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Improving Heat Exchanger Network Design of a Revamped Chemical Plant

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ABSTRACT

Pinch analysis has been known as one of the tools for smart energy management. This technique has successfully been applied in more than three decades in various industries. Here, the purpose of this study was to describe how to use pinch analysis for improving heat exchanger network design of a revamped chemical plant. In a revamping project of a chemical plant, the pinch analysis is applied to find a better design. The analysis reveals that the revamped case can be further improved to achieve more energy saving. This is done by applying one of the golden rules in pinch analysis, which is not to transfer heat across the pinch. The proposed solution is rather simple and straightforward, leading to only few months of payback period and 165 k€ per annual saving.

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1. INTRODUCTION

Pinch analysis is a well-known tool to give insights on thermal energy saving. (Aspelund *et al.*, 2007) Its diverse applications in various industries show its usefulness. (Varbanov, 2014) For further information, literatures have covered this subject in great details. (Kemp, 2005; Linnhoff, 1993; Feng & Zhu, 1997).

Previous study has been reported about early phase process evaluation, (Putra, 2016). Here, in this article, the pinch analysis has been applied to improve the design of a chemical plant. A revamp project was done on the plant to keep up to the increasing market demands. As background information, its current and revamped situations will be discussed. Next, a pinch analysis of the plant is applied and a straightforward solution is recommended. Due to confidentiality, all drawings and data have been changed from the original case, leaving only the similar problem and the recommended solution.

2. CURRENT SITUATION

The chemical production is a very simple process, where the feed is reacted in a reactor and the outlet stream is separated in two sequential distillation columns. (Douglas, 1985) Unreacted feed is recycled to a feed tank, while the product and the waste are sent to their corresponding destinations. (Adams & Seider, 2006) The plant has already had an existing heat integration feature, where the feed stream is preheated with several streams coming from reactor and distillation columns. (Stankiewicz & Moulijn, 2000)

The current plant runs without using heat exchanger HE-16, upstream of D1 (see **Figure 1**). The heat exchanger is connected to the cooling water system to further reduce the temperature of the outlet reactor before entering D1. Unfortunately, it was broken. Nonetheless, the operators did not have any problem in running the plant. Hence, HE-16 was bypassed and the stream was not further cooled (See **Figure 1**).

3. REVAMPED SITUATION

In the revamped situation, due to the new increased plant capacity, many of the unit operations are just enlarged. (Wang *et al.*, 2011) This includes many of the heat exchangers and pumps. A new identical reactor is installed, while the two distillation columns are not modified. They are apparently big enough for the new capacity. The bigger outlet stream from the reactor will now need to be cooled down to keep the current operating situation in D1 the same. Due to the fact that the HE-16 is already present and it just needs some reparations, it was decided that this heat exchanger would be re-operated. Hence, this was the slight difference from the current situation.

An energy consumption analysis was done during the project. It was shown that the revamped situation would require external heating utilities of about 5.22 MW. It was about 36% lower compared to an old case without the existing heat integration feature. Similarly, it was required to discharge 5.53 MW to the cooling water system. This was 35% lower compared to a design without heat integration feature.

