

# Heat Integration Strategies for Acetaldehyde Production: Optimizing Ethanol Dehydrogenation and Hydrogen Recovery

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## Abstract

Acetaldehyde production via ethanol dehydrogenation is inherently energy-intensive due to its endothermic characteristics, while the hydrogen generated as a co-product must achieve high purity to meet industrial specifications. Enhancing energy efficiency and hydrogen quality is therefore essential to advancing the sustainability and economic feasibility of this process. This study investigates strategies to optimize energy consumption and hydrogen purity in acetaldehyde production through systematic heat integration and absorber operating condition optimization. Process simulations were employed to quantify the influence of internal heat exchanger integration on overall heat demand and to examine the effect of absorbent flow rate variation on hydrogen purification performance. Integration of heat exchangers reduced total energy consumption by "10,148,446.64" kJ/h, corresponding to a 23% improvement in energy efficiency. Moreover, increasing the absorber water flow rate elevated hydrogen purity from 94.6% to 99.5%. The combined optimization decreased specific energy consumption to 34,316,959.07 kJ/h and lowered monthly operating costs by 22.8%. These findings demonstrate that coupling heat integration with absorber flow rate optimization constitutes an effective approach to improving energy efficiency, hydrogen quality, and economic viability in acetaldehyde production via ethanol dehydrogenation.

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**Keywords:** Acetaldehyde; Ethanol dehydrogenation; Heat integration; Hydrogen purification; Energy efficiency

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## 1. Introduction

Acetaldehyde ( $\text{CH}_3\text{CHO}$ ) is an essential petrochemical intermediate widely employed in the synthesis of various chemicals, including acetic acid, pentaerythritol, acetic anhydride, and n-butanol [1]. At ambient conditions, acetaldehyde is a colorless liquid with a pungent odor [2]. Industrial production of acetaldehyde primarily relies on three major processes: (i) oxidation of ethylene via the Wacker-Hoechst process, (ii) hydration of acetylene, and (iii) dehydrogenation of ethanol [1]. Among these, ethanol dehydrogenation is a well-established and

mature technology that offers high selectivity for the desired reaction while minimizing by-product formation [3]. The Wacker-Hoechst process currently dominates in Europe, operating at 100–130 °C and 4–10 bar with ethylene and oxygen, but requires complex homogeneous catalyst systems [1].

Ethanol dehydrogenation to acetaldehyde is particularly advantageous due to its operational simplicity and moderate temperature and pressure requirements, typically 200–300 °C for non-oxidative dehydrogenation [1]. This process not only achieves high acetaldehyde yields but also facilitates purification through conventional unit operations, which are generally less complex and more cost-effective than those required for

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alternative methods [2]. Additionally, the dehydrogenation reaction ( $\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} + \text{H}_2$ ) produces valuable hydrogen as a co-product, which can be easily separated from liquid effluents at room temperature, yielding pure hydrogen without  $\text{CO}_x$  contamination, unlike steam reforming processes [4]. Industrial-scale production typically targets outputs of 50,000–95,000 metric tons annually (MTA) with acetaldehyde purity of at least 99.5 wt% and hydrogen purity of at least 95 wt% ([2]; [5]).

Energy optimization is critical in acetaldehyde production, particularly given the global emphasis on sustainability and carbon footprint reduction in chemical manufacturing. Conventional processes often exhibit high energy consumption due to elevated operating temperatures and the endothermic nature of ethanol dehydrogenation, which requires 68.6 kJ/mol of heat input [2]. Traditional thermal processes typically demand temperatures exceeding 260 °C, while electrochemical approaches require voltages above 0.8 V, both resulting in low conversion efficiency [6]. Improving energy efficiency not only reduces operational costs but also mitigates environmental impacts associated with excessive energy use. Recent studies have proposed strategies such as heat recovery integration and reactor design optimization to enhance energy efficiency while maintaining high conversion rates [7].

The incorporation of heat exchangers plays a pivotal role in optimizing acetaldehyde production. Research indicates that heat exchanger integration significantly improves energy efficiency by minimizing heat losses during operation [5]. Simulation studies demonstrate that modified systems with heat exchangers can reduce total energy demand by approximately 10,148,446.64 kJ/h through heat recovery from process streams [5]. Advanced heating technologies such as induction heating (IH) have also shown promise, achieving high ethanol conversion and acetaldehyde selectivity at temperatures 30 °C lower than conventional furnace heating (CFH) methods [8]. IH enables instantaneous and localized heating of susceptors within the reactor, reducing energy consumption and overcoming thermal inertia compared to conventional conduction- and convection-based heating [8]. Furthermore, increasing the absorber feed rate in water absorption systems has been shown to significantly enhance hydrogen purity for advanced applications [5].

