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Time Super Targeting: Planning of Optimal HEN Design Accounting Energy Prices

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Present work delivers the methodology Time Super Targeting (TST) for optimum solution of heat exchangers networks (HEN) in dynamic when the energy prices are changed. Optimum solution can be found for time slice when the retrofit is completed taking into account the decision-making period of enterprises. Sensitivity analysis of finished solution for HEN retrofit was performed and flexibility of changes are analysed. Several representative case studies were developed for different industries to show methodology application. The results of this work can be used for analysis of reactor, separation, utility systems to update the Process Integration methodologies as well as for Total Site Integration.

1. Introduction

The changes of energy prices in recent years, as well as the necessity to curb carbon dioxide emissions, have speed-up the need for approaches that are increasing energy efficiency in the processing industry including food and beverage, chemical, petrochemical, refinery, coal reprocessing etc. Nevertheless, the implementation of retrofit projects takes long period from the analysis to the final installation and operation. This situation is typical for the factories that are the parts of big holdings and the decision-making system limits the retrofit period. It makes more important to apply the discounted cash flow methodology for evaluation and design of energy and chemical production plants as reported by (Pintarič and Kravanja, 2017). They demonstrated two large-scale case studies that used discounted cash flow methodology which result in substantially different decisions than non-discounted criteria, however, these decisions are affected by several input parameters.
Process Integration approach is one of key instruments for reduction of heat, power, water and resource in reprocessing industry (Smith, 2016). Recent developments show that the heat exchangers networks (HEN) improvement may save up to 40% of primary energy resources and it is connected with economically grounded solutions and investment efficiency as presented by (Liu et al., 2016). Hafizan et al. (2016) made a research on the optimal design of heat exchanger networks (HENs) which was primarily revolved around trading off technical design requirements for aspects of economy, such as capital cost of heat exchangers and utilities. Illustrative case study showed that one of the networks was the most flexible as it yielded the highest percentage of change at 22 %. Emanuele et al. (2017) proposes a novel approach for the simultaneous synthesis of Heat Exchanger Networks (HEN) and Utility Systems of chemical processes and energy systems. The mathematical formulation uses the SYNHEAT superstructure for the HEN, and ad hoc superstructures and nonlinear models to represent the utility systems. A methodology of a possible integration of geothermal energy within residential, commercial and industrial systems was recently proposed by (Barkaoui et al., 2016). Pinch analysis was used to find the best ways to fulfil the energy system requirements in an efficient, clean and cost-effective way. Boldyryev et al. (2016a) analysed the energy consumption of a particular cement factory in Croatia to determine the minimum energy targets of production and proposed pathways to improve energy efficiency. The authors conclude that the energy consumption of the cement factory can be reduced by 30 %, with an estimated recovery period of

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3.4 months. Bungener et al. (2015) proposed a methodology on Total Site level to identify typical operating periods of an industrial cluster made up of several production units. This algorithm exploits a multi-objective optimisation to identify n periods that delimit typical operating modes or multiple profiles. Walmsley et al. (2014) proposed a novel Cost Derivative Method (CDM) for finding the optimal area allocation for a defined Heat Exchanger Network (HEN) structure and stream data to achieve minimum total cost. After applying the new CDM, the total annual cost was reduced by 7.1 % for the distillation problem and 5.8 % for the milk powder plant. However, the realisation of mentioned methodologies and case studies into economic environment is connected to real profitability indexes. Besides the decision making by plant managers is considered by economic indicators such as NPV and IRR that are calculated based on HEN configuration and efficiency. From this point of view, it is important to find the solution which will be more profitable for enterprises. Otherwise, the difference in discounted cash flow may be lowered or, in some case, even negative.
Nevertheless, as was previously demonstrated by (Nemet et al., 2013) the energy prices prediction is very important for accounting of solution profitability. The use of Pinch Point approach allows finding the optimal temperature difference for HEN but usually the solution is founded for steady state mode. This fact makes completed retrofit design different from optimum obtained during analysis. This means that the investment efficiency is decreased because of energy prices are changed, especially last time when hydrocarbon market is moved due to influence of renewables and other factors. The main challenge of this paper is to reduce the economic losses during implementation of HEN design and help both the managers in decision making and designers in optimal design. This paper is trying to show the horizons of HEN optimality in different scenarios of implantation accounting time of equipment purchase and installation as well as start up an operation. In current paper the authors presented an approach for analysis of process industrial system in scope to determine the optimal temperature approach for HEN retrofit design accounting different energy prices. The methodology was tested on three different case studies to show the results applicability. All case studies were implemented for industrial clusters without heat recovery and new HENs were designed. The case studies show that the optimal minimum approach temperature is changed and the economic results of the retrofit are strongly depended on it and profitability of retrofit can be predicted clearly. The approach may help the decision making in process industries to efficient economic management and calculation of company economic indicators.

