

Pinch Analysis of a crude oil unit

J. Klemeš, ¹L.L.Tovazshnyanski, ¹P.A.Kapustenko, ¹N.D.Andriychuk, ¹L.M.Uliev, ¹B.D. Zulin

University of Manchester Institute of Science and Technology (UMIST), Department of Process Integration, PO Box 88, Manchester, M60 1QD, United Kingdom; Tel.: +44 161 200 4389, Fax: +44 161 236 7439, E-mail: j.klemes@umist.ac.uk; ¹Kharkov State Polytechnic University, Department of Chemical Engineering, Frunze St. 21, 310002, Kharkov, Ukraine; Tel.: +380 572-400-893, Fax: +380 572-400-632, E-mail: ulm@lotus.kpi.kharkov.ua

The problem of energy conservation assumes particular importance in the context of the Ukrainian economy. In Ukraine most of the operating power-consuming enterprises have been built around times when energy resources were available at relatively low prices. Since then the picture has changed and energy savings have become a prerequisite for a viable and profitable operation of the plants. The scope for energy savings calls upon design modifications and the application of appropriate and systematic technology. In view of the needs behind the emerging problem, the team set up by the authors has attempted an evaluation and survey of industrial sites in Ukraine with the intention to identify the potential for energy savings. The refinery site at Kremenchug is presented in this paper and accounts as the first of a series of similar studies to follow.

The design of heat exchanger networks for crude oil distillation units has been previously considered by approaches in which matches between streams have been assembled and sorted out by various criteria which provide no guarantees for the developed network [1]. These methods are based on simple procedures that take little advantage of available technological developments [2,3] of the exergy-topological simulation of heat exchange systems. It is common knowledge that the application of simplistic methods leads to poor and inferior designs which under-utilised capital and consume energy much larger than needed. In the past these methods have been viewed as a compromise for speedups in the design process as they can reach decisions quickly. Such a view is particularly false in the case of a refinery where the number of streams is very large and the network development calls upon special attention and requires significant time. As a result, simple methods not only compromise for quality but also lead to messy, conflicting and time consuming procedures. Nowadays, rigorous and advanced procedures, such as the ones discussed in this paper, can provide results quickly and without any compromises for quality.

THE CRUDE OIL PROCESS

The crude oil process of this study is presented in Figure 1. The crude is first preheated from 30°C up to 115°C. The heat required by the preheating stage is made available by streams from the heavy oil cuts, heavy and light diesel fuel of the column K-3, and top pumparounds from the columns K-2 and K-13. After being preheated, the oil is forwarded to a water and brine separator and heated up to 210-220°C with heat available from the heavy oil and bottom pumparounds of columns K-2 and K-13. Technical constraints impose an upper bound of 250°C on the temperature which in fact

