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Research article

Process integration of crude oil distillation with technological and economic restrictions

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ABSTRACT

The petrochemical industry is one of the most important industries in the world economy. In the largest oil-producing countries, more than half of GDP is generated by hydrocarbons production and refining. Reduction of oil prices and new environmental regulations are forcing petrochemical companies to improve their energy efficiency.

Improvement of the energy efficiency of Crude oil distillation process at atmospheric vacuum distillation unit (AVDU) with a capacity of 3.3 million ton per year is considered in this paper. The amount of fuel spent for reprocessing of one ton of crude oil has been defined and it is 3.79 kg of natural gas.

This paper shows the ways to achieve the objectives of retrofit in the context of administrative and technical restrictions. The retrofit goal was achieved by the retrofit of the heat exchange network, which allowed reducing gas consumption by 0.98 t/h (natural gas).

The provided case studies show the pathway for efficient retrofit of crude oil distillation and most profitable ways for investment taking into account various administrative and technical constraints. The results of this work allow achieving reduction of energy consumption by 26%.

1. Introduction

World refining industry continues to evolve, but in many countries, its development is hampered due to unreasoned fiscal policy and vague legislation in the area of alternative fuels, which leads to a slowdown in the growth of energy efficiency of industries and low depth of the refinery of the country's (Meshcheryakova, 2015). Refining and petrochemicals are energy intensive industries and energy consumption affects to the finished product cost vastly. Increased energy efficiency in processes at existing refineries is an important element of sustainable development for many oil-producing countries.

In this work during an investigation of Oil Refinery, atmospheric and vacuum distillation processes were examined. With the help of stationary and portable devices, the measurements of process streams parameters were made. There were measured streams temperatures, stream flow rates and compositions of the waste gases of the furnace. The cooling water stream flow rate and temperature of cooling water were measured as well as fuel consumption in the furnaces.

When analyzing the statistical data of the unit for three years, it was determined that the unit consumes mainly thermal energy (Fig. 1).

There are several approaches for exchanger networks design of chemical processes that allow reducing energy consumptions. Process Integration is the most common method to reduce energy consumption in processing industry (Smith, 2016). The main areas are methods of mathematical programming and Pinch Analysis.

Methods of mathematical programming allow solving practically any problem of optimization of energy consumption in industry Pavão et al., 2018 in their work, a meta-heuristic two-level method based on Simulated Annealing and Rocket Fireworks Optimization (SA-RFO), originally developed for single-period HEN synthesis, is adapted to handle multiperiod HEN optimization. Alipour et al., 2018 in their paper presented a multi-follower bilevel programming approach to solve the 24-h decision-making problem faced by a combined heat and power (CHP) based micro-grid (MG). The methodology based on heat integration and mixed integer linear programming to represent process energy requirements with different heat exchange interfaces was proposed by Bütün et al., 2018. Kim et al., 2010 proposed approach consists of unit modeling using thermodynamic principles, mass and energy

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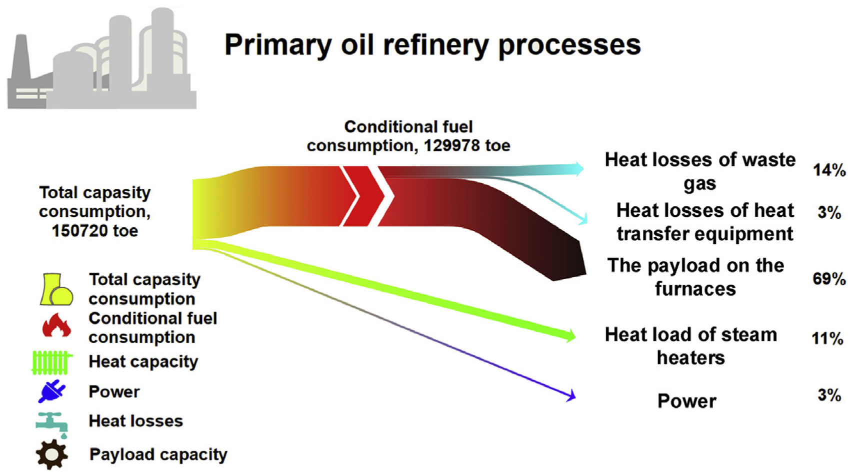

Fig. 1. Energy consumption structure for a typical primary petroleum refining process (for 3 years of operation work).

balances, development of a multi-period Mixed Integer Linear Programming model for the integration of utility systems in an industrial complex, and an economic/environmental analysis of the results. Methods of mathematical programming can be applied to optimize water resources. So Agana et al., 2013 presented the application of an integrated water management strategy at two large Australian manufacturing companies that are contrasting in terms of their respective products. Despite its effectiveness, mathematical methods have their shortcomings, the main one of which is the complexity of checking the results obtained. This greatly complicates the use of mathematical programming in the optimization of real production.

