooling and 10 cold streams to be heated.

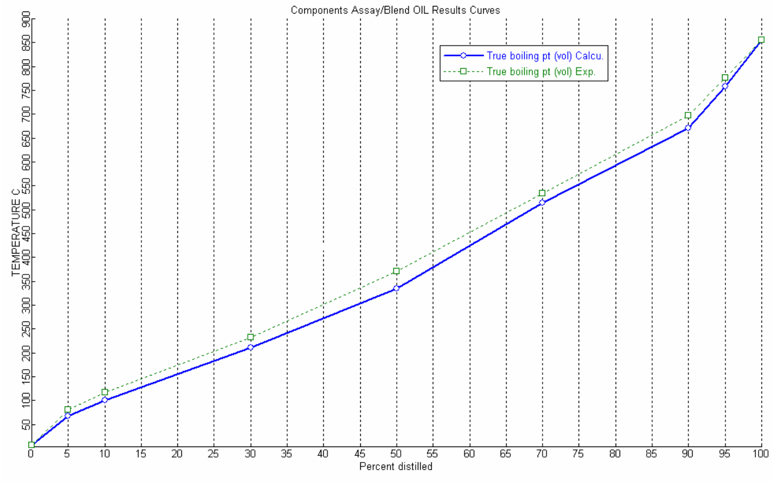

Figure 2 Compare of TBP, feed entries (---) to refinery and calculation

The grid diagram includes 15 heat exchangers, 12 coolers using cooling water, and three heaters using natural gas and flue gases. The energy consumption of the existing HEN was taken from the Aspen simulation using the extracted data. The existing process requires a total hot utility load of 96962.09 Kw, and a total cold utility of 26350.5Kw. The Total existing area for the heat exchanger network energy is 12677.1 m^2. Although many of the heat exchangers were 1-2 shell and tube heat exchanger i.e. single shell two pass model, the analysis calculated HEN area using the A1-1 (counter-current) as this gave the ideal minimum area for a heat exchanger match (Gadalla M., Jobson M. and Smith R., 2003).

4. Cost data

The correct cost data is essential for a successful retrofit project. The cost needs to annualize to study the economics in terms of yearly saving and payback time. The basic economic data consists of yearly operating years (0.96), plant life (3.5 years), and interest rate (14%). The heating utilities currently include flue gas, whilst the cold utilities include water cooling. The average costs of these utilities were as follows:

CW (Cooling water)	1.51630e-05 US$/Kg
TW (Cooling water)	1.51630e-05 US$/Kg
Flue Gas	81.59 US$/1000 scft
Natural Gas	(0.163US$/$m^3$)

The resulting annualized costs then as follows:

Cooling water	195274.27	US$/yr
Flue Gas	10274211.46	US$/yr
Annualized energy cost	10469485.73	US$/yr

The cooling water was supplied at 29.4°C and returned at 49°C; condensed water was supplied at 68°C and returned at 77°C. The capital cost of heat exchanger followed recommendation of Ref (Shanazari M. M. , 2006):

$$\text{HE cost} = A + B\,(\text{area})^{C} \qquad (1)$$

Where A represents a fixed cost of installation independent of the area, B the exchanger cost per unit area and which also accounts carbon steel (cs) of construction.

$Cost = 2435.17*Area^{0.837}$

5. Study of HEN and Determination of ΔT_{min} for retrofit design

For retrofit design, the area efficiency, α, of an existing HEN is important. The area efficiency measures the performance of the existing design compared to the ideal target of the process data. The closer the existing HEN is to the ideal curve in an energy area plot the better the performance, as this indicates that the design is utilizing the installed area efficiently. If there is poor correspondence between the two than there exists inefficient use of energy recovery, which implies that there is a large scope for improvement of the existing design. There are two area efficiency concepts, namely constant and incremental. The constant α method states that the network would use the additional area as efficiently as the existing network over the full energy span. This is a conservative approach, which give good targets for networks with high α. For low α values, the incremental α approach is used assuming α value of unity for the additional area. The existing HEN has an area efficiency of 0.5895. The investment cost for additional area and energy costs can be calculated for different energy recoveries ahead of design. This provides information about the economics of the process so we are able to set targets for the retrofit of the HEN. Payback and investment are the determining factors for the retrofit of the HEN.

