HEN Retrofit Solution in an AVCODU by Using Process Heat Integration and Process Simulation Methodologies

GHEORGHE BUMBAC[1]*, MUHAMMAD BURHAN UD-DIN[2]*
[1] University Politehnica of Bucharest, Department of Chemical Engineering,, 1 Polizu Str., 011061, Bucharest, Romania
[2]PAEC, K-Block, P.O. Box 1114, Islamabad, Pakistan

The recent energy and environmental issues urge the need to revamp the existing plants in order to minimize the energy requirements and consequently decreases environmental pollution. This paper represents an application of methods for performance analysis of existing processes and finding of retrofit solutions through the application of techniques for process modeling and simulation and process integration. An in atmospheric and in vacuum conditions crude oil distillation unit (AVCODU) from a typical refinery [Kaes G., 2002] is considered as the case study for above mentioned scope of this work. Various Heat exchanger Networks (HENs) has been developed by applying the process heat integration (HI) pinch approach. However, it has been estimated that 16.2 MW hot utility and 16.22 MW of cold utility can be saved in a year by revamping of pre-heating train of AVCODU. Furthermore, capital cost of revamping can be recovered within 2.3 year of plant operation.

Keywords: oil atmospheric/vacuum distillation; heat integration, pinch points methodology, capital/operating costs, heat exchanger network (HEN) topology, find a HEN retrofit candidate, adopt a HEN retrofit solution from the candidates group

One of the major energy demands within AVCODU process in refineries comes from the need to heat the crude feedstock upstream of the crude distillation column to obtain the desired flash temperatures and adequate characteristics and yield of distillation products. Energy requirement can be minimized by adopting process scheme ensuring an advanced heat recovery inside that process. Process modeling, simulation and HI techniques help process engineers for finding design solution to make process in refinery to be more efficient in energy use. Conventionally, the HI was achieved by experience of operation and engineering insights. The best design was chosen by the set of case studies. However, in late 70 and early 80, the development of pinch analysis (PA) methodology [Linnhoff et al, 1978] brought revolution in the field of HI. PA is systematic approach based on the first and second law of thermodynamic. In PA, thermodynamic feasible energy targets (based on fixed process condition) are established ahead of design. However, perfect HI may limit the control of distillation units and increase the fouling in heat exchanger due to low critical velocity of process streams. Therefore, PA is not the only solution to achieve the best heat exchanger network (HEN). In engineering practice HEN design is obtained as an optimal solution of applying simultaneously techniques in pinch approach, in synthesis of process plant control strategy and in adjusted process streams velocity above the critical velocity in the flowing spaces of heat exchangers.

Problem description and methodology

Process modeling and simulation of existing plant is the first step of procedure to finding solution for pre-heating train revamp. Process data is extracted by process modeling and simulation or/and from indication of instrumentation serving to process control of the existing plant. The said data is then used for setting the performance targets by using pinch approach. Then Process modifications, network design, design evolution and new process simulation are the next steps to develop the best energy efficient pre-heating train.

Case study

The refinery's **AVCODU** is processing 85000 barrels / day light Arabian crude oil. Process configuration, given in figure 1, consists of atmospheric, vacuum and naphtha stabilizer distillation columns along with pre-heating train and flue gas furnaces.

Pre-heating train configuration, given in figure 2 had eleven shell and tube heat exchangers that heated the crude oil by exchanging heat with product streams from distillation columns (overhead gases of atmospheric column, kerosene, diesel, Kerosene P/A, Diesel P/A, Heavy Vacuum Gas Oil (HVGO) and residue of vacuum column). The said HEN ensure the increasing of the crude oil temperature from 38^oC (approx) to 245.9^oC (approx) in the existing process plant.