2. Methods

The methodology of Super Targeting which was good described by Smith (2016) uses fixed variables of utility cost. In this paper, the authors investigate the range of utility cost and calculate the dimension of total reduced cost of heat exchangers network. The dimension of total reduced cost forms the optimum minimum temperature approach for different energy prices. Based on optimal line, the optimality of heat exchangers network could be analysed for each time slice or predicted basing on energy prices fluctuation calculated by (Nemet et al., 2013). The method appears to only account for energy price fluctuations, without regard to the fact that capital investment also becomes more expensive with time because the purchase of an equipment is done, the price is defined and cannot be changed by producers after sign of agreement. Considered case studies are implemented for industrial clusters without heat recovery system that means new design of HEN. The term “retrofit” is used as it is an enterprise under operation and any changes of PFD mean a retrofit procedure.
The methodology is started from data extraction of considered process specifying the initial energy prices. The second step is to apply the Super Targeting procedure considering different energy prices, both increasing and decreasing to see the behaviour of the optimum point. Since the variation of energy price results in a surface array of total reduce cost it gives the optimal line. Economic indicators can be calculated for current energy price, such as NPV_1. From the optimal line and the basing on energy prices fluctuation calculated by (Nemet et al., 2013) the predicted energy prices may be found. The implementation of the HEN is depended also from company decision making period and equipment purchase procedure, basing on this the start-up of new HEN is defined as well as energy prices of start-up period and further operation. The optimal minimum approach temperature of start-up period is also found from optimal line NPV_2. Two NPVs show the differences in cash flow and give the basis for decision making. As the last step, the HEN design is performed and equipment purchased for the chosen variation of minimum approach temperature. As presented in case study, it can be very big difference of considered option as well as no differences.

3. Case studies

Three representative case studies were demonstrated to show the results exploitation and methodology viability. The authors have analysed previously investigated data on benzene hydrocarbon extraction (Tovazhnyansky et al., 2011), integration of ammonia refrigeration cycle to heating system (Boldyryev et al., 2013) and Total Site data presented by Boldyryev et al. (2016) with different energy prices. The low and upper bound of energy price were selected taking into account the base case to show the optimum while energy prices going up and down. The retrofit base case designs were presented in papers sited above. This paper presents targeting part of the project and does not show the design for new optimal temperature approach. The main idea of this paper is to present approach for different case studies to show the approach for decision making. The energy prices were defined from Croatia, Ukraine and Kazakhstan for different industries where case studies were implemented. This the reason why the ranges are different. During analysis, the ranges were selected low and upper the base price to show the optimum changes around base price.

3.1 Case study 1 – benzene hydrocarbon extraction

Extraction of benzene hydrocarbons is the part of complex purification process of coke-oven gas. Coke-oven gas is delivered from desulfurization plant to scrubber where benzene hydrocarbons are extracted by stripping oil. The case study includes 5 process streams and optimum temperature approach of based case was 10 °C. Figure 1 shows the total reduced cost of benzene hydrocarbon extraction with energy price changing. Figure 2 demonstrates the changes of optimum minimum temperature approach of HEN for different energy prices.

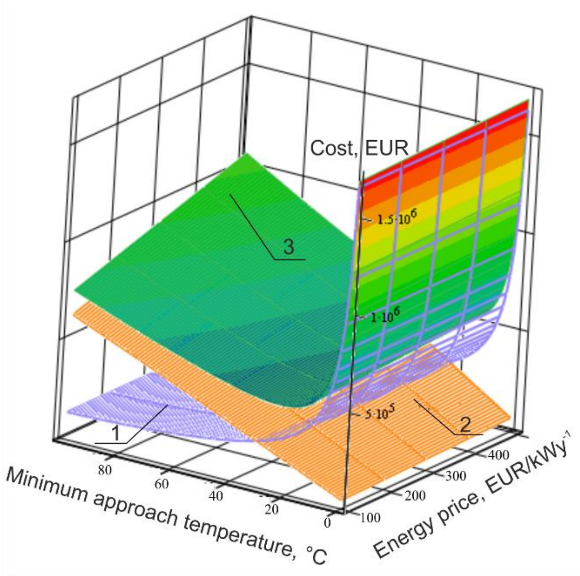

Figure 1. Cost surfaces of benzene hydrocarbon extraction. 1- Investment cost; 2 – operation cost; 3 – total reduced cost