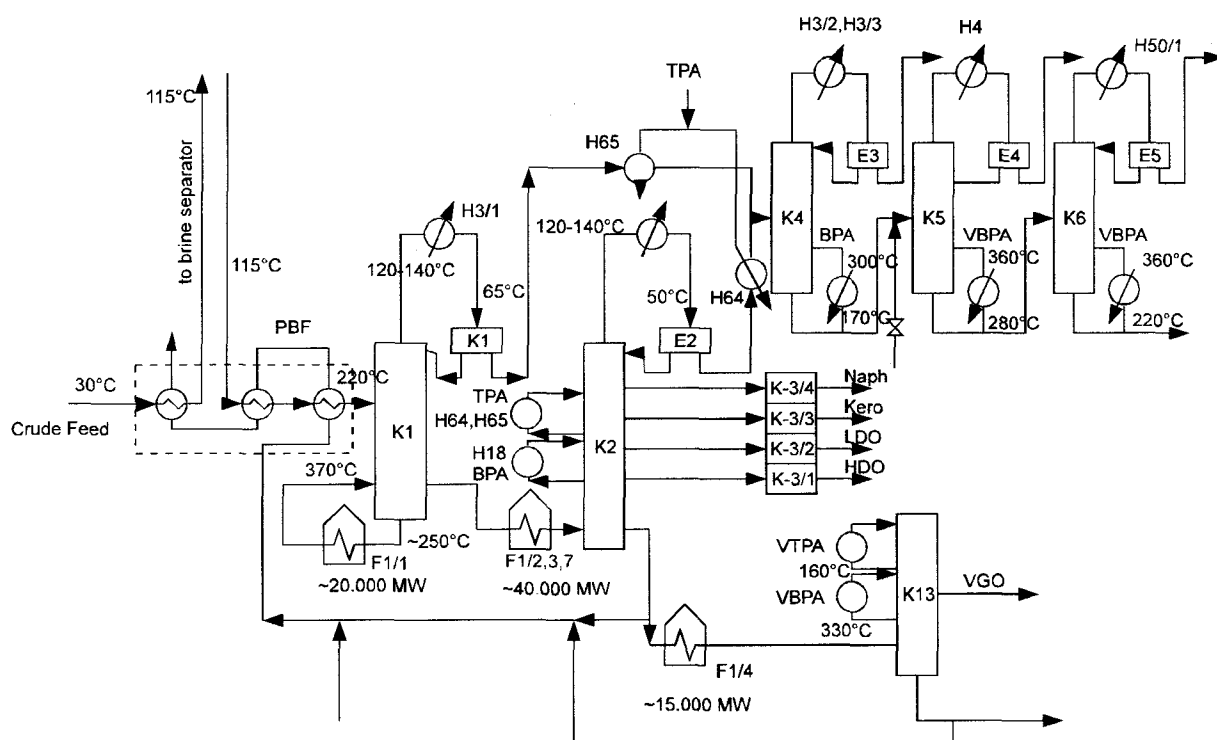


Fig. 1. Principle outline of crude oil unit. BPF- the block pre-heating of crude oil; K1- preliminary fractionating column; K2- basic rectification column; K3- steamed column; K4- stabilisation column; K5- rectification column for receipt fraction 62°C; K6- column for receipt fraction 62-105°C; K13-column for vacuum distillation of mazut; E1...E4- capacities; H2-H4,H50- air condenser; F- pipe still.

does not even reach 220°C. The basic heat recovery takes place in the heat exchanger block of the pre-heating stage. Additional recovery is achieved at columns K-4 to K-6 where the duties of the reboilers are matched with heat available from the BPA streams of columns K-2 and K-13.

The application of Pinch Analysis has called upon the extraction of basic data from the process. The data included construction parameters of the equipment, physical and thermal parameters, as well as the temperatures and the heat transfer coefficients required for the development of the heat exchanger network. The network streams have been identified by their enthalpies, CP, and their supply and target temperatures, T_s , and T_T respectively. Based upon the stream information, the hot and cold composites are constructed so that energy integration targets can be evaluated. The composites are plot on a temperature-enthalpy diagram and the targets provide the scope and incentives for energy integration and are calculated ahead of the network design.

The principle of Pinch Analysis is well documented in the literature [4] and is not explained in detail here. The composites define the energy resources of the process and can overlap each other in integration scenarios. The minimum vertical distance represents a location of limiting driving forces which is identified as the minimum temperature difference for maximum energy recovery and is known as $\Delta T_{\min, \text{MER}}$. At $\Delta T_{\min, \text{MER}}$ the composites accommodate for maximum heat integration. Their overshoots represent the utility targets that are needed for heating and cooling. As the composites are shifted apart (higher values of ΔT_{\min}), they allow for higher driving forces and higher

usage of utilities. This implies a direction of higher operating costs and capital savings and the economic trade-off should be targeted at the optimal value of ΔT_{min} . The economic targets can be found ahead of design using Pinch Analysis principles.

There are 26 process streams that are provided on Table 1. The table shows the type of the stream, the supply and outlet temperature and the overall enthalpies involved. Streams with large variations of the CPs are segmented accordingly.