Four types of utilities are used in the existing plant. Two hot utilities i.e. medium steam (187^oC) and flue gas while two cold utilities i.e. cooled air and cooling water are used in the existing process plant. Flue gas furnace is used to heat the crude oil (from 245.9 to 343.3^oC) and topped crude oil (bottom product of the atmospheric distillation column, from 330^oC to 397.2^oC) while the bottom of naphtha stabilizer distillation column is heated in the reboiler by using steam. Cooled air (temperature range: 45^oC to 55^oC) and cooling water (temperature range: 25^oC to 35^oC) are used to cool the kerosene, diesel and HVGO products to room temperature.

The refinery's AVCODU products are: gases, light naphtha (unstable), heavy naphtha, kerosene, diesel, atmospheric gas oil (AGO) and topped crude as separate streams leaving the atmospheric distillation column while Vacuum system gases, Light vacuum gas oil (LVGO), heavy vacuum gas oil and vacuum residue are obtained from vacuum distillation column.

* email: g_bumbac@chim.upb.ro, Tel. + 4021-402 3867; burhanietian@yahoo.com

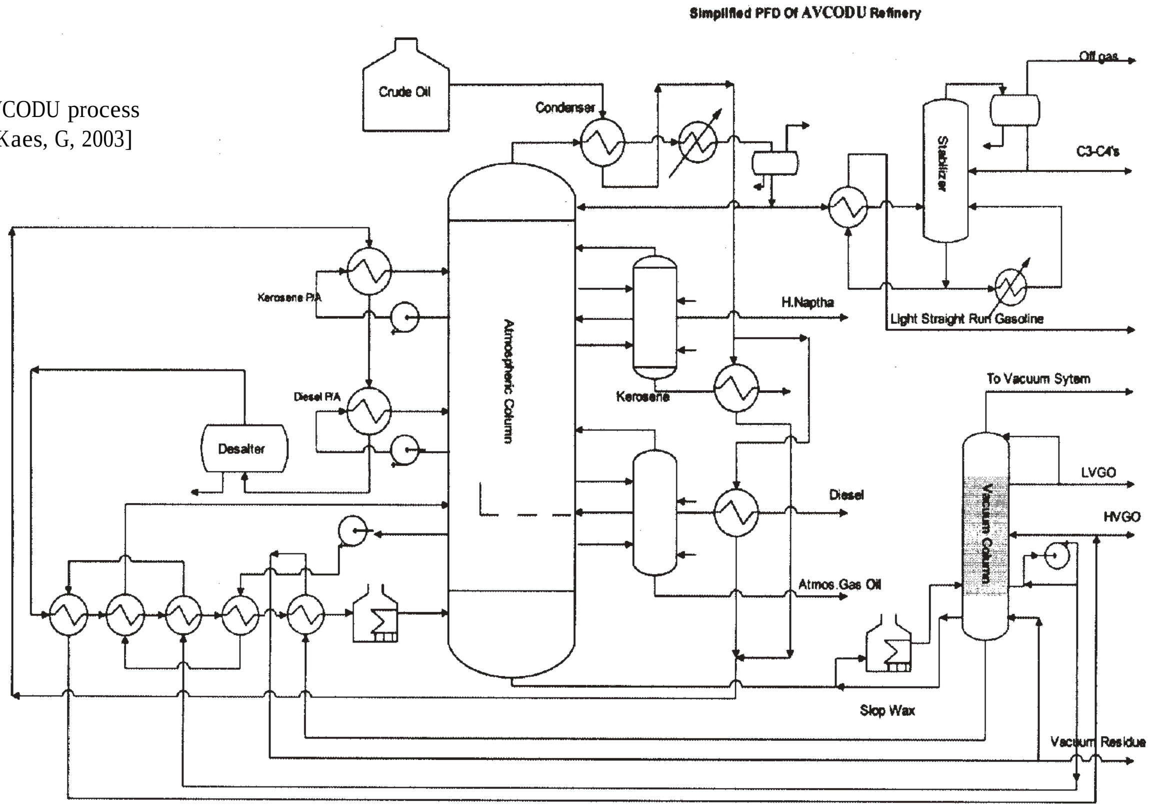


Fig. 1. AVCODU process structure [Kaes, G, 2003]

