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Energy and economy savings in the process of methanol synthesis using Pinch technology

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Abstract: A heat exchanger network (HEN) for the process of methanol synthesis has been studied by pinch design analysis. Great economic and energy savings were realized by the pinch analysis in comparison to the existing plant. Also, it was found that it is possible to reduce the requirements for the consumption of utilities. The HEN was reconstruded by adding new heat exchangers. In order to produce new HEN, the capital costs had to be increased, but the total cost trade-off between the capital and energy costs will be decrease by 30 %.

Keywords: energy recovery, pinch technology, HEN design, plant for methanol synthesis.

INTRODUCTION

An important aspect of energy conservation is the establishment of an optional heat exchanger network (HEN) during the design of a plant. The problem of designing an optimal HEN synthesizing has received significant attention and an extensive review of the papers can be found in the current literature.[1–8] Also, a very large number of analyses of HEN is well known which are now generally applied to the design of a chemical plant. The pinch technology has been successfully applied to many different industrial application.[9–16] In this work the principles of the pinch technology[17] used for energy integration will be applied to the heat exchanger network of a plant for methanol synthesis. Pinch technology is an attractive and practical methodology for the systematic application of thermodynamics laws. The application of this technique enables a fundamental insight into the thermal interactions between a chemical process and the utility systems to be gained. This means that a certain reconstruction and financial investment in an existing process can considerably reduce capital and energy consumption. This has great significance not just

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from an economic point of view but also from the aspect of environment preservation and reduction of heat pollution is achieved. The main goal of this work was to obtain preliminary results to ascertain whether the reconstruction of the heat exchangers network in methanol synthesis process would be profitable or not.

The investigation performed in this work within our process modelling framework consisted of the following stages: (*i*) the change of the existing HEN (base case design) using a pinch decomposition strategy in order to save energy by increasing the heat-transfer area; this solution represents the maximum energy recovery design, (*ii*) using multiple pinches in order to reduce the cost of the utilities for heating and cooling.

CASE STUDY

Analysis of the energy in the process

Table I gives the basic stream data for the methanol synthesis process presented as a flow sheet diagram[18] in Fig. 1.

TABLE I Stream table

Steam	T_S/ºC	T_T/ºC	$m\Delta h$/kW	CP/(kW/ºC)
1	424.3	120.0	–1521.50	5.0
2	342.1	120.0	–1110.50	5.0
3	342.2	120.0	–1111.00	5.0
4	343.1	160.0	–933.81	5.1
5	403.1	210.0	–1004.12	5.2
6	349.7	450.0	1925.76	19.2
7	37.7	450.0	1896.58	4.6
8	14.5	70.0	227.55	4.1
9	62.0	62.0	–1108.00	–
10	98.9	98.9	1126.00	–
11	60.6	60.6	–1869.00	–
12	76.4	76.4	1866.00	–
13	60.6	30.0	–76.50	2.5
14	98.9	30.0	–75.79	1.1
15	76.4	30.0	–13.92	0.3

In Fig. 1 the streams involved in the heat exchanger network (HEN) design are labelled with the numbers 1 to 15.

As can be seen from Fig. 1, a gaseous product, after leaving reactor R100 is ejected to a consecutive compression with a middle stage refrigeration (from C129 to C139). This high-pressure gaseous compound, after blending of the outlet stream of the flash F220 with the feed that comes from compressor C139, is additionally heated to 450 ºC and led into reactor R200 where the chemical reaction of methanol synthesis is performed. The products