Second direction in the heat integration is Pinch Analysis. Pinch Design method has been developed by Linnhoff and Flower (1978) and is applied to find an optimum energy policy in chemical process industries.

Pinch Analysis due to its simplicity is widely used for targeting of energy consumption, designing the Heat Exchanger Network and identifying Process Integration opportunities. Fodor et al., 2012 modified Total Site Heat Integration methodology and showed possibilities of using the graphical approach. Farhata et al., 2015 presented a new methodology combining Total Site analysis with exergy analysis. Liew et al., 2012 demonstrated the possibility of using the numerical methodology. Liu et al., 2017 and others proposed new absorption-stabilization process with a two-stage condensation section. Compared with the existing process, the proposed process can reduce the cold utility and hot utility by 17.98% and 25.65%, respectively, as well as decrease the total annual operating costs of the heat exchanger network by 17.48%.

Ul'ev and Vasil'ev, 2015 examined the potential for the application of the Pinch method in the coke-chemical industry, including a Total Site approach (Ulyev et al., 2013).

The minimum energy consumption for the overall process of biodiesel synthesis from vegetable oil and methanol was presented Pleşu et al., 2015 using the Pinch Analysis method.

Despite the fact that the Pinch Analysis method has long been known and is widely used in the design of optimal heat exchange networks, the method is constantly evolving, including its graphics component. New graphical technique, based on Pinch Analysis, for the grassroots design of heat exchanger networks, was presented by Gadalla (2015). Pinch Analysis is widely used to assess the potential of using heat pumps (Olsen et al., 2017).

Pinch Analysis is widely used not only for heat integration but also for optimizing power consumption (Fernández-Polanco and Tatsumi, 2016). The use of the Pinch method allows receiving substantial financial profit by minimizing of energy consumption for the account of maximizing heat recovery within the considered energy-technological system.

The flexibility of the Pinch Analysis method makes it possible to use it in financial planning. Roychaudhuri and Bandyopadhyay, 2018 proposed a new algorithm, the minimum opportunity cost targeting algorithm, to address the capital budgeting problems for selecting environmental management projects. This algorithm is based on the principles of Pinch Analysis, a well-established resource conservation methodology and can be directly applied to partially acceptable projects that can be formulated as a linear programming problem.

The literature review shows the universality and wide distribution of the Pinch Analysis method, as well as its effectiveness in various areas of industry, which ensures transparency of the results obtained.

However, in reality, it is not always possible to implement a completely new heat exchange network. This is especially true for oil refining, where the initial heat exchange network has a high heat transfer area and the space for new heat exchangers is limited. Modern methods of process integration do not offer system solutions that take into account the available heat exchange capacities. For example Boldyryev et al., 2016 tried to implement a Process Integration measures accounting limited process conditions in cement manufacturing, such as streams with solid particles, solid–gas and solid–air heat transfer. This paper proposes an updated methodology of improved heat integration of crude oil refinery with additional variables that generated by the feasibility of unit retrofit. There are some technological, administrative and economic restrictions including limited unit space, equipment purchasing time, start-up and shut-down schedule, target saving etc. The novelty of current research is to find the optimal retrofit pathways taking into account technical, economic and administrative variables and get more realistic and sustainable in terms of future operation.

2. Methods

In this work the solution for the achievement of the objectives, near optimal to the decision. This methodology allows you to maintain the maximum possible number of existing heat exchangers. Heat exchangers network is crude oil distillation was optimized taking into account the next restrictions:

- Limited purchase time for new equipment.
- Separate tender as each type of equipment.
- Reduce energy consumption by at least 10%.
- Minimum changes to existing PFD.
- Limited space for new equipment.
- Retrofit is possible only during planned repairs.

Using the classical method of analysis, we obtained design targets: