

Process Modification for Energy Demand Reduction in Acetic Acid Production

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Abstract

Methanol carbonylation via the Cativa Process is the dominant technology for acetic acid production, offering high selectivity and operational efficiency. In the initial design of plants based on this process, however, heating energy demand was substantial, particularly during the methanol preheating stage prior to compression, which increased operating costs. Energy optimization is therefore critical to improving the economic viability of the process. This study aims to reduce utility energy demand through modifications in the feed preheating stage. The modification involved installing heat exchangers in the stream supplying the main heater and utilizing the recycle stream as an internal heat source. Simulation results demonstrated a significant reduction in the heating load of the main heater, thereby lowering steam demand compared with the original design. Overall, the total heat load decreased by 102,015.82 kJ/h, equivalent to approximately 22.27% relative to baseline conditions. These findings confirm that simple heat integration in the preheating stage can substantially enhance energy efficiency without compromising process performance.

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Keywords: Energy efficiency; Acetic Acid; Methanol; Reducing Energy; process design

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1. Introduction

Acetic acid, the principal component of vinegar, is an organic compound characterized by its carboxyl functional group, which imparts acidic properties [1]. Beyond its role in food, acetic acid is widely applied across industries: as an acidity regulator in food processing, a precursor in pharmaceutical synthesis, and a key agent in textile dyeing. It also serves as a building block for numerous high-value downstream chemicals [2]. Commercial production of acetic acid is dominated by chemical synthesis, with methanol carbonylation being the most widely adopted route. This thermochemical pathway is preferred over biological processes used for food-grade vinegar because it offers high conversion

efficiency and superior product quality [2]. The primary reaction involves methanol (CH_3OH) and carbon monoxide (CO) forming acetic acid (CH_3COOH), while side reactions may yield methyl acetate ($\text{CH}_3\text{COOCH}_3$), which must be carefully controlled [3]. Global demand for acetic acid has grown substantially, rising from approximately 14 million tons in 2015 to nearly 18 million tons in 2022. This trend underscores the need for more efficient and sustainable production technologies to meet expanding market requirements [4].

Energy consumption is a critical factor in acetic acid plant design. Process modifications are essential to reduce utility demand without compromising product quality. Simulation tools such as Aspen HYSYS enable energy balance analysis, utility evaluation, and identification of energy-intensive units [5]. In the original Cativa Process, feed preheating was identified as one of

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the largest contributors to steam demand, with limited internal heat recovery. Despite its significance, heat integration strategies for this stage have not been extensively studied. To address this gap, the present work proposes a novel preheating configuration that incorporates an additional heat exchanger and utilizes the recycle stream, thereby reducing steam demand and improving energy efficiency.

This study investigates process modifications in acetic acid production with the primary objective of minimizing energy consumption. Aspen HYSYS simulations were employed to evaluate modification scenarios and determine optimal operating conditions. The approach builds on prior research: Dimian & Kiss [6] introduced a methanol carbonylation process with reduced energy requirements; Martín-Espejo *et al.* [7] compared conventional acetic acid routes with biogas-based low-carbon alternatives; and Abir Abdelftah [8] demonstrated the role of process simulation in optimizing operational parameters. Collectively, these studies highlight the importance of heat integration and recycle stream utilization as effective strategies for reducing energy demand in chemical processes.

This study aims to develop a modified preheating system for the Cativa Process by integrating heat exchangers and recycle streams to reduce steam demand and thereby decrease energy consumption in acetic acid production. Several modification scenarios were assessed through Aspen HYSYS simulations to identify the most effective operating configuration. The proposed design is expected to enhance energy efficiency, achieve meaningful reductions in energy demand, and strengthen the sustainability of the chemical industry through energy-conscious process strategies.

2. Methods

2.1. Process Simulation Using Aspen HYSYS

Aspen HYSYS is a widely adopted process simulation platform that supports complex applications in chemical and process engineering. Within the oil, gas, and refining industries, it provides a robust thermodynamic framework capable of accurately computing physical properties, transport parameters, and phase-equilibrium behavior, thereby enabling reliable prediction of fluid property variations and overall process performance [9]. Beyond these capabilities, Aspen HYSYS is extensively employed for systematic performance evaluation and process optimization [10].

The software incorporates advanced thermodynamic models including COM Thermo, NRTL, and Peng–Robinson to represent non-ideal phase behavior and to generate precise material

and energy balance predictions [11]. In addition, it offers a comprehensive library of unit operation models, such as distillation columns, reactors, heat-transfer equipment, rotating machinery, and control systems, supporting both steady-state and dynamic simulations [12].

In this study, Aspen HYSYS is utilized to model the complete process flow for acetic acid production. The Peng–Robinson thermodynamic model was selected due to its ability to accurately represent hydrocarbon and carbon monoxide gas–liquid mixtures under high-pressure conditions. Simulation was conducted using operating parameters derived from reaction kinetics data reported in the literature, enabling detailed mass and energy balance calculations for each unit operation.

2.2. Process Modification Description

The unit operations employed in this study include a conversion-type reactor, heat exchangers, a flash drum, and a distillation column. Subsequently, system performance is analyzed by evaluating the energy consumption of the reboiler and condenser, as well as the cooling and heating utility requirements. Several process modification scenarios are then examined to identify the design that yields the highest energy efficiency.

The main modification implemented in this study is the addition of a more thermally integrated heat exchanger design before the heater (E-113), aimed at reducing the energy required by the heater for the methanol feedstock heating process. Another modification involves adding a splitter (TEE-100), which functions to divide the reactor's output flow so that a portion is directed to the expander to continue the production process until the product is formed, while the remaining portion enters the recycle stream to be used as heating fluid in the methanol preheating process. Heat exchangers play a crucial role in chemical processes by functioning as heating and cooling units. Therefore, optimizing the heat exchangers can reduce utility demands and improve overall energy efficiency. Enhancements in heat-exchanger configuration can significantly reduce energy consumption and improve process sustainability [13].

2.3. Energy Reduction Calculation Method

To quantitatively evaluate the effectiveness of the proposed heat exchanger modification, the percentage of energy reduction was calculated based on the total heat load of the system before and after modification. The percentage of energy efficiency (η , %) in the system can be calculated using the following formula:

$$\eta = \frac{(Q_0 - Q_1)}{Q_0} \times 100\% \quad (1)$$

where Q_0 is the total heat load before modification and Q_1 is the total heat load after modification.

3. Results and Discussion

3.1. Process Overview Before and After Heat Exchanger Modification

In the production of acetic acid via methanol carbonylation, a substantial share of the overall energy demand is devoted to feed preheating, recycle stream heating, condensation, and other auxiliary units. Under the initial configuration, the heat flow distribution revealed relatively high energy consumption, with units G-118, COND, and E-119 identified as the primary contributors to the system's total heat load (Figures 1 and 2).

To enhance energy efficiency, a process adjustment was made by installing a heat exchanger before the main heater. This unit enables recovery of part of the outlet stream's heat, which is then reused to preheat the incoming feed. For this setup, a splitter was added to the reactor's outlet stream to divert a fraction of the hot effluent into the new heat exchanger, while the rest continues along the original route. With the addition of both the splitter and the heat exchanger, heat that was previously discharged to cooling utilities can now be utilized to preheat the feed stream before entering the main heater. This arrangement improves internal heat recovery without changing the reactor's operating conditions.