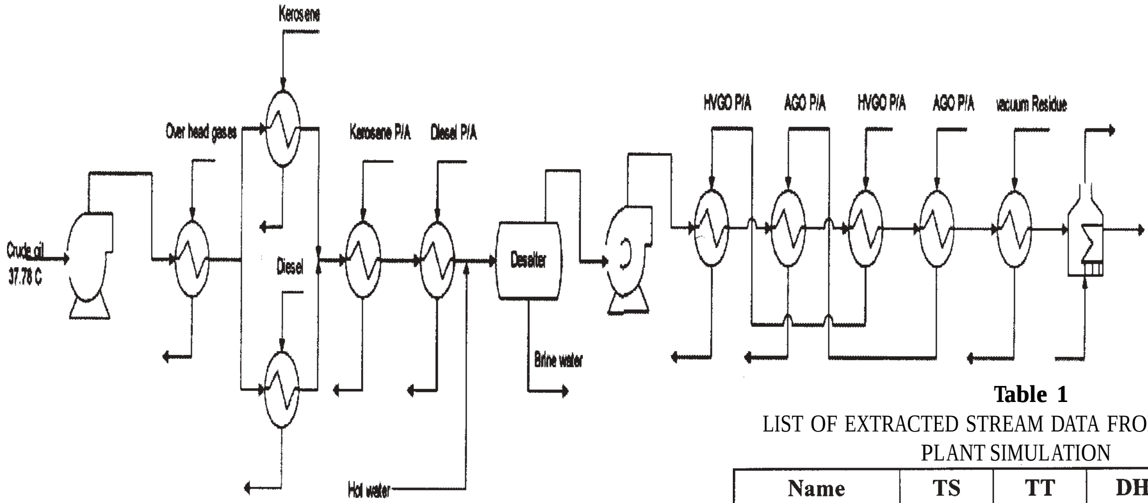


Fig. 2. AVCODU process preheating train structure

ASPEN HYSYS 7.3 version has been used to model and simulate the above said process plant. Crude properties and product cut point temperature are evaluated by the chemistry lab data and described in the above mentioned literature source [Kaes, R., G., 2002]. HYSYS models for *Distillation column* and for *Absorber* were used to simulate processes of the atmospheric and vacuum distillation column respectively. Furnace is modeled as the HYSYS model named *heater* and desalter as the *three phases separator*.

After successful modeling and simulation of AVCODU process, the data of pre-heating train are extracted and the analysis of the efficiency of using heat inside the process was realized.

Process streams list, including streams from crude oil preheating train of AVCODU is presented in table 1.

Results of the steady state simulation informed us that in the existing AVCODU process are used 52.4 MW and 35.7 MW as hot and respectively cold utility. The minimum approach temperature (DTmin) in the heat transfer apparatus from the existing HEN of AVCODU process are as follows:

- process stream vs. process stream changing heat at minimum approach temperature of 38.8 °C

Table 1
LIST OF EXTRACTED STREAM DATA FROM THE EXISTING PLANT SIMULATION

Name	TS °C	TT °C	DH kW	CP kW/°C
Vacuum residue	359.9	314	5631	122.68
AGO PA	311.6	215.3	7990	82.97
HVGO	273.2	191.7	23740	291.29
Diesel PA	263.5	205.3	10060	172.85
Diesel	249.7	40	9026	43.04
Kerosene PA	202.7	158.4	8617	194.51
HVGO Product	191.7	40	8044.4	53.03
Kerosene	183.6	40	6654.2	46.34
Over head gas	95.5	80	4413	284.71
Condenser 1	80	45	19577	559.34
Condenser 2	55.5	48	549.3	73.24
Reboiler	125.4	135.6	2082	204.12
Crude oil	37.8	343.3	118916	389.25

- utility stream vs. process stream changing heat at minimum approach temperature of 13.4°C
- overall Minimum Approach Temperature:13.4 °C

Composite and Grand composite curves (fig. 3) are developed by the help of HI software SPRINT (from Department of Process Integration of University of Manchester Institute of Science and Technology - UK) using Overall Minimum Approach Temperature of 13.4 °C.