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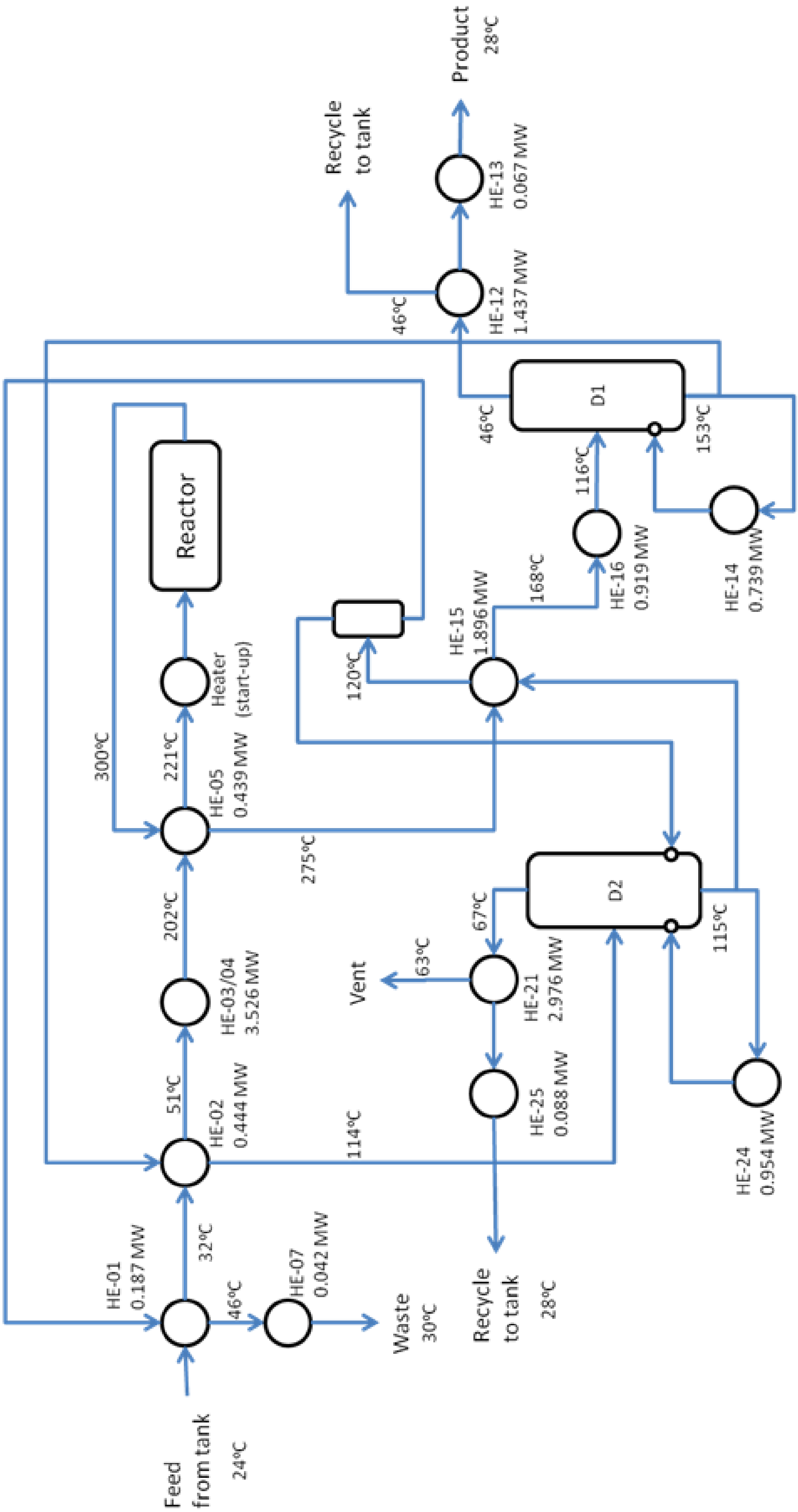

Figure 1. The revamped situation of a chemical plant

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A pinch analysis was performed (see **Figure 2**). This figure shows relationship between yielded hot/cold composite curves and temperature. The curves were obtained by different temperature minimum ($\Delta Tmin$) of 30°C. It was calculated that the revamped case would be about 29% higher and 27% higher compared to the heating and the cooling utility targets (4.05 and 4.36 MW, respectively). Hence, based on these numbers, it seems that the current heat exchanger network design does not far off of the target. Nonetheless, an intriguing question was raised; could we do better within this expansion project regarding the energy consumption? If it is possible, how much energy could be reduced and how would be done that?

4. ANALYSIS OF THE EXISTING HEAT EXCHANGER NETWORK DESIGN

To answer such questions, the composite curves were revisited and the heat exchanger network design was observed deeper. (Kazantzi, 2006) Squeezing more from the heat integration does not lead to significant saving. This is shown in **Figure 3**, where ΔT_{min} is varied from 5 to 60°C, whereas the current heat exchanger network design could be said to have an average of 50°C.

From this figure, it has been found that even using a small temperature ΔT_{min}, it would not reduce both utilities significantly. On the contrary, it would definitely increase the plant complexity. Another look at the current heat exchanger network design, presented in a grid diagram, is shown in **Figure 4**. The grid diagram is constructed with the temperature $\Delta Tmin$ of 30°C and pinch temperature of 52°C (see **Figure 2**).