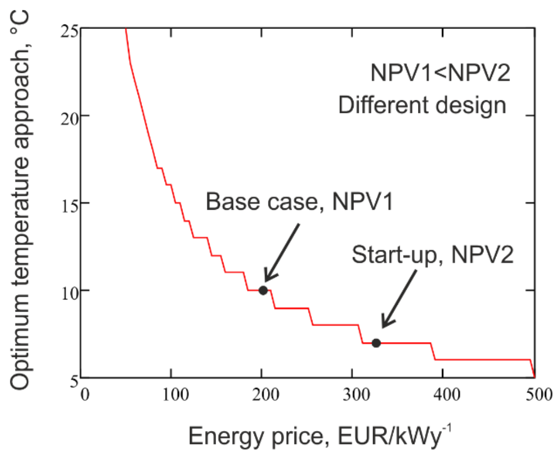

Figure 2. Optimum minimal temperature approach of HEN in benzene hydrocarbon extraction

3.2 Case study 2 – integration of ammonia refrigeration cycle

This case study analyses the possibility of integration of waste heat from ammonia refrigeration cycle into heating systems of buildings. The possibility of utilising the condensation heat of a supermarket refrigeration unit for existing heat consumers was analysed. There are two option to integrate an ammonia refrigeration cycle:

base case and additional compression of ammonia. The optimum temperature approach of base case was obtained at 17 °C. Figure 3 and Figure 4 show the total reduced cost and optimum positioning of integrated ammonia refrigeration cycle.

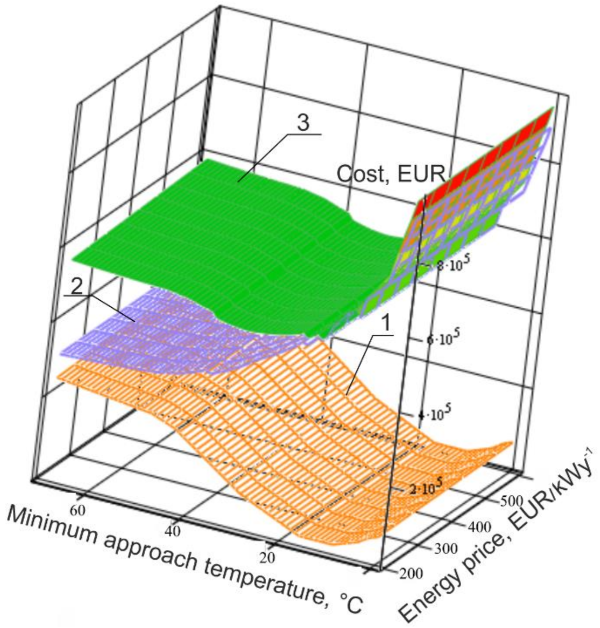

Figure 3. Cost surfaces of ammonia refrigeration cycle integration into building heating system. 1- Investment cost; 2 – operation cost; 3 – total reduced cost

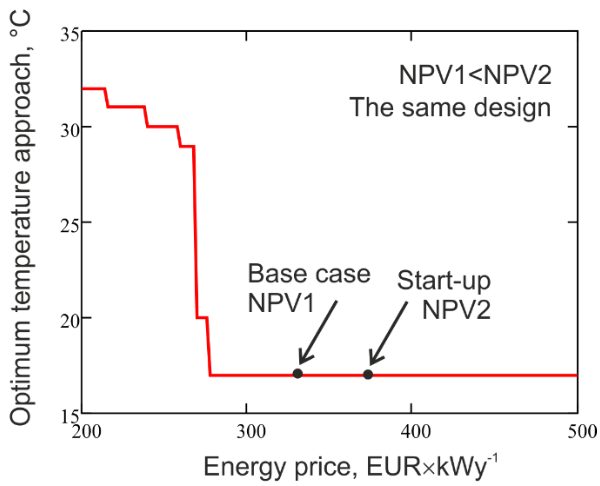

Figure 4. Optimum minimal temperature approach of HEN for ammonia refrigeration cycle integration.

3.3 Total Site Integration

Third case study uses the stream data of three individual processes. These processes were integrated by Pinch Analysis and streams are accounted for when plotting Total Site Profile described Nemet et al. (2012). This case calculated the selection of optimum level of Total Site heat recovery and minimisation of heat transfer area on Total Site. Price of hot utility of the base case is 366 EUR/kWy that is corresponded with prices of natural gas 0.042 EUR/kWh in Croatia.