Simplifying assumptions used for the calculation of energy and capital costs are:

1. The investment cost considers only the cost of extra area required to achieve the energy recovery target. No piping or other costs are considered.
2. The average size of the heat exchanger shell is calculated from the existing HEN area and number of shells.
3. The existing average area per shell in the HEN is the same for the added area.
4. The investment cost for installation of heat exchanger considers equal a purchase of Heat exchanger.

The investment cost, and amount of saving and ΔT_{min} calculated in some of the payback, best of result show up in table (1). Composite curve of Distillation unit with optimum ΔT_{min} and network of HEN shows in fig (4) and (5) prospectively.

Table 1 Investment and saving in optimal ΔTmin

Payout	432.0000 day
ΔTmin	33.01606 C
New area required	4020.234 m2
Money savings	3368354. US$/y
Investment	4000464. US$
Energy target at ΔTmin	81346.77 kW
Area target at ΔTmin	7761.226 m2

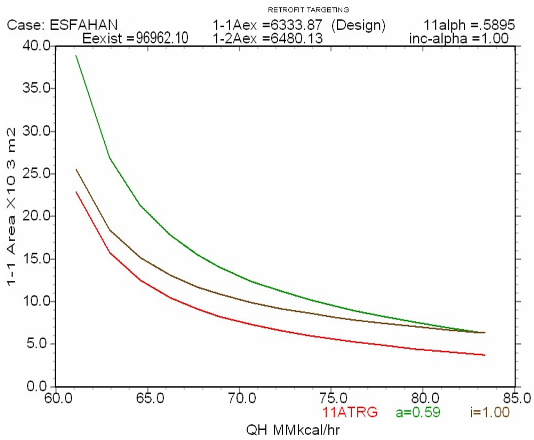

Figure 3 Energy area plot of HEN

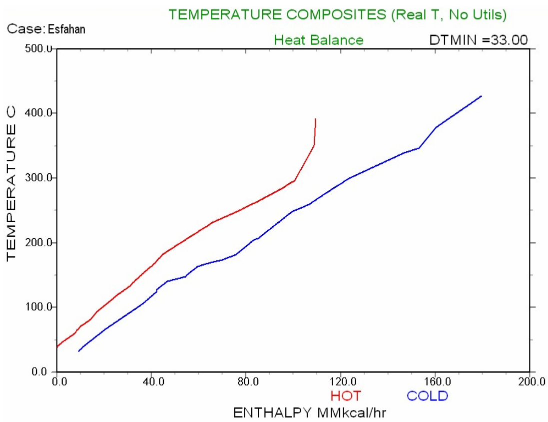

Figure 4 Composite curve with optimum ΔTmin

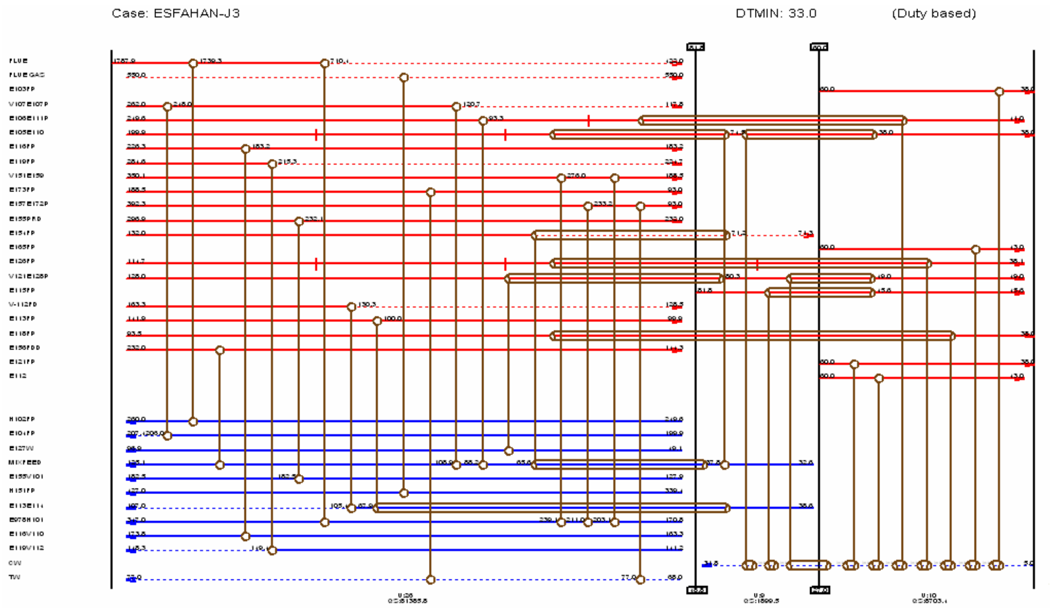

Figure 5 Grid diagram of existing HEN of Distillation Unit with optimum ΔTmin

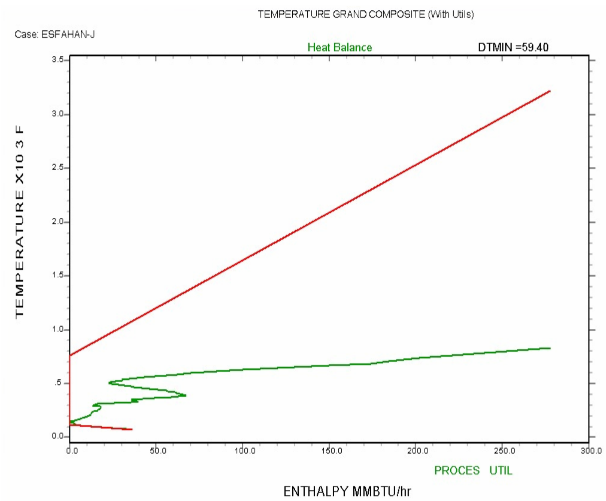

Figure 6 Grand composite curve without the steam generation

6. Network pinch method retrofit