The modified setup effectively changes the heat distribution pattern, allowing energy that

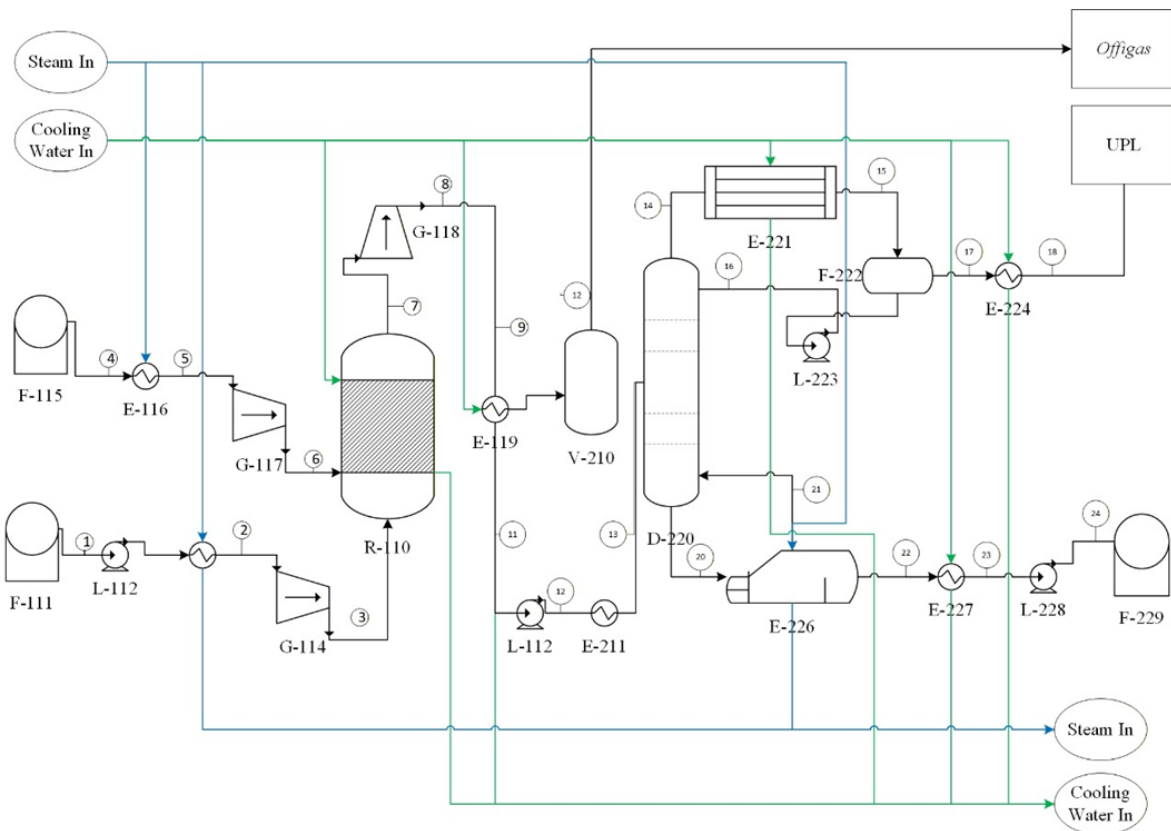


Figure 1. Process Flow Diagram (PFD) of process before process modifications.

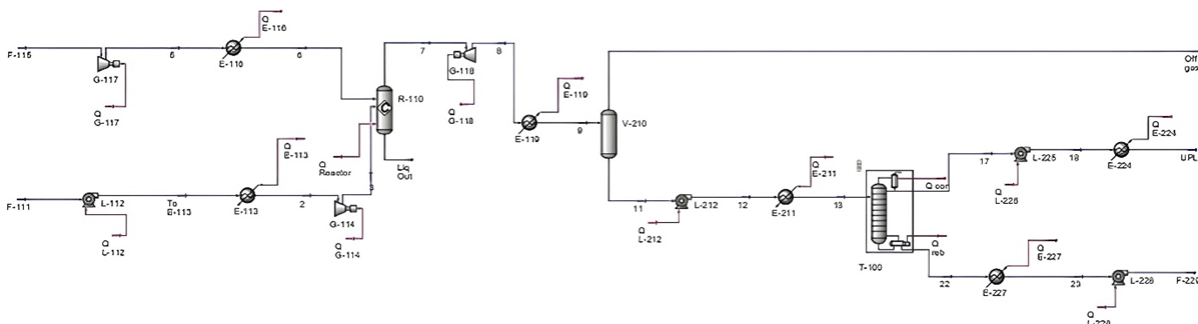


Figure 2. Aspen HYSYS simulation of process before modifications.

was previously discharged to utilities to be recovered and reused within the process. The simulation was performed in Aspen HYSYS under constant operating conditions (fixed pressure), and the effects of the configuration adjustments were assessed through comprehensive mass and energy balance evaluations (Figures 3 and 4).