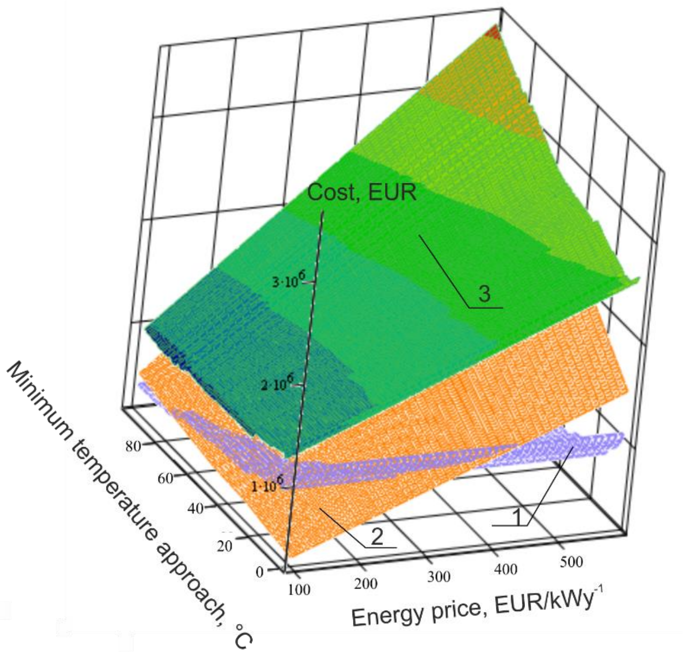

Figure 5. Optimum minimal temperature approach of Total Site heat recovery described by (Boldyryev et al. 2016b). 1- Investment cost; 2 – operation cost; 3 – total reduced cost

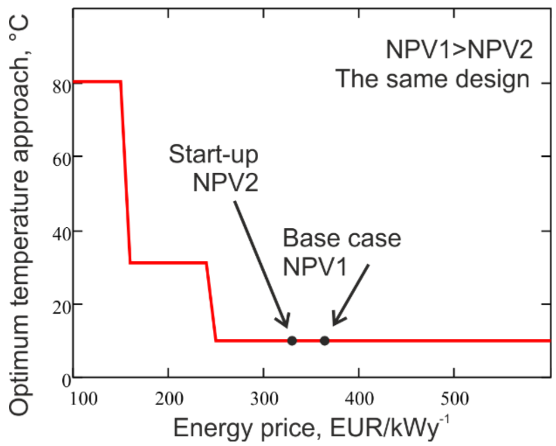

Figure 6. Optimum minimal temperature approach of Total Site heat recovery.

4. Discussion

Three case studies show different dependency of optimum ΔT_{min} from energy price. Analysis of benzene hydrocarbon extraction was performed when the energy prices was 200 $/kWy, but the energy price was changed during project realisation and get 330 $/kWy. So, it more profitable to make the retrofit for ΔT_{min} = 5 °C. Analysis of ammonia cycle integration was performed for energy price 330 $/kWy and Figure 4 shows that this value won't be changed if energy prices will go up. Nevertheless, reduction of energy prices on 20% moves the optimum ΔT_{min} from 17 °C to 30 °C and the targets for design of heat exchangers network should performed changed. The reduction of energy prices could be possible, for example, by applying renewable energy sources or other market changes.

Third case study was performed for energy price 365 $/kWy and Figure 6 shows that this solution will be stable for wide range of energy prices. Big changes of third case study optimum are possible only if the energy prices drop down 2.5 times. It is not possible very fast and it is recommended to keep the design targets as during analysis. There a lot of variables that influence on optimum point accounting dynamic mode of heat exchangers network, all of these factors have to be additionally investigated to improves the accuracy of obtained optimal solution.

5. Conclusions

Time Super Targeting methodology was proposed in this paper for estimation of optimum solution of heat exchangers networks HEN when the energy prices are changed. Three representative case study are delivered to approve the methodology and show applicability of proposed approach. Optimal HEN can be design for time period taking into account the decision-making period of enterprises. The optimal minimum approach temperature of start-up period is also found from optimal line. Two project NPVs were defined to show the differences in cash flow and give the basis for decision making. The results of case studies show the sensitivity of HEN retrofit taking into account the energy prices, decision making period and start-up of industrial unit. The results of this work have wide application can be used for decision making tools of HEN retrofit, retrofit planning and calculation of economic indicators of investment projects.

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