At the targeting stage, the potential for energy saving is set by the economics of the process. The existing is analyzed to determine where it violates the set targets, by determining the heat exchanger units that transfer heat across pinch. The optimum energy recovery corresponds to a minimum approach temperature of 33°C, and the minimum energy consumption of the process is given by the composite curves. If the energy recovery of the existing HEN is constrained by a bottleneck in the process this is known as the network pinch (Asante N.D., 1996). Overcoming this bottleneck, thereby increasing the energy recovery, can be overcome by topology changes. In the diagnosis stage, searches for topology changes, which increase energy saving by shifting heat from below to above the network pinch, are carried out. The modifications considered include resequencing, repiping and the addition of new heat exchangers. Split modifications are implemented to see a maximum heat recovery too.

We study a lot of option of modification contain: Resequence, repiping, add of a new heat exchanger and split of stream, the result of this study shows that only option of add a new heat exchanger has recovery energy in first option and another option have negative recovery so in search for maximum heat recovery the option is started with add a new heat exchanger. Fig (7) shows the strategic for heat recovery in add new exchanger. In each option we reconsider new networks with new Aspen B-jac file and simulate and research for heat recovery in aspen pinch environmental.

The best design options are identified at this stage. These can be optimized to find the optimum network topology. The addition area required for the existing exchangers can be reduced by carrying out heat transfer enhancement technique analysis (Wadekar V., Stehlik P., 2000; Zhu X.X., Zanfir M., Klemes J., 2000).