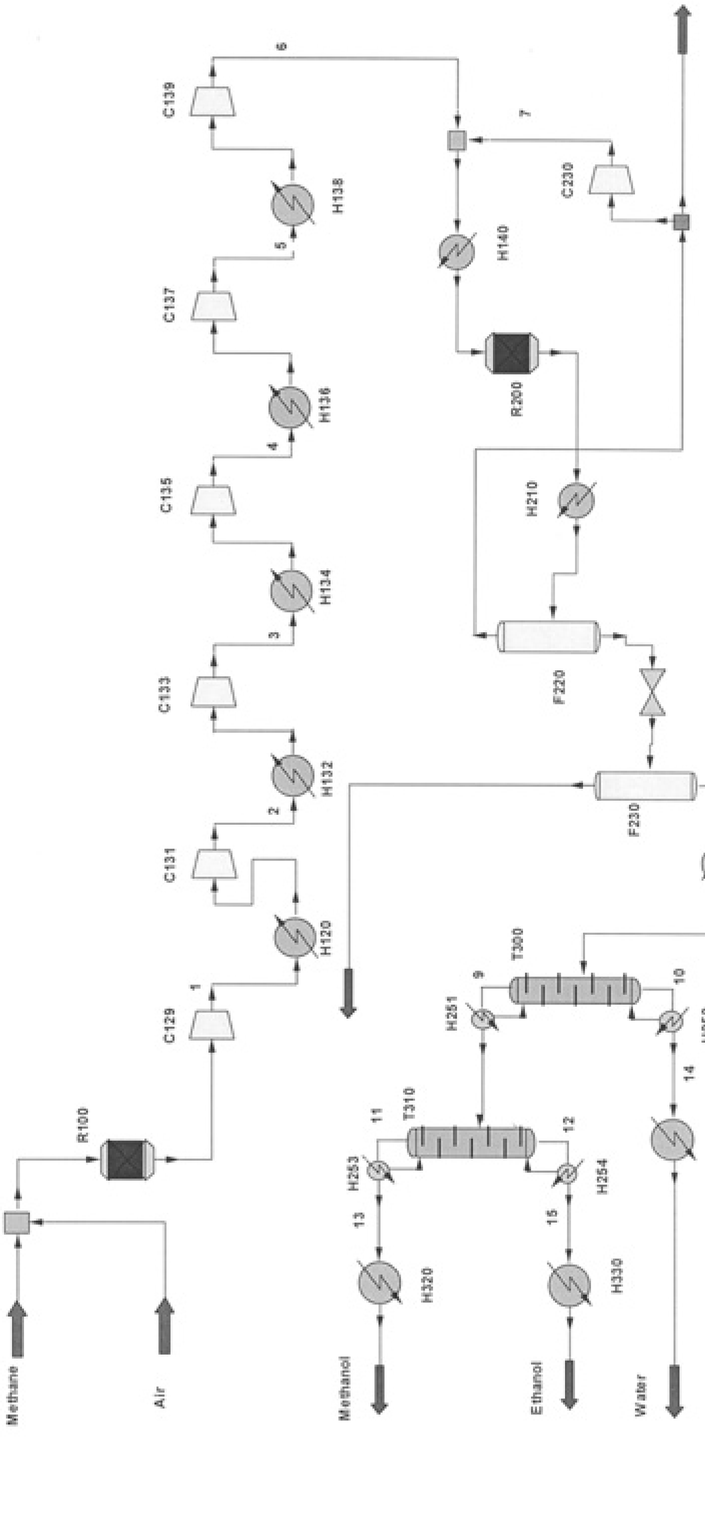

Fig. 1. The process flowsheet of a methanol synthesis plant.

from reactor R200 are partially condensed and conduced into the flash F220. The gaseous product (from the top of the vessel), as already mentioned, returns as a recycle to reactor R200, while the liquid product is taken to the second flash F230 and into the distillation system (T300 and T310) for further methanol purification. In the analysis of the heat integration of the presented process, all middle stage refrigeration of consecutive compressions are engaged; energy is also consumed by consumption all the reboilers (H252, H254) and condensers (H251, H253) of the distillation columns.

The original process of methanol producing includes 15 heat exchangers (H120, H132, H134, H136, H138, H140, H210, H240, H251, H252, H253, H254, H320, H330, H340) 7 compressors (C219, C131, C133, C135, C137, C139, C230), 2 reactors (R100 and R200), 2 flash vessels (F220 and F230) and 2 distillation columns (T300 and T310).

THE NETWORK DESIGN

As can be seen from Fig. 1, all the heat exchangers, presented on the active HEN, demand an involvement of extra hot or cold utilities, without the existence of energy conservation. For the network design,[17] the problem of choosing the ΔT_{min} is one of the most important parts in energy conservation, since increasing ΔT_{min} will decrease the amount of heat echanged in the system, and *vice versa*. The correct value of ΔT_{min} can be easily identified using the process pinch design method. For this plant, the recommended[19] ΔT_{min} value is ΔT_{min} = 15 ºC which was also obtained as the optimal value.

For the process pinch design strategy, leading to maximum heat recovery with the lowest number of units, the following steps should be involved:[17,20] (*i*) the problem should always be solved from the most constrained region – the Pinch point, (*ii*) temperature feasibility requires constraints on the *CP* values for the hot and cold streams to be satisfied for matches between streams in the pinch region, (*iii*) the use of the tick-off heuristic technique to achieve the minimum number of units. These rules were introduced in order to simplify the pinch analysis approach. With the chosen ΔT_{min} a Pinch temperature of 357.2 ºC was obtained. The complete network design, after the synthesis above and below the pinch, is shown in Fig. 2. The network consists of ten hot streams, 1–5, 9, 11 and 13–15 (at the top running from left to right), and five cold streams, 6–8, 10 and 12 (at the bottom running from right to left).

The network above the pinch contains two hot and two cold streams (Fig. 2). In the first step it is suggested to link streams 5 and 6 because the term $CP_c \geq CP_h$ is fulfilled. There is one heat exchanger HE1 (shown as linked circles on the relevant streams). The network design above the pinch is completed by satisfying the heating utility requirement with heaters H1 and H2.

The network design immediately below the pinch contains two hot and one cold stream passing through the pinch. The first step below the pinch point is to connect streams 1 and 7 by exchanger HE2. That connection is feasible because $CP_h \geq CP_c$. The next step is to connect streams 5 and 7 (with heat exchanger HE3) and 1 and 7 (with heat exchanger HE4). 11 streams are situated far away from the pinch region and they are connected with

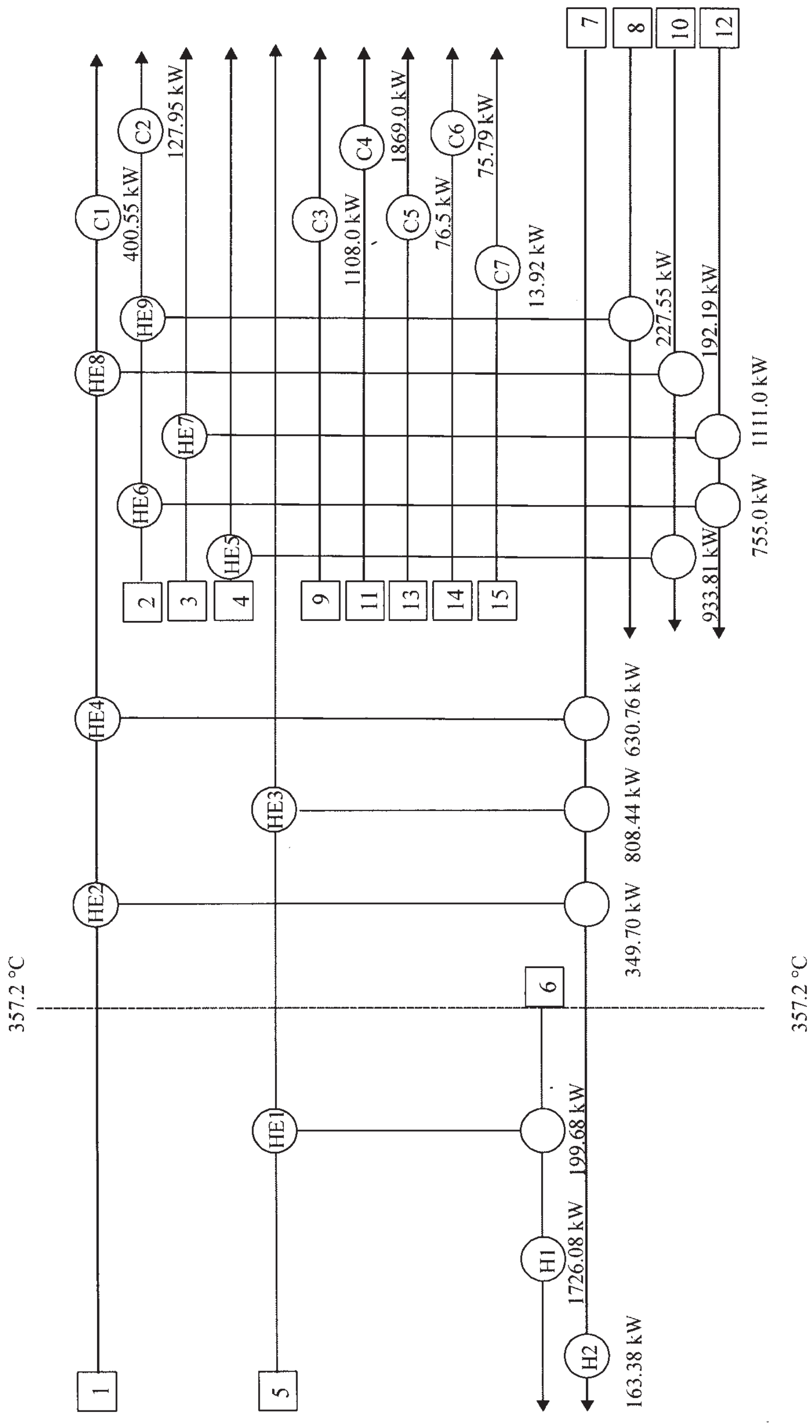

Fig. 2. The proposed heat exchangers network.

heat exchangers HE5 – HE9. The additional energy requirements below the pinch are completed by suppling the cooling utility with coolers C1 – C7.

Using the energy cascade calculation, the following results for energy requirements were obtained:

– Hot utility requirement 1889.46 kW and

– Cold utility requirement 3671.71 kW.

To calculate the cost targets and to annualise them, approximate average values of the utility prices, a pay back time of five years with an interest rate of 5.0 % and a Long Factor of 3.4. were used. The capital cost estimated for the heat exchangers of the original design and that after pinch analysis are based on the purchase cost.

The capital cost (C) are estimated using the following correlation

$$C = a + bA^c \tag{1}$$

with different values of parameters a, b and c for different types of heat exchangers.[7,21,22]

On the basis of all the above-mentioned parameters, the following results for area and cost targets were estimated. The approximate result of this procedure is a significant decrease of the estimated total cost targets (about 30 %) compared with those obtained for the original heat exchangers network.

In this way, it is clear that the energy – efficiency of the process and the capital cost strongly depends on the heat exchanger network design.

PROCESS OTPIMISATION – REMAINING PROBLEM ANALYSIS

Further optimisation of the HEN can be performed using multiple pinch analysis.[20,23–25]

It is very important to incorporate a multiple pinch analysis in the optimisation of the heat exchanger network, since in this way, the driving forces between the utilities and the process can be reduced, and so, theoretically, the operating cost for stream production can be reduced.

The best way to make a selection of the utilities is to construct a grand composite curve diagram where the number of utilities used can be easily seen, and on what energy levels they should be introduced. The point where the lower temperature stream touches the grand composite curve leads to the utility pinch. Figure 3 shows the grand composite curve with the heating steam introduced on two different levels $T_1 = 500$ ºC and $T_2 = 400$ ºC. In this way the consumption of the higher temperature steam is reduced, especially in the part of the grand composite curve near to the process pinch where parts of the lower temperature process streams are situated. In this region, a less expensive hot utility steam (temperature 400 ºC) was used and fit to the grand composite curve covering its energetic part from the process pinch to the temperature 400 ºC where the utility pinc occur.[17]

The methodology of HEN designing is to start at the pinch (utility or process) and move away. At the pinch, the rules for *CP* must be obeyed.

Following the steps for network design introduced in the previous section, there

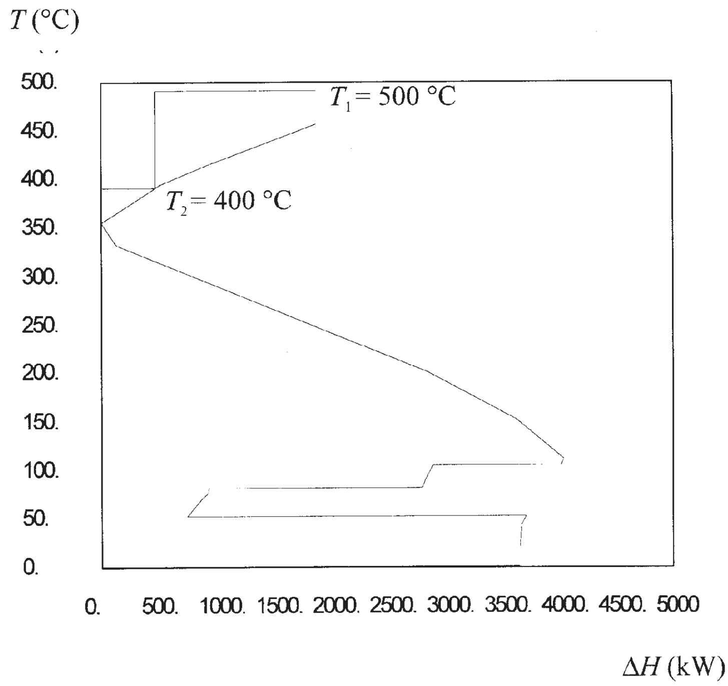

Fig. 3. Process utility grand composite curve.