Table 1 - Technological data of streams of unit

Streams	Name	Supply temperature, °C	Target temperature, °C	Changing of enthalpy, kW
1 H	Benzine	190	50	-2148.0
2 H	Kerosene	210	50	3663.0
3 H	LDO	270	50	-10374.0
3.1		270	170	-5189.0
3.2		170	50	-5185.0
4 H	HDO	310	50	-5623.1
4.1		310	170	-3323.0
4.2		170	50	-2300.0
5 H	VTPA K13	200	50	-10128.0
5.1		200	130	-5064.0
5.2		130	50	-5064.0
6 H	TPA K12	230	120	-5310.0
6.1		230	168	-3109.0
6.2		168	120	-2201.0
7 H	BPA K2	300	120	-11694.0
7.1		300	178	-8281.0
7.2		178	120	-3413.0
8 H	VBPA K2	330	160	-10673.1
8.1		330	250	-5357.0
8.2		250	220	-1856.0
8.3		220	160	-3460.0
9 H	Diesel	250	70	-3276.0
10 H	VGO	250	80	-12453.0
10.1		250	220	-2455.0
10.2		220	150	-5299.0
10.3		150	80	-4699.0
11 H	Mazut	350	99	-22165.7
11.1		350	250	-9639.1
11.2		250	200	-4488.5
11.3		200	160	-3353.0
11.4		160	99	-4685.0
12 C	C. crude	30	115	23914.0
13 C	M. crude	115	220	38953.0
14 C	K1 reb.	250	330	9288.0
15 H	K1 cond.	140	50	-8540.0

16 C	K2 feed	250	360	50472.9
17 H	K2 cond.	150	50	-17204.0
18 C	K4 feed	50	120	3109.0
19 H	K4 cond.	60	35	-7958.0
20 C	K4 reb.	150	155	8281.0
21 H	K5 cond.	90	35	-3098.0
22 C	K5 reb.	150	155	2773.0
23 H	K6 cond.	96	35	-2877.0
24 C	K6 reb.	170	175	2873.0
25 C	K13 feed	340	380	16378.0
26 H	K13 cond.	120	50	-2744.0

CASE A:

The current operation corresponds to $\Delta T_{\min} = 56^{\circ}\text{C}$. Figure 2 provides the grid diagram [4] based upon $\Delta T_{\min} = 56^{\circ}\text{C}$ and features the existing heat exchangers. It can be seen from the Figure that the location of the pinch is at 150°C (cold) - 206°C (hot). The energy target for hot utilities is 76.9 MW and the target for cold utilities is 60.8 MW.

The installed heat exchanger area is $17,000 \text{ m}^2$ and Figure 2 shows that 10 heat exchangers are placed violating the pinch principles (cross-pinch heat exchangers).

The retrofiting of the existing design is studied next. This requires the evaluation of area-energy trade-offs that are optimised using Pinch Analysis. The result of this study has converged to an optimal value of $\Delta T_{\min} = 35^{\circ}\text{C}$. The energy savings at this level are 10.5 MW. The retrofitted process requires 66.4 MW hot utilities and 50.3 MW cold utilities.

The development of a network design at this ΔT_{\min} can be achieved by following the Pinch Analysis rules. This requires the use of the CP rules [4] which:

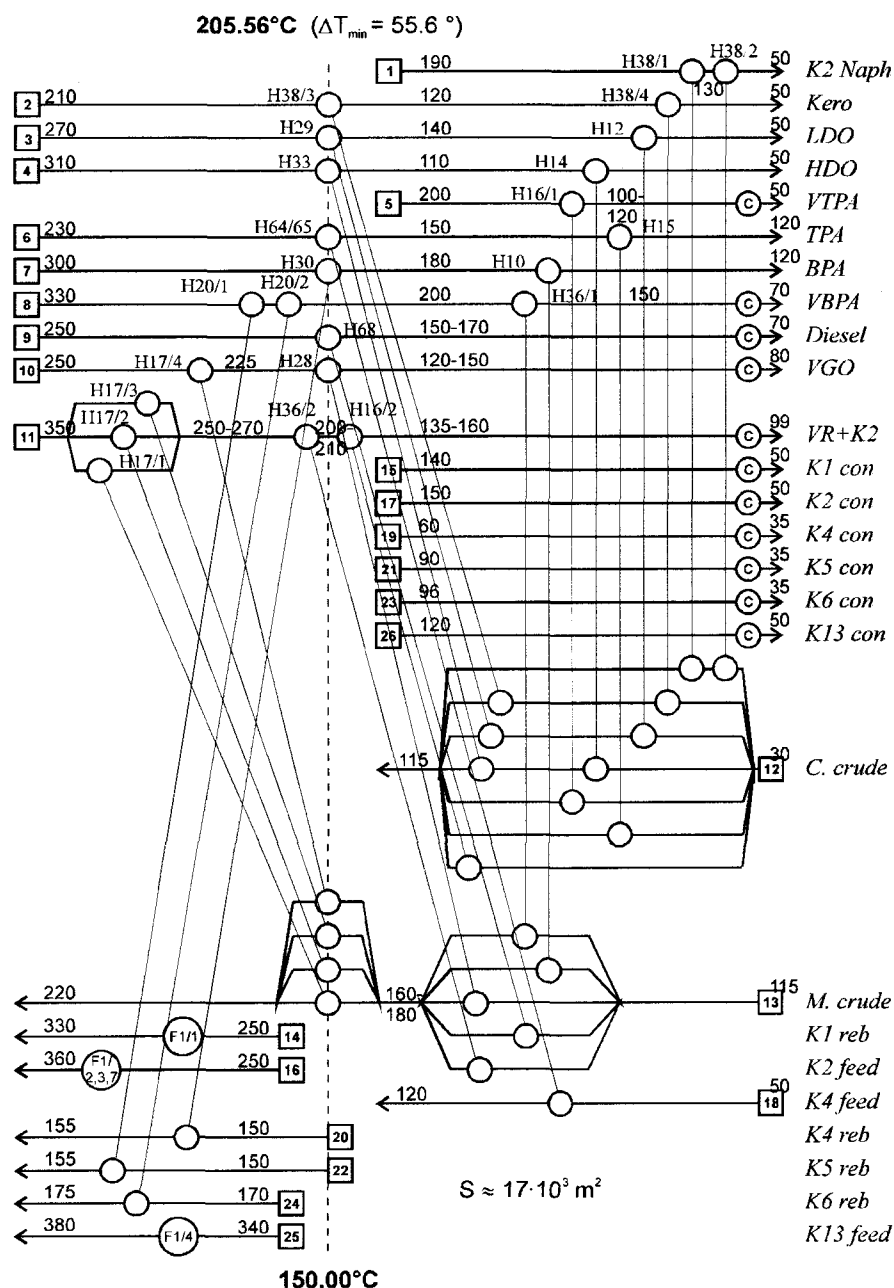
- allow matches in which $CP_{\text{hot}} \leq CP_{\text{cold}}$ above pinch temperature, and
- allow matches in which $CP_{\text{hot}} \geq CP_{\text{cold}}$ below pinch temperature.