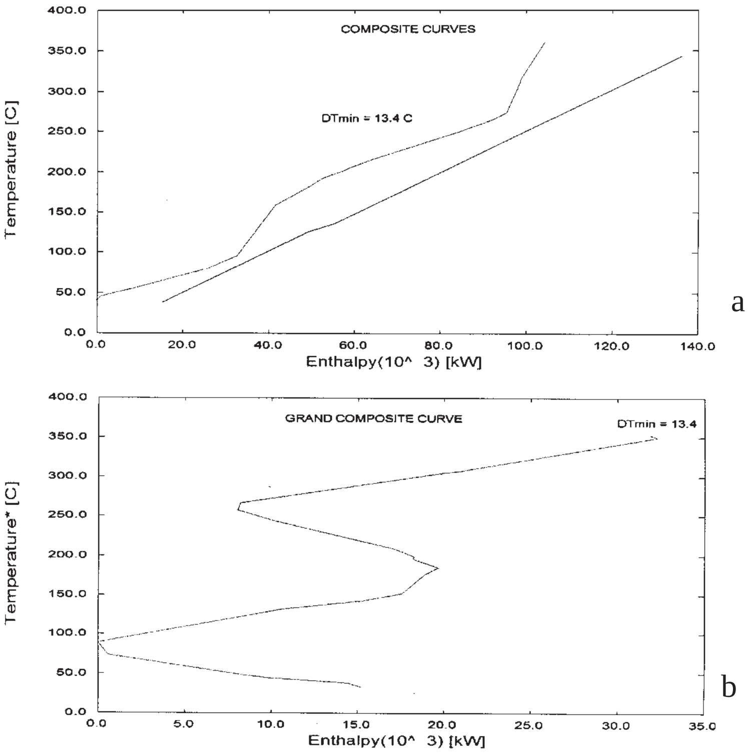


Fig.3. Composite Curves (a) and Grand Composite Curves (b)

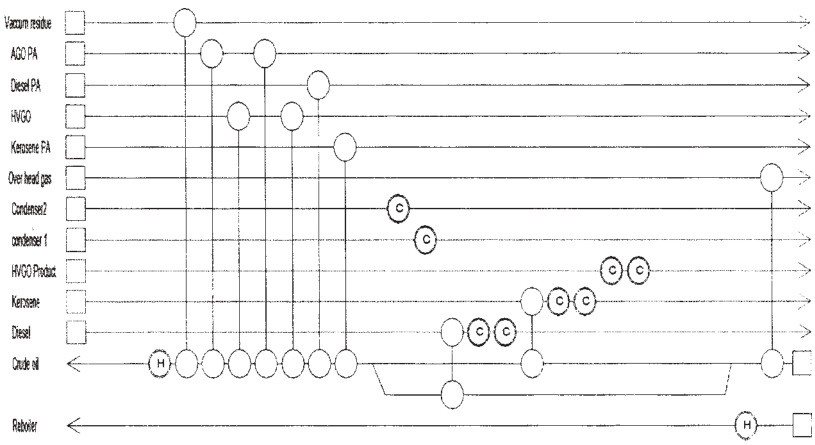
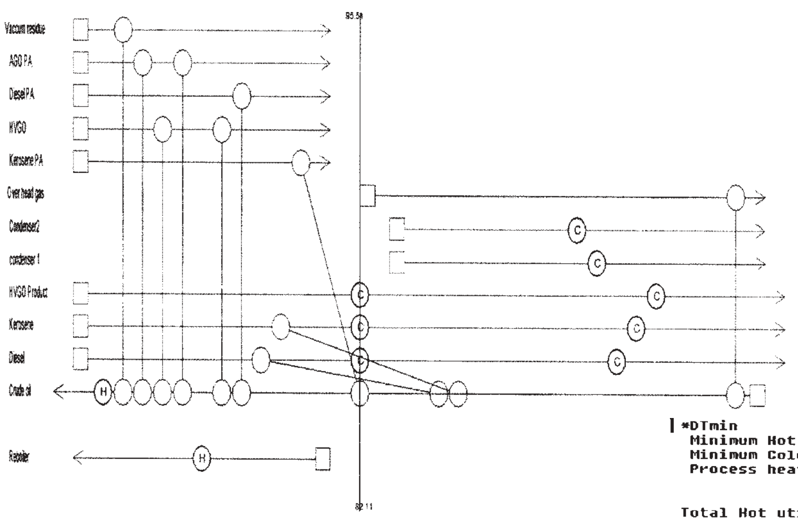