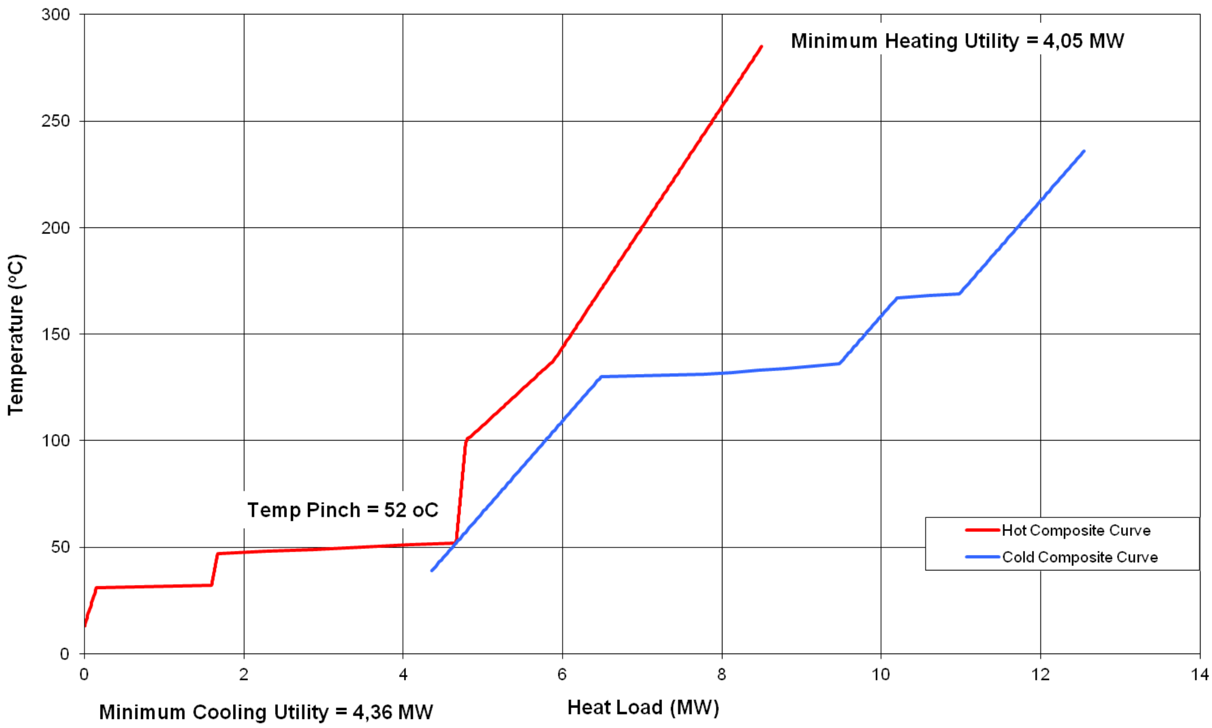

Figure 2. Composite curves of the plant

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Based on this analysis, there are two violations to the golden rules in pinch analysis. To make clear the discussion, dotted red lines can be shown in detail. First, the existing operation of HE-16 with cooling water is violating the rule of not to use cooling utility above the pinch temperature. Hence, its cooling water duty of 0.92 MW also yields the same amount of penalty to the heating utility.

The second violation is a heat transferred across pinch in HE-01. The amount of heat is with the amount of 0.134 MW. This will also give the same amount of penalties to both heating and cooling utilities.

5. PROPOSED SOLUTION

The above observation clearly shows what needs to be done to improve the current heat exchanger network design. Due to its significant amount and simpler to implement, removing the first violation is relatively a straightforward solution. Hence, the feed stream downstream of HE-01 is split into two streams. One part goes to its current destination (the existing HE-02), and the other part is rerouted to the existing HE-16. With this modification, the heating utility in HE-03/04 is reduced to 2.6 MW, from previously 3.5 MW (**Figures 1 and 4**). This is shown in **Figures 5 and 6**, in the grid and the block diagram, respectively. The dotted lines in both figures show the proposed modification.