3.2. Comparison of Energy Requirement Before and After Modification

A comparison of the heat load for each unit before and after the modification is shown in Table 1. In general, most units experienced a decrease in heat demand, particularly the key process units:

G-118 : from $1,46 \times 10^5$ kJ/h to $1,13 \times 10^5$ kJ/h

COND : from $1,24 \times 10^5$ kJ/h to $9,64 \times 10^4$ kJ/h

E-119 : from $3,60 \times 10^4$ kJ/h to $2,80 \times 10^4$ kJ/h

This observed reduction demonstrates the success of the inter-stream heat integration strategy. Table 1 shows that almost all process units experienced a reduction in heat duty after modification. The most substantial reductions were observed in the following units:

G-118 : decreased by 33,000 kJ/h

Q Cond: decreased by 27,600 kJ/h

Q Reb : decreased by 24,600 kJ/h

According to the simulation outcomes, the system's total heat load was reduced by 102,015.82 kJ/h, representing an overall energy savings of 22.27% compared to the original condition (Figures 3 and 4). This finding highlights the successful recovery and reuse of internal heat achieved through the introduced heat exchanger modifications.

3.3. Thermodynamic Consideration and Heat Balance Evaluation

The carbonylation of methanol to form acetic acid is an exothermic reaction occurring in the

liquid phase, generating a considerable amount of heat as documented in the literature [14]. Effective management of this released heat is essential to ensure stable reactor operation and to promote overall energy efficiency within the process. From a thermodynamic standpoint, the carbonylation of methanol is strongly favorable for acetic acid production under typical industrial conditions [15]. Consequently, the efficiency of the overall process is determined more by heat management than by thermodynamic constraints. This reinforces the rationale for introducing heat exchanger modifications to lower external energy requirements.

3.4. Impact of Heat Exchanger Modification on Energy Consumption

The implementation of heat exchanger modifications significantly reduced the energy requirements across several key process units, leading to a 22.27% decrease in the total system energy consumption. This improvement was achieved through enhanced heat integration, whereby a portion of the thermal energy previously dissipated through cooling utilities was effectively recovered and reused within the process (Table 1). The implementation of these modifications is consistent with the principles of heat integration in chemical processes, where inter-stream heat recovery is applied to reduce both heating and cooling demands without altering reactor operating conditions. In the methanol carbonylation process, this heat integration strategy has demonstrated strong thermal feasibility and offers further potential for optimization through pinch analysis or the application of more advanced heat integration configurations.

Overall, the results indicate that enhanced waste heat recovery reduces dependence on