Fig. 4. HEN topology of existing plant (“H” are heaters, “C” are coolers and the rest are process heat exchangers)




```
*DTmin                      =     13.4000      [C]
 Minimum Hot Utility        =     31886.2      [kW]
 Minimum Cold Utility       =     15190.1      [kW]
 Process heat recovery=           89111.8      [kW]

Total Hot utility     =   52442.0      [kW]
Total Cold utility    =   35745.9      [kW]
Total Cross Pinch heat transfer =  20555.8      [kW]

Pinch Information
--------------------------------------------------------------------
  1 Process     95.51 -    82.11  [C]   Total XP   20555.8      [kW]
--------------------------------------------------------------------

Exchanger cross pinch heat transfer
--------------------------------------------------------------------
  2    2 [<Unnamed>    ]   5100.80       [kW]         Pinch Number   1
  3    3 [<Unnamed>    ]   3056.00       [kW]         Pinch Number   1
  4    4 [<Unnamed>    ]   5049.00       [kW]         Pinch Number   1
  5    5 [<Unnamed>    ]   4736.34       [kW]         Pinch Number   1
 14   31 [<Unnamed>    ]   1025.95       [kW]         Pinch Number   1
 16   41 [<Unnamed>    ]   1587.71       [kW]         Pinch Number   1
--------------------------------------------------------------------
Total exchanger cross pinch heat flow =   20555.8      [kW]

There is no cross pinch mixing
```

Fig. 5. Heat transfer across the pinch in the existing network (graphical representation and data report)

