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# Total Site Integration of Light Hydrocarbons Separation Process

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Ukraine is the largest consumer of hydrocarbons per unit of production in Europe (Ukraine policy review, 2006). The most important point is a reduction of energy consumption in chemical and metallurgical industries as a biggest consumer. This paper deals with energy savings potential of light hydrocarbons separation process. Energy consumption of light hydrocarbons separation process processes typical of Eastern European countries were analysed. Process Integration (PI) was used to perform a preliminary analysis of different units and fulfil the retrofit project of Total Site Integration (TSI). A new heat exchanger network (HEN) were developed and the equipment was calculated with use of the Pinch principles. A complex method was developed and applied to integrate several units at the enterprise site demonstrating the possibility to use heat pumps. Heat pump integration increases heat recovery and offers a solution in order to increase energy savings and project profitability. The heat transfer area and number of heat exchangers for a retrofitted heat exchanger network have been identified. The estimated payback period for integration Heat Pump of Gas Separation Enterprise is about 127 days and the pathways of plant modernization have been also proposed.

## 1. Introduction

Ukraine is one of the most energy-intensive countries in the region. Chemical production is one of the most energy-intensive industries Due to the stable trend towards increasing the price on energy and high competition in energy-intensive industries, the problems of energy conservation in industry have become exclusively important. The most important point is the reduction of energy consumption in chemical and metallurgical industries, where the energy prices are the basic component of production cost.

There are some systematic approaches for the system design of chemical processes that allow to recycle waste heat that allow to reduce energy consumptions. Process Integrational is the most common method to reduce energy consumption in processing industry. One of the directions in the heat integration is Pinch Analysis. The pinch design method has been developed by Linnhoff and Flower (1978) and is applied to find an optimum energy policy in chemical process industries. Dhole et al. (1993) demonstrated the potential for expanding of the Heat Integration concept from individual process level to a Total Site (TS) level, which comprises of several production processes or industrial clusters (Klemeš et al., 1997). Fodor et al. (2012) modified Total Site Heat Integration (TSI) methodology and shown the possibility of using the graphical methodologies and demonstrates using an industrial case study the implementation of a total site methodology using a stream specific $\Delta T_{cont}$ approach. The procedure allows making differences between heat transfer in the process streams inside the process and between process to utility and vice versa (Fodor et al., 2012). The paper Liew et al. (2012) demonstrated new method for calculating multiple utility levels in the Problem Table Algorithm. We further demonstrated that the Total Site Problem Table Algorithm yields more accurate results for Total Site Heat Integration analysis when compared with a graphical approach, which is

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prone to inaccuracies (Liew et al., 2013). These methodologies are proposed for targeting of the minimum energy requirement of Total Site system. Velasco-Garcia et al. had put a lot of effort to show opportunities to optimize the utility system and cogeneration system in Total Site context (Velasco-Garcia et al., 2011). An important part is applications of methodology in practice. Ulyev al. (2013) considered the possibility of applying the Total Site Analysis (TSA) for the coke. Ulyev et al. (2015) recently presented the research where have compared efficiency of general and separate units integration for coke.

In this paper, Total Site Integration for optimized processes of light hydrocarbons production is carried out accounting the features of gas separation industry in order to get solution, which is close to optimal, and provide the pathway for efficient retrofit and manager decisions.

## 2. Process description

This paper deals with energy savings potential of Gas Separation Plant by using the Pinch Analysis and Total Site Analysis method. The Gas Separation Plant is designed for the separation of raw material - Wide Spread of Light Hydrocarbons (WSLH) and technical butane to trade fractions: propane, propylene, iso-butane, normal butane, iso-pentane, normal pentane and hexane. Two units of light hydrocarbons separation were considered (Figure 1).