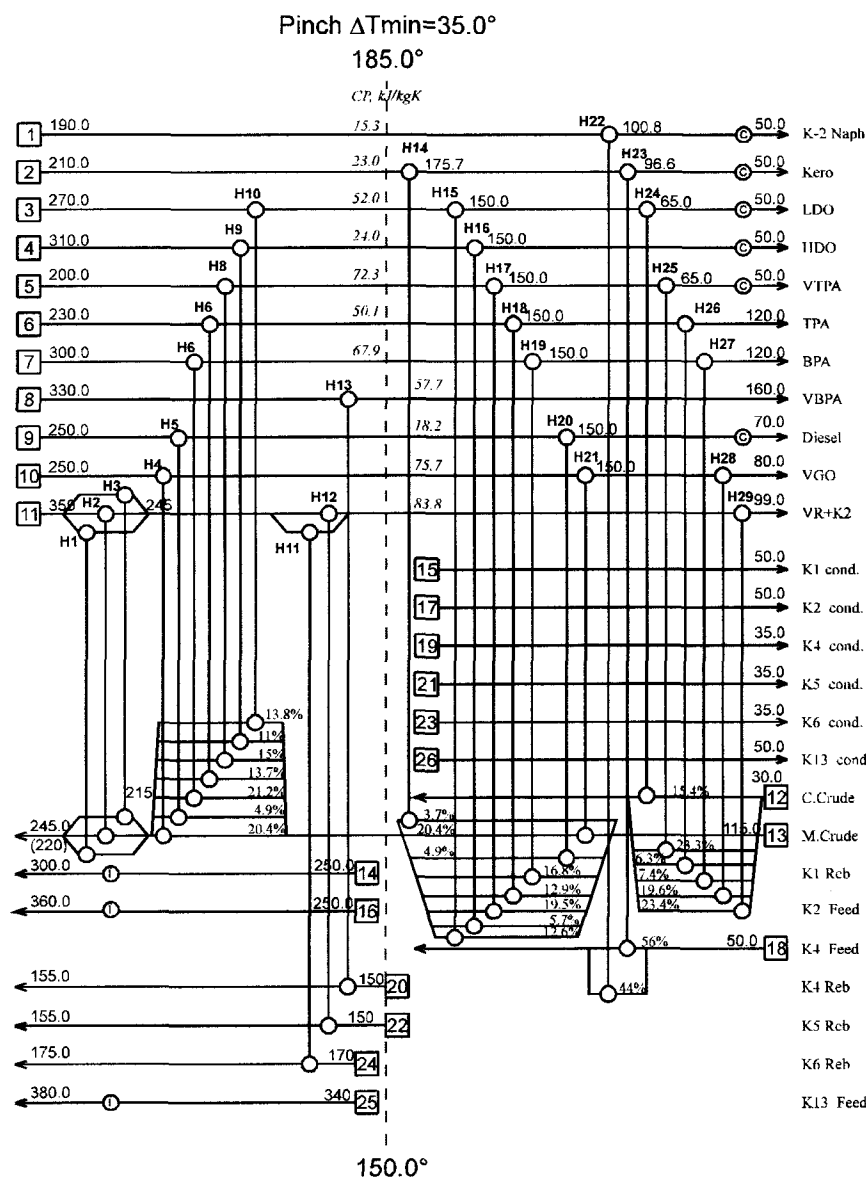
These rules have been used to develop the network of Figure 3. The savings represent 15% savings though a design strictly based upon these numbers requires large capital investment as it requires many new heat exchangers, reallocation of units and extensive repiping.

CASE B:

A much better scenario is presented in Figure 4 where only 5 new heat exchangers need to be used. This attractive option results to savings of 9 MW and an area target of about $18,100 \text{ m}^2$ (about $1,100 \text{ m}^2$ more than the installed) The retrofitted process requires 65.9 MW hot utilities and 51.8 MW cold utilities. The savings represent 12% savings and the

estimated payback time based upon the economic parameters in place is only 10 months.





The further evolution of project supposes consolidation of the built thermal networks above and below of the temperature of the pinch.

Fig. 3. The network designed for match of heat exchangers above and below of the pinch. On the split of streams displayed percentage for heat capacity flowrates. Another, therefore we may do not consider them at the projecting of the network above of the temperature of the pinch.

We have some flexibility in the distribution of the stream 12 below of the pinch. We unite the splits of stream 13 for heat exchangers 14-21, utilising its flexibility.

One of collectors on stream 13 lets us without supplementary modernisation to use the heat of stream 8 for the heat of crude oil. As a result we obtain heat exchanger network with 23 matches between streams (Fig. 4), i.e. on one transposition less, than at available network.

The general area of heat exchange composes $\sim 18,100 \text{ m}^2$, i.e. on 7.7% more available, but given project lets to heat crude oil behaving on column K-1 till 245°C , i.e. to lower the output of pipe still F-1 on 9 MW, that economically is equivalent to drill of a new oil well.