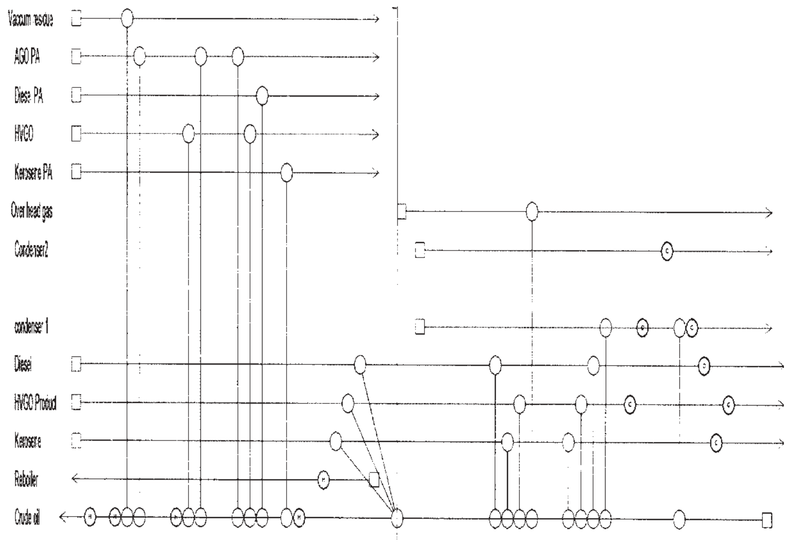


Fig. 6. New HEN topology as Grid Diagram

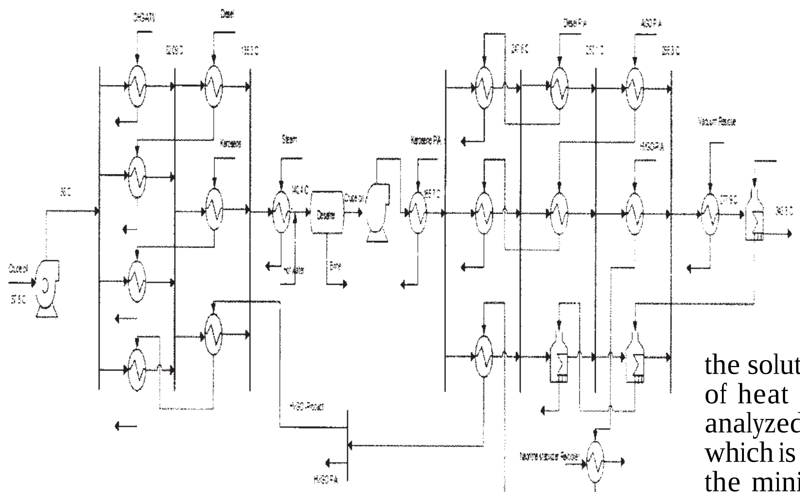


Fig. 7. New topology proposed for AVCODU process (ΔTmin=10.8°C)

These curves point out 31.9 MW of hot and 15.2 MW of cold utilities are the minimum demands of AVCODU process for ΔTmin=13.4°C. The mentioned ΔTmin was identified from the Grid Diagram of the existing HEN (fig.4.).

Consequently, there is a good potential for retrofit of existing HEN in order to save operating cost by modifying its topology and adding more heat transfer area. Inefficient use of heat in the existing HEN at a ΔTmin=13.4°C, is due to defective transfer across the pinch in some of the network heat exchangers (fig.5.).

As can be seen the six heat exchange devices that transfer heat across the pinch contributes to a significant heat loss of about 20 MW from the theoretical target corresponding to those of ΔTmin = 13.4°C.

Using Tjoe and Linnhoff (1986) method, costs data and a maximum duration for the investment payback of 2.5 years revealed that a new Overall Minimum Approach Temperature ΔTmin, is in range of 10 to 11°C as it is more favorable from economic point of view in our search for the solution of the problem. Therefore, several structures of heat exchanger network (HEN) are developed and analyzed by obeying the PA principle. The HEN topology, which is more attractive from economic point of view, with the minimum approach temperature 10.8 °C has been considered the best solution for pre-heating train. Configuration of the new HEN in the Grid Diagram is given in figure 6. Only the best (as economic performance) candidate structure was considered and it is presented in this research work (fig. 7).

The new configuration of HEN topology for AVCODU was performed by adding heat exchange area (by adding new heat exchange devices, or by increasing the heat exchange area of existing devices). Compared to the configuration given in figure 6, in final form rendered in figure 7 heat exchange apparatus with small thermal load were excluded, and the radiation and convection furnace zones were represented by a single icon (the furnace).

AVCODU process with modified HEN was again modeled and simulated. It has been analyzed that steady state simulation with the modified HEN of *AVCODU* process considered uses only 49.8MW of hot utilities instead of 52.44 MW while 19.52 MW of cold utility is used instead of 35.75 MW (table 2). In that way, the annual

Table 2
UTILITY CHARACTERISTICS AND SPECIFIC CONSUMPTION IN THE NEW HEN OF AVCODU PROCESS

nal Energy Target for the given study case				
	Utility Name	***Supply Temp*** °C	***Target Temp*** °C	***Load*** *kW*
1	*Flue gases*	*1200*	*260*	*48074.6*
2	*Saturated Steam*	*187*	*187*	*1752.4*
3	*Cooled air*	*45.00*	*55.00*	*0.0000*
4	*Cooling water*	*25.00*	*35.00*	*19525.6*