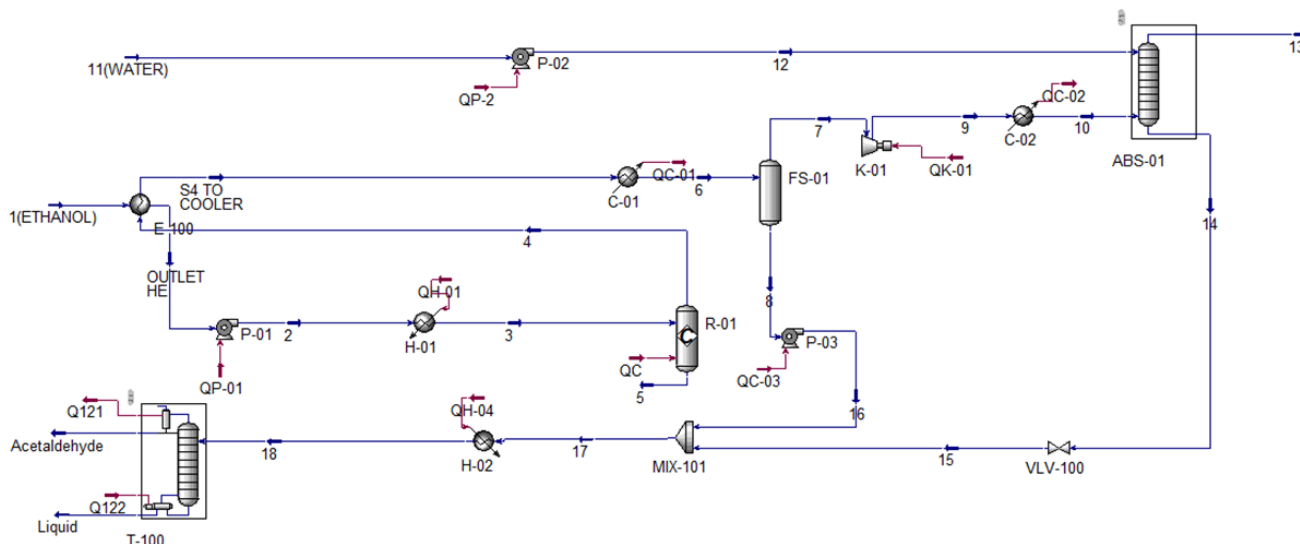


Figure 4. Modified process flow diagram of acetaldehyde using ASPEN HYSYS simulation.

external utilities and lowers the total process energy demand without compromising operational performance. Consequently, the implemented heat exchanger modifications not only provide substantial energy savings but also contribute to improved economic efficiency in the acetic acid production process.

4. Conclusion

The modification of the acetic acid production process using Aspen HYSYS successfully reduced the overall energy requirement of the system. The proposed modification involved the installation of an additional heat exchanger upstream of the heater unit. A portion of the heat from the reactor outlet stream was recovered and redirected to this heat exchanger, allowing the available thermal energy to be utilized more effectively prior to entering the heater. As a result, the total heat load decreased by 102,015.82 kJ/h, corresponding to an energy reduction of approximately 22.27% compared to the initial process configuration. This improvement in energy efficiency contributes to the sustainability of the chemical process by lowering energy consumption and enhancing heat recovery within the production system.

CRedit Author Statement

Author Contributions: A. Ramadhan: Conceptualization, Methodology, Formal Analysis, Resources, Writing, Review and Editing, Data Curation, Visualization; E. Saputri: Conceptualization, Methodology, Formal Analysis, Resources, Writing, Review and Editing, Data Curation, Visualization; F. Maulida: Conceptualization, Methodology, Software, Resource, Writing, Review and Editing, Data Curation, Visualization; H. Maulida: Conceptualization, Methodology, Software, Resource, Writing, Review and Editing, Data

Curation, Visualization; K. Priyanto: Conceptualization, Methodology, Software, Resource, Writing, Review and Editing, Data Curation, Visualization. All authors have read and agreed to the published version of the manuscript.

References

- [1] Salma, A.F., Ramadhan, G., Maharani, N.Y., Fatimah, R.S. (2025). Optimization of acetic acid production process using the Cativa method for increasing product purity. *Journal of Chemical Engineering Research Progress*, 2(1), 103–114. DOI: 10.9767/jcerp.20320
- [2] Vidra, A., Németh, Á. (2018). Bio-produced acetic acid: A review. *Periodica Polytechnica Chemical Engineering*, 62(3), 245–256. DOI: 10.3311/PPch.11004
- [3] Yan, Q. (2024). A review of process of methanol carbonylation to produce acetic acid. *Applied and Computational Engineering*, 61(1), 216–221. DOI: 10.54254/2755-2721/61/20240959.
- [4] Pacheco, M., Perrière, B.A., Moura, P., Silva, C. (2025). Industrial off-gas fermentation for acetic acid production: A carbon footprint assessment in the context of energy transition. *Journal of Carbon Research*, 11(3), 1-24. DOI: 10.3390/c11030054
- [5] Yehya, R., Sharaf, A.N., Riachi, B., Assaf, J.C., Hamd, W. (2025). A novel integrated simulation approach for natural gas sweetening and dehydration: H₂S, CO₂, and H₂O removal with energy optimization using Aspen HYSYS. *Results in Engineering*, 28, 107972. DOI: 10.1016/j.rineng.2025.107972
- [6] Dimian, A.C., Kiss, A.A. (2020). Novel energy efficient process for acetic acid production by methanol carbonylation. *Chemical Engineering Research and Design*, 159, 1–12. DOI: 10.1016/j.cherd.2020.04.013