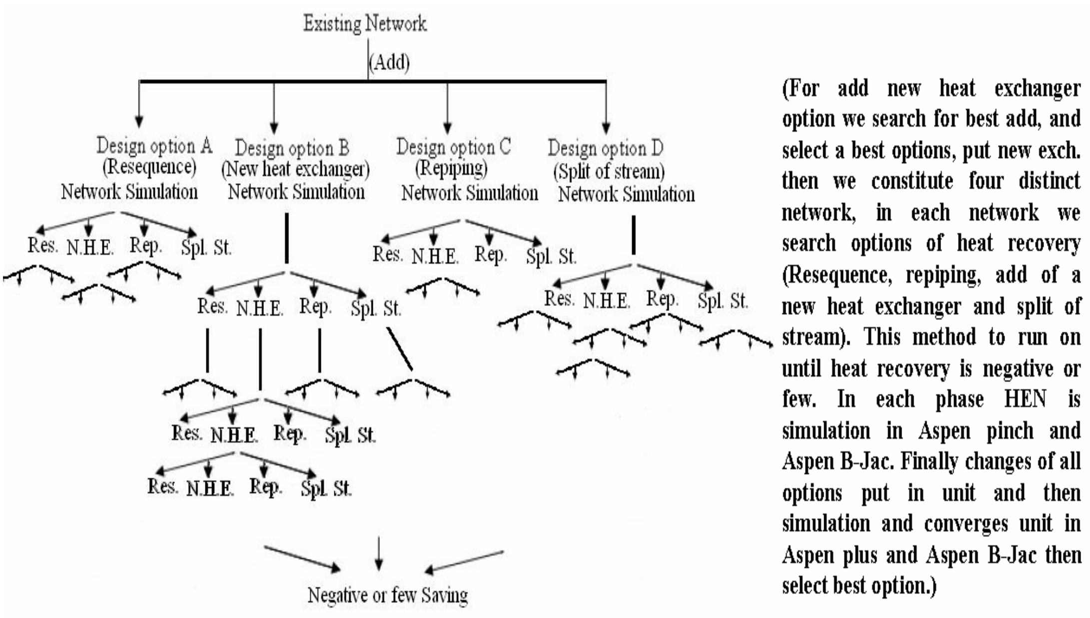

Figure 7 Strategic for heat recovery in add new exchanger

7. Conclusions

The use of Pinch Technology in a Site Assessment provides a means of evaluating the interaction between the process units and the utility system from an overall site perspective. In this paper we propose an integrated analysis for the CDU, including S.R.G. unit and HEN. Data from operating plant was used to simulate in ASPEN PLUS the CDU and use of Aspen B-Jac for simulation of heat exchanger with details. Automatic data transfer to process integration software Aspen Pinch. Targets for hot and utilities show that the CDU has high utility consumption. The optimum approach temperature for the retrofit design it was 33°C. The area efficiency, α, of the existing network was 0.5895 which indicated that the existing design used the area reasonably efficiently. Some solutions are proposed. In all the design option we have a few changes to existing plant. Search for the heat recovery, we take notice resequencing , repiping and Split have negative recovery in first option and the search continued with addition of new exchangers By add new exchanger, we move heat from below to above the pinch and hence increase energy recovery and reduce cost. The comparison of results of design options together with the existing design and hot utility load, we regard, the best retrofit option have the 9.2464% saving of overall energy consumption in furnace and also the smallest extra area required which is selected for retrofit. Result of change shows in fig (8).