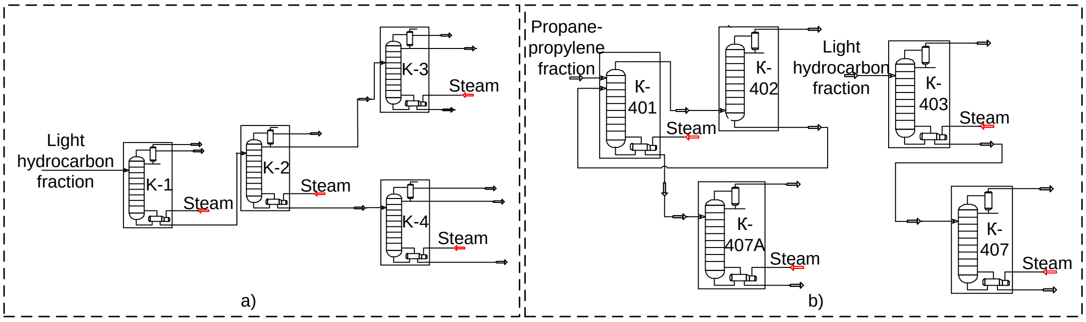


*Figure 1: Flowsheet for two unit of Gas Separation plant*

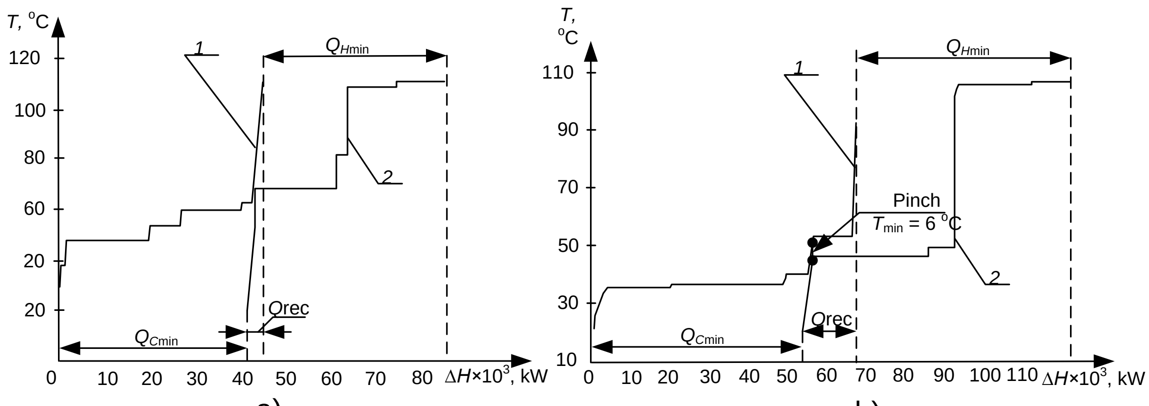
In the separation process of a WSLH (Figure 1(a)) receive iso-butane, normal butane, iso-pentane, normal pentane and hexane. In the separation process of a propane-propylene fraction (Figure 1(b)) receive light hydrocarbons (C1 C2) and a stable propane-propylene fraction which is divided into a propane and a propylene.

## 3. Partite integration of processes

Partite integration of Gas Separation processes were considered in the previous researches by Ulyev et al (2013) that presented the research for reduction of energy consumption of Gas Separation unit using Pinch Analyses method. Ulyev et al. (2015) presented the research for reduction of energy consumption of Gas Separation processes by the application of heat pump.

Compound curves of the partite integrated processes are presented in Figure 2.

After the Partite integration the considered processes consumes 94.68 MW and 95.4 MW by the external cold hot utilities. The potential use of this capacity in the industrial complex can be estimated by means of Total Site Analysis.



a) b)

*Figure 2: Composite curves of the partite integrated process; 1: Hot composite curves, 2: Cold Composite curves, QREC: heat recovery; QCmin: requirement for cold utility; QHmin: requirement for hot utilityTotal Site Integration*

The use of the total temperature profiles of the production complex has enabled the estimation of the target energy values for several processes. The temperature profile for the complex of two processes is plotted in Figure 3.