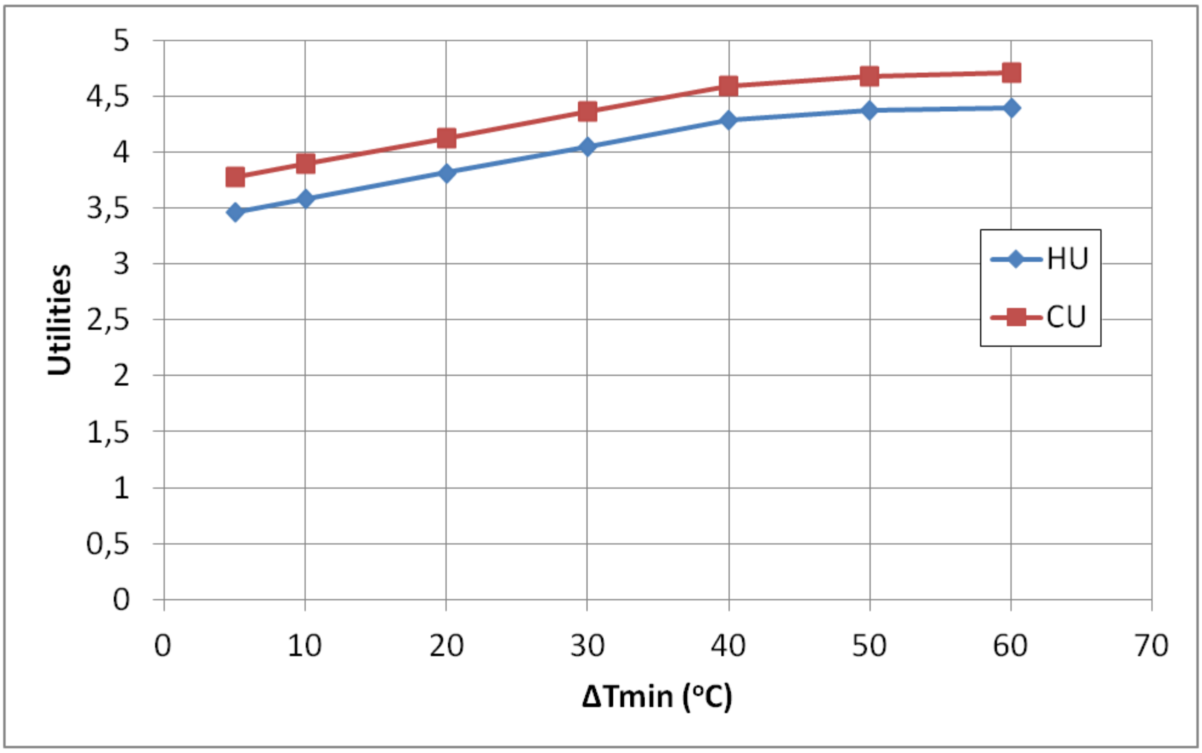

Figure 3. *ΔTmin* variation of the composite curves

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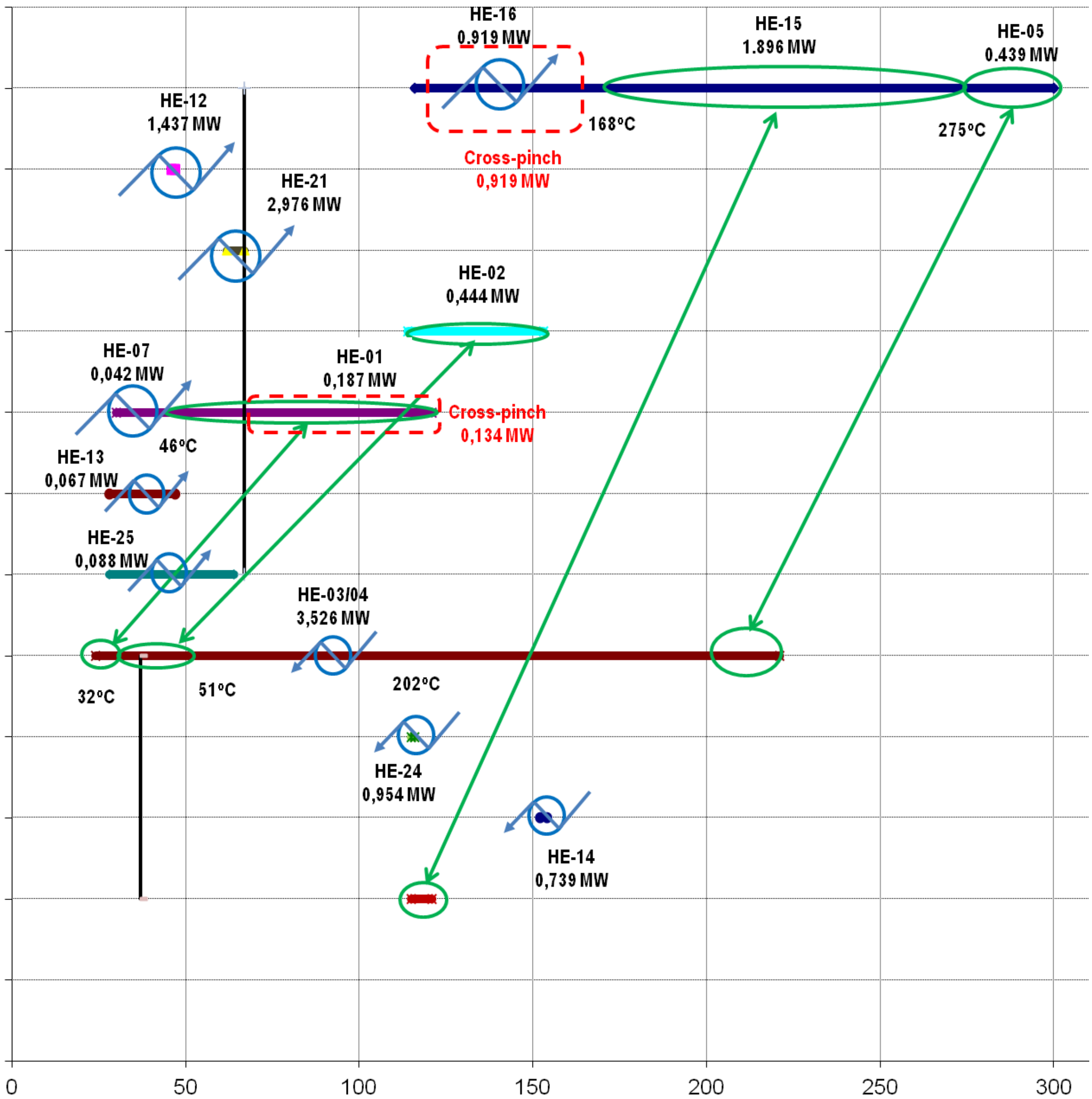