In conclusion we are marking that employment of the methods of pinch analyses appreciably simplified the procedure of the optimisation of available the installation of heat exchangers, and imbedment created design will reduce the consumed currently output of unit on 12% and it will pay-back via 10 months after going out on design output.

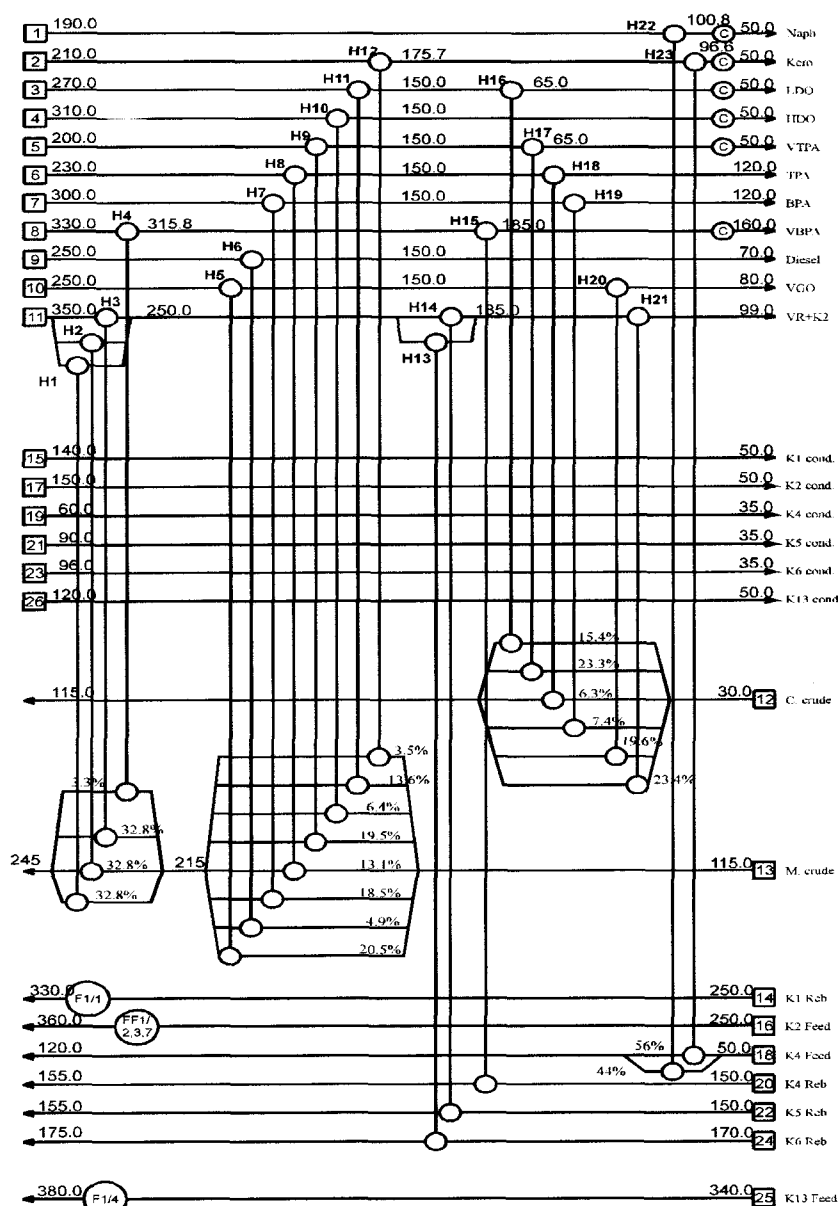


Fig. 4. Final design of the network. On the split streams displayed percentage for heat capacity flowrates.

NOMENCLATURE

BPA- bottom pumparound of K-2; CP-heat capacity flowrate; H-enthalpy; LDO- light diesel oil; T, T_s, T_r - temperature, supply and target temperature; TPA- top pumparound of K2; VGO- vacuum gas oil; VTPA- vacuum top pumparound;

Subscripts: cold- for cold stream; hot- for hot stream; pinch- for values localised in point of the pinch.

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