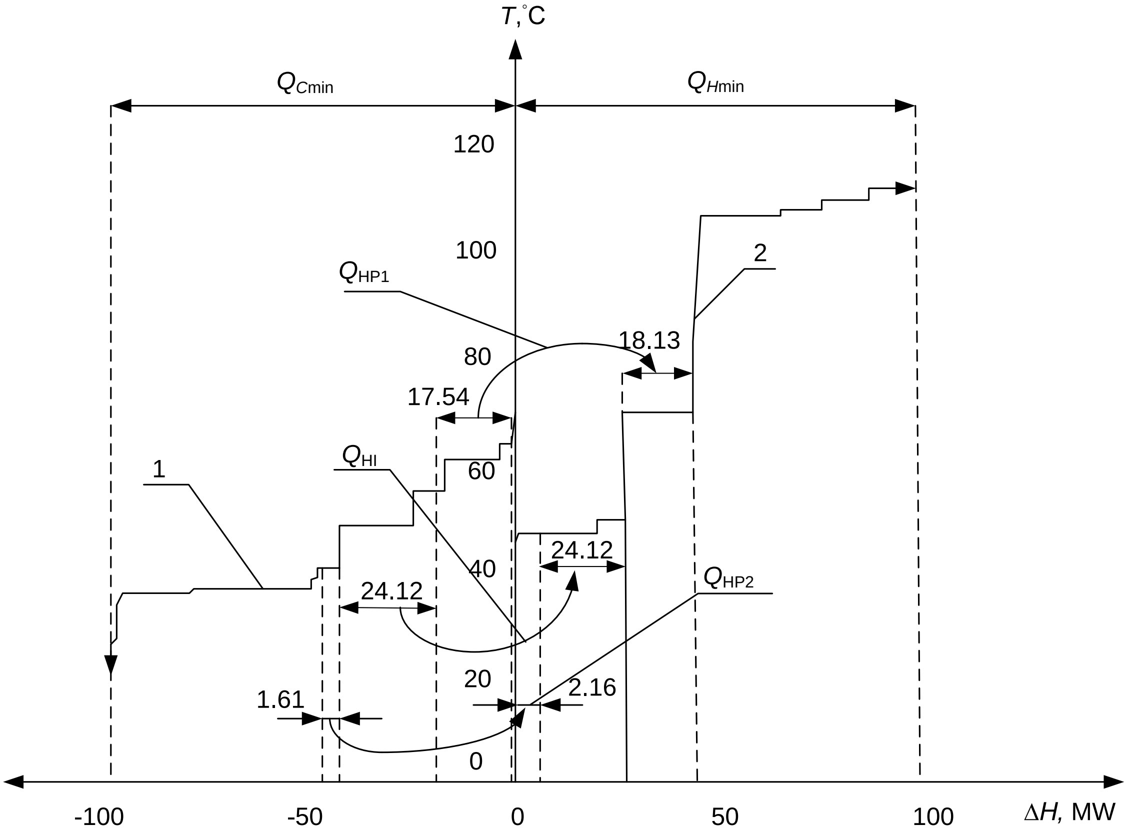


*Figure 3: Total Site Profiles 1: Site source profile; 2: Site sink profile;* $Q_{HP1}$, $Q_{HP2}$*: the possibility to install a heat pump;* $Q_{HI}$ *: Heat integration without heat pump*

The total temperature profile (Figure 3) allows one to consider the possibility of integration for a heat pump within the overall production complex. TSP shows the possibility to install two heat pumps. Heat pumps loads were calculated using the Aspen HYSYS software. The calculations show that the compressors power must by 0.125 MW for the first case and 0.350 MW for the second case to attain the target values. The total heat pump conversion ratio (ε) is calculated by Eq(1) and is equal to 4.08 for the first case and 5 for the second case. Wiring diagram for heat pump is shown in Figure 4.