Figure 4. Grid diagram of the heat exchanger network for the current design

This modification requires additional areas in the existing HE-16, which is symbolized in the additional blue part of HE-16 in **Figure 6**. In-house capital expenditure (CAPEX) estimation shows a required installed cost of about 40 k€. This cost can be considered good.

The comparison of utilities in several cases (including the targets with different temperatures ΔT_{min}) is shown in **Table 1**. This table describes about comparison for heating utility and cooling utility. The table compares without heat integration, current utilities, target at temperature $\Delta Tmin$ = 30°C, and proposed solution. The utility consumptions of the proposed solution are shown under the column of "proposed solution". The proposed solution requires each heating and cooling utility of only about 6% lower than the targets. It has been improved significantly from the original revamped case.

Compared to the current utilities of the revamped case, the proposed modification has a saving opportunity of about 0.92 MW. This translates into 165 k€/yr of saving, which is significant. Based on the estimated investment, the payback period is about 3 months.

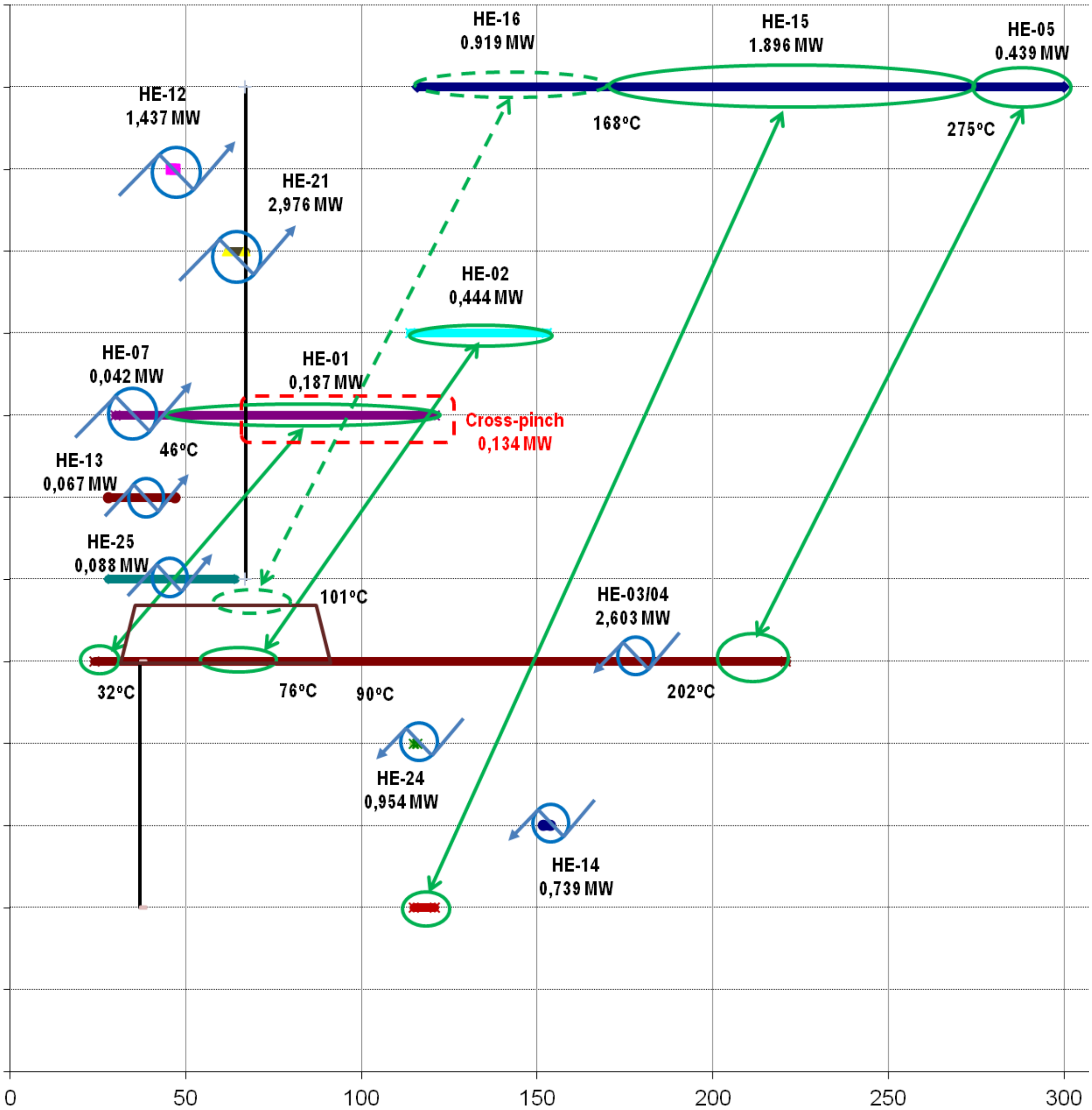

Figure 5. Proposed modification shown in the grid diagram

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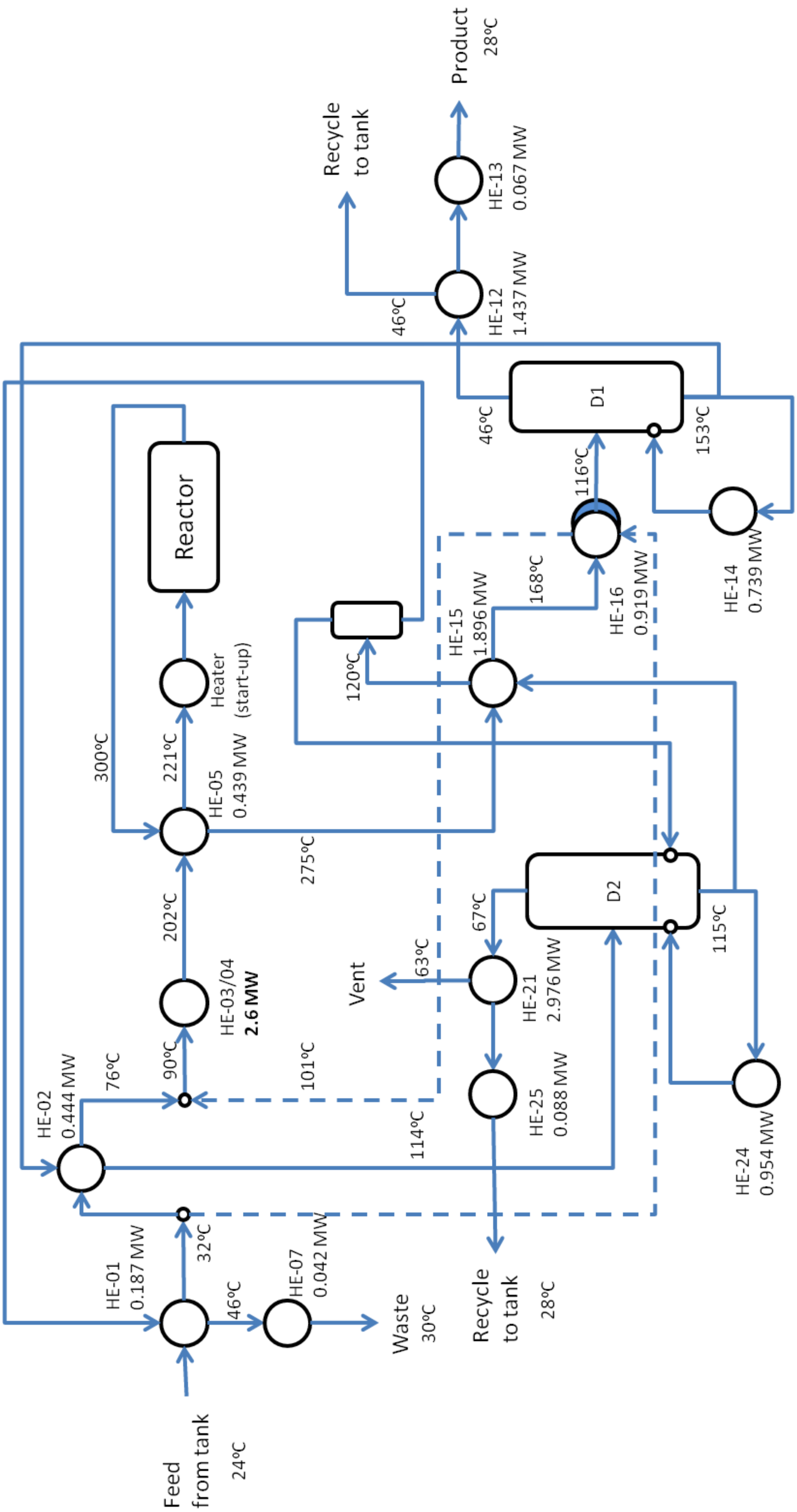