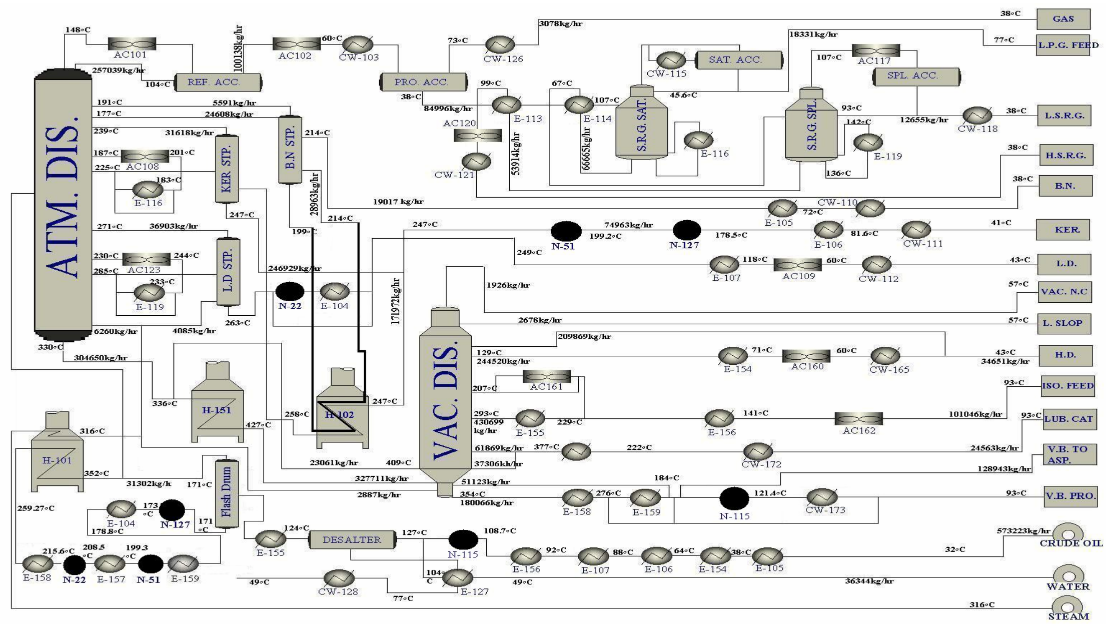

Figure 8 Distillation units with proposed changes (● 4 New Heat exchanger)

References

Asante N.D., *Automated and interactive retrofit design of practical heat exchanger network*, Ph.D. Thesis, UMIST, UK (1996).

Aspen Engineering Suite 11.1, Aspen Technology, Inc., Ten Canal Park, Cambridge, MA 02141-2201, USA, October 2001

Dhole, V. R.; Linnhoff, B. (1993), *Distillation Column Target, Computer*. Chem. Eng., 17 (5/6), 549.
Ishida, M.; Ohno, T. (1983), *Application of Energy-Direction Factor Diagram for Exergy Analysis of a Distillation Column*, J. Chem. Eng. Jpn., 16 (4), 281.
Kesler, A. G. (1988), *Retrofitting Refinery and Petrochemical Plants*, Chem. Eng. Prog. June, 59. M.Gadalla, M. Jobson and R. Smith (2003*), Optimization of Existing Heat- Integrated Refinery Distillation Systems*, IchemE, Vol 81, Part A, January.
Naka, Y.; Terasita, M.; Hayashiguchi, S.; Takamatsu, T. (1980), *An intermediate Heating and Cooling ethod for a Distillation Column*, J. Chem. Eng. Jpn, 13 (2), 123.
Pritchard, C.; Halfani, M. (1980), *Heat Economy in the Tanzanian Oil Refinery*, Chem. Eng., Dec, 747.
Shanazari M. M. (2006), *HEN Retrofit and design of Distillation Unit of Esfahan Refinery using Pinch technology*, M.Sc. Dissertation, USB, Zahedan.
Wadekar V., Stehlik P. (2000), *Different strategies to improve industrial heat exchanger*. PRES'2000, Prague, H6.1.
Zhu X.X., Zanfir M., Klemes J. (2000), *Heat transfer enhancement for heat exchanger network retrofit*, Heat Transfer Engng. Vol 21, 7- 18.