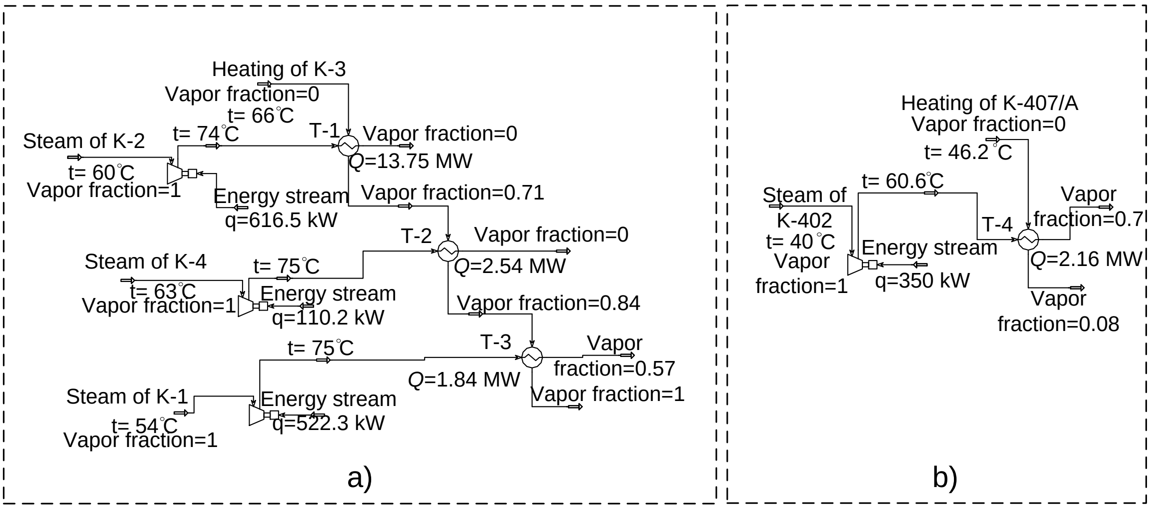


*Figure 4: Wiring diagram for heat pump a: for the first heat pump; b: for the second heat pump*

$$\varepsilon = \frac{Q_{\mathrm{TH}} + W}{W}, \qquad (1)$$

Where $Q_{\mathrm{TH}}$: requirement for hot stream = 17.54 MW for the first case and 1.61 MW for the second case, $W$ : power of the compressor = 1.248 MW for the first case and 0.350 MW for the second case, ε = 15 for the first case and ε = 5.6 for the second case.

## 4. Results and discussion

The brief characteristics of the heat exchangers T-1–T-5 are listed in Table 1.

*Table 1: Brief characteristics of the heat exchangers shown in Figure 4*

| Name of heat exchanger | Heat capacity, MW | Hot flow | | | | | Cold flow | | | | | Surface area, m$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | stream name | $T_{\mathrm{init}}$, °C | $T_{\mathrm{fin}}$, °C | Vapour fraction | | stream name | $T_{\mathrm{ini}}$, °C | $T_{\mathrm{fin}}$ °C | Vapour fraction | | |
| | | | | | init. | fin. | | | | init. | fin. | |
| T-1 | 13.75 | Steam of K-2 | 74 | 70 | 1 | 0 | Heating of K-3 | 66 | 66 | 0 | 0.71 | 954 |
| T-2 | 2.54 | Steam of K-4 | 75 | 70 | 1 | 0 | Heating of K-3 | 66 | 66 | 0.71 | 0.84 | 185 |
| T-3 | 1.84 | Steam of K-1 | 75 | 75 | 1 | 0.84 | Heating of K-3 | 66 | 66 | 0.84 | 1 | 130 |
| T-4 | 2.16 | Steam of K-402 | 60.6 | 53 | 1 | 0.7 | Heating of K-407/A | 46.2 | 46.2 | 0 | 0.08 | 210 |

Numerical estimates of the energy consumption and recuperation in the existing and proposed projects are given in Table 2. The obtained data indicate the effectiveness of the project, but does not take into account the difficulties that may arise directly during the integration of heat exchangers. For example, such as limited space for integrating heat exchangers, etc.

In addition, still there is a considerable potential of utilization of waste heat of the considered processes. It is also necessary to note that considered process consumes after retrofit the external hot utilities 50.65 MW and cold utilities 52.25 MW that in the future can be used for various needs.