should not be heat transfer across either the process pinch or the utility pinch. Also, there must be no use of inappropriate utilities. This means that above the utility pinch (Fig. 4) only the use of high temperature steam HT at 500 ºC is allowed (no low temperature stream or cooling water). Between the utility pinch and the process pinch, a low temperature steam LT (at 400 ºC) should be used as the least expensive heat source (no high temperature stream or cooling water). Only cooling water should be used below the process pinch in Fig. 4. The appropriate utility streams have been included with the process streams in Fig. 4.

On the bases of the methodology followed in the HEN design presented in Fig. 2, it can be seen that the network above the utility pinch contains two hot streams and two cold streams linked with the heat exchangers HE1 and HE2 (Fig. 4). The network design above the utility pinch is completed by satisfying the heating utility requirement with a high temperature stream (heaters H1 and H2).

However, between the two pinches it is very important to simultaneously follow the *CP* rules for both sides since designing away from both pinches could lead to a conflict where both meet. In Fig. 4, it can be seen that the correctness of the HEN in that region assumed streams 1 and 6 (HE3) to be linked below the utility pinch and streams 5 and 7 (HE5) and 1 and 7 (HE4) above the process pinch. The network design below the utility pinch and above the process pinch is completed by satisfying the heating utility requirement with a low temperature stream (heater H3).