Table 1. Comparison of heat duties (Q) of process units before and after modification.

Unit Operation	Heat Duty Before Modification (kJ/h)	Heat Duty After Modification (kJ/h)
Pump L-212	5,772	4,487
Heater E-211	3.35 × 10 ⁴	2.61 × 10 ⁴
Reboiler (REB)	1.11 × 10 ⁵	8.65 × 10 ⁴
Pump L-225	3,960	3,078
Pump L-228	2,932	2,279
Expander G-118	1.46 × 10 ⁵	1.13 × 10 ⁵
Cooler E-119	3.60 × 10 ⁴	2.80 × 10 ⁴
Condenser (COND)	1.24 × 10 ⁵	9.64 × 10 ⁴
Cooler E-227	4,500	3,500
Cooler E-224	3,106	2,414
Total Heat Energy	458,045.6	356,029.8

- [7] Espejo, J. L., Loe, J., Odriozola, J.A., Reina, T.R., Pérez, L. (2022). Sustainable routes for acetic acid production: Traditional processes vs a low-carbon, biogas-based strategy. *Science of the Total Environment*, 840, 1-16. DOI: 10.1016/j.scitotenv.2022.156663
- [8] Maiuf, A., Ramadan, N. (2024). The acetic acid production by modeling oxidation of ethylene with Aspen Plus. *Surman Journal for Science and Technology*, 6(2), 139–149. DOI: 10.5281/zenodo.111139
- [9] Al-Jammali, A.S.I. (2022). Study the effect of the main variables on the objectives of the natural gas dehydration plant by ASPEN-HYSYS v8.8. *Journal of Petroleum Research and Studies*, 12(2), 47–63. DOI: 10.52716/jprs.v12i2.65
- [10] Huang, H., Li, X., Yuan, Z., Wu, T., Ye, W., Deng, W., Liu, J. (2025). Energy consumption analysis and optimization of LNG terminals based on Aspen HYSYS dynamic simulation. *Processes*, 13(9). DOI: 10.3390/pr1309296
- [11] Sultana, S.T., Amin, M.R. (2011). Aspen HYSYS simulation of sulfuric acid plant. *Journal of Chemical Engineering*, 26(1), 1–10. DOI: 10.5281/zenodo.264041530
- [12] Ningsih, E., Albanna, I., Witari, A.P., Anggraini, G.L. (2022). Performance simulation on the shell and tube of heat exchanger by Aspen HYSYS V.10. *Rekayasa Mesin*, 13(3), 701–706. DOI: 10.21776/jrm.v13i3.1078
- [13] Lee, J.Y., Chen, P.Y. (2023). Optimization of heat recovery networks for energy savings in industrial processes. *Processes*, 11(2), 321. DOI: 10.3390/pr1102032
- [14] Smith, J.M., Van Ness, H.C., Abbott, M.M., Swihart, M.T. (2018). Introduction to Chemical Engineering Thermodynamics. 8th Edition. New York: Mc Graw Hill.
- [15] Kalck, P., Berre, B.C., Serp, P. (2020). Recent advances in the methanol carbonylation reaction into acetic acid. *Coordination Chemistry Reviews*, 402, 1-13. DOI: 10.1016/j.ccr.2019.213078.