The simple payback period of a heat pump (P) is calculated by Eq(2) as the ratio of the capital cost to the annual saving due to a decrease in the consumption of outer energy carriers as:

$$P = \frac{A_{\text{HP}} + S_{\text{compressor}} + 4 \cdot A_{\text{HE}} + B_T \left( S_{HE} \right)^{c}}{Q_{\text{hot}} \cdot S_{\text{hot}} + Q_{\text{cold}} \cdot S_{\text{cold}} - W_{\text{compressor}} \cdot S_{elec}}, \tag{2}$$

where P: payback period; $A_{\text{TH:}}$ total cost of the installation of a heat pump; $A_{\text{HE}}$: cost of the installation of a heat exchanger; Q: external utilities; $S_{\text{hot}}$ and $S_{\text{cold}}$: cost of external utilities; $S_{\text{T9C}}$, $S_{\text{T5C,}}$ $S_{\text{compressor}}$: the cost of the installed equipment, $W_{\text{compressor:}}$ compressor power; P = 0.48 y; $Q_{\text{hot}}$ = 20.29 MW; $S_{\text{hot}}$ = 250 USD/kWy; $Q_{\text{cold}}$ = 19.35 MW; $S_{\text{cold}}$ = 25 USD/kWy; $W_{\text{compressor}}$ = 1.598 MW; $S_{\text{elec}}$ = 500 USD/kWy; $B_{\text{T}}$: rate equivalent to the cost of 1 $m^2$ surface area of heat transfer, for heat exchangers $B_{\text{T}}$ = 1,000; $S_{\text{HE}}$: heat exchange surface area of heat exchanger; c: factor reflecting the non-linear dependence on the value of the cost of the heat exchanger to the heat transfer surface, c = 0.87 for plate heat exchangers (Klemeš et al., 2015); $S_{\text{compressor}}$ : 1,200,000 USD. The price of the heat pump compressor was taken from the previously published works (Gorshkov, 2004).

*Table 2: Energy consumption and recuperation in the existing heat exchange system and the heat exchange system from the proposed project of reconstruction*

| Energy characteristic of the process | Process with existing heat exchange system | Partite integration process | Percent of existing value, % | Total Site integration process | Percent of existing value, % |
|---|---|---|---|---|---|
| Capacity of hot outer energy carriers, MW | 109.35 | 95.06 | 86.93 | 50.65 | 46 |
| Capacity of cold outer energy carriers, MW | 108.65 | 94.68 | 87.14 | 52.25 | 48 |
| Heat recuperation capacity, MW | 3.098 | 17.26 | 557.13 | 67.91 | 2,192 |

## 5. Conclusions

The retrofit project for the gas separation plant was suggested using the Pinch Analysis technique. Heat integration allows decreasing the external hot utilities usage by 13.07 % and cold utilities usage by 12.86 %, and also offered the way of step-by-step retrofit of the plant. The use of Total Site Profiles has demonstrated the possibility of heat pumps integration, which allows decreasing the external hot utilities usage by 53.68 % and cold utilities usage by 52 %, respectively. The payback period for integration Heat Pump is about 127 days.

The provided case studies show the pathway for efficient retrofit of light hydrocarbon production and most profitable ways for investment. The results of this work can be used in gas separation and other industries for efficient energy use, $CO_2$ mitigation and sustainability improvement of industrial regions.

### Notation

$\Delta H$: change in flow enthalpy (kW); *CP*: heat capacity flowrate (kW/°C); $\Delta T_{\text{min}}$: minimum allowed temperature difference (°C); $Q_{\text{Cmin}}$: minimum feasible cold utility (kW); $Q_{\text{Hmin}}$: minimum feasible hot utility (kW); $Q_{\text{Rec}}$: the value of energy recovery in the heat exchange network; *c*: coefficient characterizing the linear dependence between the cost of a heat exchanger and its heat-exchange surface area; P: payback period; $A_{\text{HE}}$: cost of the installation of a heat exchanger; $A_{\text{HP}}$: total cost of the installation of a heat pump; $B_{\text{T}}$: rate equivalent to the cost of 1 $m^2$ surface area of heat transfer; $S_{\text{hot}}$ and $S_{\text{cold}}$: cost of external utilities;

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