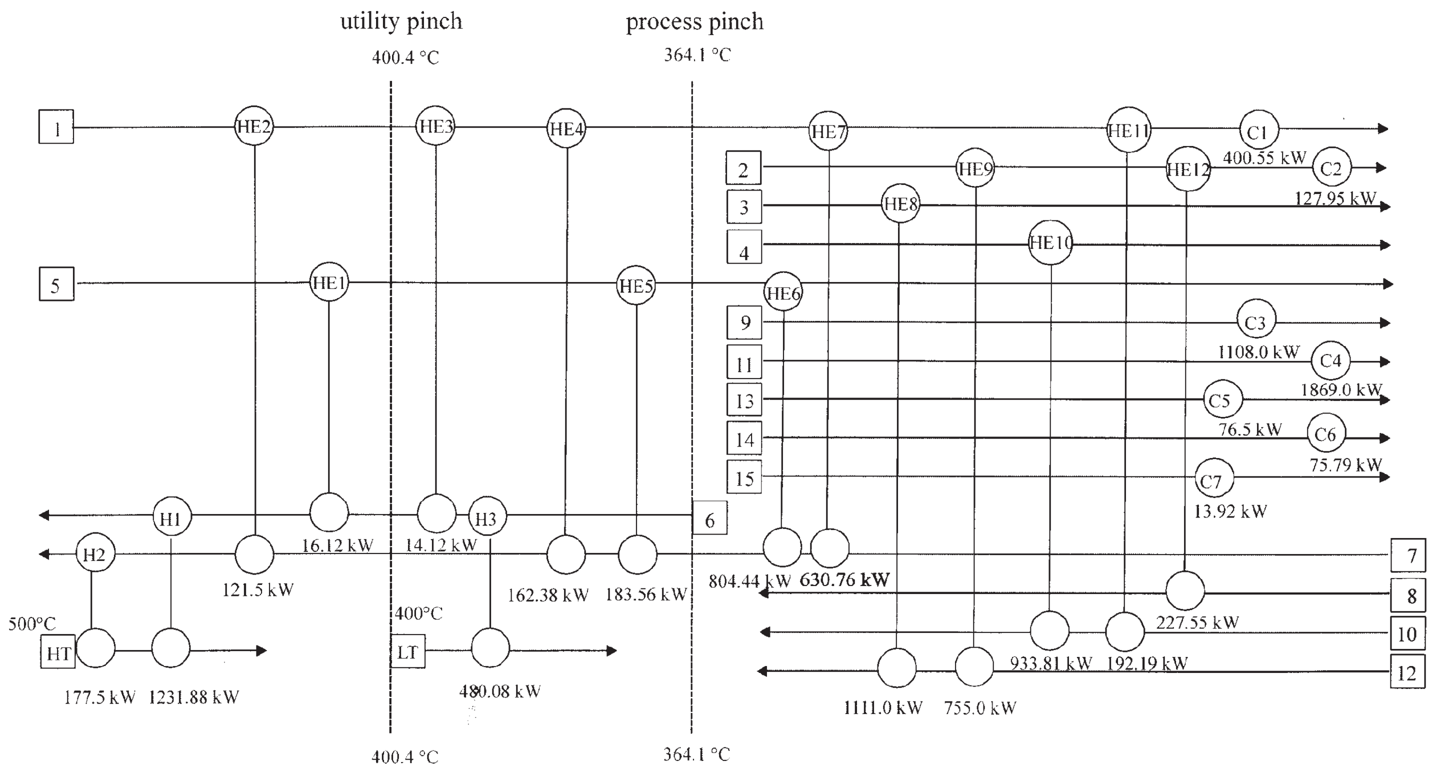

Fig. 4. The heat exchangers network after retrofit analysis.

The network design immediately below the process pinch contains two hot and one cold stream passing through the process pinch. The first step below the process pinch point is to connect streams 5 and 7 (HE6) and streams 1 and 7 (HE7). Far removed from the process pinch, 11 streams are situated and connected with the heat exchangers HE8 – HE12. The additional energy requests below the process pinch are completed by satisfying the cooling utility with coolers C1 – C7.

The number of heat exchangers in the HEN presented in Fig. 4 has increased by three apparatus comparing to the minimal calculated number given in Fig. 2.

Of course, as it was mentioned before, the pinch method was performed only to obtain the preliminary results that will show if the HEN reconstruction is profitable or not.

Comparison of the HENs obtained by the process pinch and multiple pinch procedure (Fig. 2 and Fig. 4) shows that the introduction of an additional utility (Fig. 4) decreased the operating costs by nearly 25 % of the energy, which has been supplied on lower temperature and pressure level, but also it caused the total number of units to increase from 18 to 22. So, this analysis leads to total costs which are slightly higher (6 %).

CONCLUSION

Comparison of the original HEN of the process of methanol synthesis and those obtained by process pinch and multiple pinch analysis (Fig. 2 and Fig. 4) shows that total costs are about 30 % lower for the situation obtained with the process pinch design method. Introduction of an additional utility in the multiple pinch procedure decreases the operating costs by the part of the energy (25 %) supplied to the lower temperature and pressure level by a steam utility, compared to the HEN obtained with the process pinch design. However, the total number of units was increased. Therefore, the multiple pinch analysis led to total costs which are slightly higher.

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LIST OF SYMBOLS

a, b and c – Heat exchangers cost parameters
C – Capital cost
Ci – Cooler i
CP – Heat capacity, kW/ºC
Δh – Change in enthalpy, kJ/kg
Hi – Heater i
HEi – Heater exchanger i
HT – High temperature stream
LT – Low temperature stream
T – Temperature, ºC
ΔT_{min} – Minimum temperature difference, ºC

Subscript

T – Target state
S – Source state
c – Cold stream
h – Hot stream

ИЗВОД

ЕНЕРГЕТСКО И ЕКОНОМСКО ПОБОЉШАЊЕ ПРОЦЕСА СИНТЕЗЕ МЕТАНОЛА ПРИМЕНОМ Pinch ТЕХНОЛОГИЈЕ

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У овом раду је показано како се применом Pinch методологије на реконструкцију постојеће мреже размењивача топлоте, у посматраном индустријском постројењу могу добити знатне енергетске и економске уштеде. Проучаван је процесс синтезе метанола и приказана је могућност смањења трошкова везаних за енергетске захтеве у процесу пре свега везаних за коришћење помоћних топлотних извора. Добијени резултат указује да је за реконструкцију неопходно увођење нових размењивача топлоте, што повећава капиталне трошкове саме мреже али укупни трошкови, који обухватају капиталне и енергетске трошкове, су смањени за око 30 %.

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