Figure 6. Proposed solution shown in the block diagram

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Tabel 1. Comparison of utilities

	Without heat integration	Current utilities	Target at $\Delta Tmin$=30°C	Proposed solution
Heating Utility (MW)	8.19	5.22	4.05	4.3
Cooling Utility	8.50	5.53	4.36	4.61

6. CONCLUSION

A pinch analysis has been performed to improve a design of a revamping chemical project. A slight difference in the revamped case that was thought not to give any issue is apparently the reason for higher energy consumption. Some pipe rerouting and additional heat exchanger areas are proposed, which gives only 3 months of payback period and 165 k€ of annual saving.

7. ACKNOWLEDGEMENTS

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8. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

9. REFERENCES

Adams, T. A., & Seider, W. D. (2006). Semicontinuous distillation with chemical reaction in a middle vessel. *Industrial and engineering chemistry research*, *45*(16), 5548-5560.

Aspelund, A., Berstad, D. O., & Gundersen, T. (2007). An extended pinch analysis and design procedure utilizing pressure based exergy for subambient cooling. *Applied thermal engineering*, *27*(16), 2633-2649.

Douglas, J. M. (1985). A hierarchical decision procedure for process synthesis. *AIChE journal*, *31*(3), 353-362.

Feng, X., & Zhu, X. X. (1997). Combining pinch and exergy analysis for process modifications. *Applied thermal engineering*, *17*(3), 249-261.

Kazantzi, V. (2006). *Novel visualization and algebraic techniques for sustainable development through property integration* (Doctoral dissertation, Texas A&M University).

Kemp, I. C. (2005). Reducing dryer energy use by process integration and pinch analysis. *Drying technology*, *23*(9-11), 2089-2104.

Linnhoff, B. (1993). Pinch analysis: a state-of-the-art overview: Techno-economic analysis. *Chemical engineering research and design*, *71*(5), 503-522.

Putra, Z. A. (2016). Early phase process evaluation: Industrial practices. *Indonesian journal of science and technology*, *1*(2), 238-248.

Stankiewicz, A. I., & Moulijn, J. A. (2000). Process intensification: transforming chemical engineering. *Chemical engineering progress*, *96*(1), 22-34.

Varbanov, P. S. (2014). Energy and water interactions: implications for industry. *Current opinion in chemical engineering*, *5*, 15-21.

Wang, G. Q., Xu, Z. C., & Ji, J. B. (2011). Progress on Higee distillation—Introduction to a new device and its industrial applications. *Chemical engineering research and design*, *89*(8), 1434-1442.

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