Table 3
OPERATING COST AND COST SAVINGS ESTIMATED

Annual Savings in utilities bill of modified plant			
Utility	Existing plant US$/year	Modified plant US$/year	Saving US$/year
Flue gases	4789722	3599819	1189904
Steam	108264	91127	17138
Cool air	147656	0	147656
Cooling water	169228	146207	23021
Total	5,214,870	3,837,153	1,377,719

Table 4
PAYBACK PERIOD ESTIMATED

	Capital cost required (US$)	Annual saving (US$)	Time to recover capital cost (years)
1	3.15E+06	1,377,718	2.3

operating cost of US$ 1.38 x 10^6 can be saved in the domain of utility bill however capital cost of US$ 3.15 x 10^6 must be invested to modify the existing HEN (table 3). Capital cost has to be recovered within 2.3 year of plant operation (table 4).

Conclusions

Reasonable amount of plant utilities can be saved by modifying the existing HEN i.e. adding new amount of heat exchange area. The capital costs required for additional area can be amortized in about 2.3 years. After this period saving in operating costs of the process unit would be about 1.3 MUS$. In addition, the environmental impact will improve considerably as a result of this new process topology change favoring an advanced heat recovery within the process. However, in the new HEN topology the main stream of crude oil must be branched in many other streams. As a consequence some heat exchangers has lower flow rate of crude oil at the tube side of heat exchanger. These lower flow rates can decreases the domain of process control in regards of flow rate and temperature. Therefore, the process control strategy should be modified and adapted to change shown above to avoid the unsteady state operation which in turn decrease the product quality and quantity. Furthermore, low fluid velocities abate the heat transfer which result in undesirable temperature out of heat exchanger. Finally, the proposed complex network requires special attention toward operation and maintenance job which may cause problems during plant operation. Consequently, pinch approach must be combined with procedure for fouling management, procedure for introducing solutions to intensify heat transfer with turbulence enhancers, thus procedure for retrofit solution searching in this particular case leads toward techniques for solving an optimizing problem as a future research work.

References

1.GERALD L. KAES (Author), "Refinery Process Modeling: Sample Problem 1- Crude/Vacuum", Paperback 33 pages, Publisher: Elliott & Fitzpatrick, August 15, 2002.

2.LINNHOFF, B., FLOWER, J., R., AIChE Journal Vol 24, Issue 4, July 1978, Pages: 633–642;

3.GUNDERSEN T., Heat Integration: Targets and Heat Exchanger Network Design(Chapter 4), in: J.J. Klemes (Ed.), Handbook of Process Integration (PI): Minimisation of Energy and Water Use, Waste Emissions, Woodhead Publishing, Cambridge, UK, 2013.

4.TJOE, T., N. and LINNHOFF, B., Chem. Engng., 93, (April) 1986.

5.***, "ASPEN HYSYS® 2004 - User guide", chapters 5, 6 and 11;

6. SMITH, R., "Chemical Process Design and Integration", Wiley, January 2005, ISBN: 978-0-471-48681-7;

7.KEMP I., C., Pinch Analysis and Process Integration – A User Guide on Process Integration for Efficient Use of Energy, 2nd ed., Butterworth-Heinemann, Burlington, USA, 2007, 415 ps.

8.***, SPRINT, 2012, Process Integration Software (CPI, CEAS, The University of Manchester, UK), website (last accessed 24.09.2014): http://www.cpi.umist.ac.uk/Software/products/Spr_hlp/Spr_contents.Htm

9.SEIKOVA, I., VARBANOV, P., IVANOVA, E., in F. Friedler and J. Klemeš (Eds.), Proceedings of PRES'99 Conference, Budapest, Hungary: Hungarian Chemical Society, pp. 583–588, 1999

Manuscript received: 16.05.2015