The novelty of this research lies in combining two approaches: (i) improving hydrogen purity through optimized separation processes, and (ii) integrating heat exchangers to enhance thermal

efficiency in acetaldehyde production. In oxidative ethanol dehydrogenation, high selectivity toward acetaldehyde can be achieved at reduced operating temperatures, with recent chemical looping configurations attaining 92–98% selectivity at temperatures approximately 250 °C lower than the traditional Veba-Chemie process [1]. Advanced electrochemical hydrogen separation techniques have demonstrated threefold improvements in hydrogen and acetaldehyde yields by coupling thermal dehydrogenation with electrochemical hydrogen pumps operating at reduced temperatures (120 °C) and low voltage (0.06 V) [6]. This electrochemical approach not only purifies hydrogen at the cathode but also accelerates acetaldehyde production by shifting the reaction [6]. Additionally, heat exchanger integration is expected to recover and utilize waste heat, further reducing overall energy consumption. Collectively, these strategies aim to establish a more sustainable and energy-efficient acetaldehyde production process.

## **2. Methods**

### **2.1 Property Package**

Aspen HYSYS provides a range of thermodynamic models, and selecting an appropriate equation of state is critical for accurately predicting phase equilibria, enthalpy, and other fluid properties in multicomponent systems. For the simulation of ethanol dehydrogenation to acetaldehyde, the Non-Random Two-Liquid (NRTL) property package was employed. The NRTL model is particularly suitable for this process because it effectively accounts for non-ideal behavior in mixtures containing polar components and potential multiphase interactions, making it an appropriate choice for representing the thermodynamic characteristics of ethanol dehydrogenation [9].

### **2.2. Energy Optimization using Heat Exchanger**

A heat exchanger is a device designed to transfer thermal energy between two media without direct contact, enabling both heating and cooling of process streams [10]. This equipment plays a critical role across various industries, including acetaldehyde production, where efficient design is essential to achieve optimal thermal performance at minimal cost. To meet these objectives, design optimization techniques are typically applied during early development stages to reduce utility consumption, such as steam and cooling water [11]. In practice, heat exchangers can function as heaters, utilizing steam from boilers to raise the temperature of cold process streams, or as coolers, employing cooling

water from towers to lower process temperatures. Since the generation of these utilities incurs significant operating costs, their integration within a plant is managed through a Heat Exchanger Network (HEN), which systematically coordinates heaters and coolers to minimize energy requirements and overall expenses [12]. In acetaldehyde production, heat exchangers serve as essential heat transfer units, reducing energy consumption by recovering waste heat to adjust fluid temperatures.

The ethanol dehydrogenation process operates at elevated temperatures [9]. So, before the ethanol feed enters the reactor, a heater must be added. To enhance energy efficiency in acetaldehyde production, a heat exchanger was selected. This heat exchanger makes use of the heat generated during the production process. This approach is feasible because the process involves both cooling and heating, allowing heat transfer between the two streams without requiring external energy input. The Total Energy Conserved (%) can be determined using the following equation:

$$\text{Total Energy Conserved (\%)} = \frac{\text{Energy Reduction } \left(\frac{kJ}{h}\right)}{\Delta H_{\text{Unmodified}} \left(\frac{kJ}{h}\right)} \times 100\% \quad (1)$$

This metric provides a quantitative measure of energy utilization efficiency within the process. A higher value reflects improved heat recovery and reduced reliance on external utilities. When applied to acetaldehyde production, the Energy Efficiency Indicator enables engineers to evaluate the effectiveness of heat integration strategies and identify potential areas for further optimization, thereby supporting cost reduction and sustainability objectives.

### 2.3. Hydrogen Purity Improvement

Hydrogen purification from the reactor effluent is achieved using a gas absorption unit

(scrubber) with water as the solvent. This separation method is selected due to the substantial solubility differences among the components: acetaldehyde and unreacted ethanol exhibit high solubility in water owing to their polarity and hydrogen-bonding capabilities, whereas hydrogen is non-polar and virtually insoluble in the aqueous phase [2]. As a result, the water solvent selectively absorbs the organic compounds, producing a hydrogen-rich overhead stream.

To improve hydrogen purity, the optimization strategy involves adjusting the absorbent mass flow rate. Based on mass transfer principles, increasing the liquid solvent flow rate raises the Liquid-to-Gas (L/G) ratio, which subsequently enhances the absorption factor (A) for the soluble components. A higher absorption factor provides a greater driving force for mass transfer, enabling more efficient removal of acetaldehyde and ethanol traces from the gas stream. In this study, a sensitivity analysis is conducted using Aspen HYSYS by incrementally increasing the water feed rate to identify the optimal operating point that maximizes hydrogen purity while minimizing excessive solvent consumption.

## 3. Results and Discussion

### 3.1. Basic Process Flow Diagram of Ethanol Dehydrogenation and Hydrogen Purification

The unmodified process flow diagram for acetaldehyde production is shown in Figure 1, and the corresponding process simulation developed using Aspen HYSYS is also illustrated in Figure 2. Acetaldehyde (CH<sub>3</sub>CHO) is a key petrochemical intermediate extensively used in the manufacture of acetic acid, pentaerythritol, acetic anhydride, and n-butanol [15]. Industrially, acetaldehyde can be synthesized through several routes, including ethylene oxidation, acetylene hydration, and ethanol dehydrogenation. Among these pathways, ethanol dehydrogenation is generally preferred

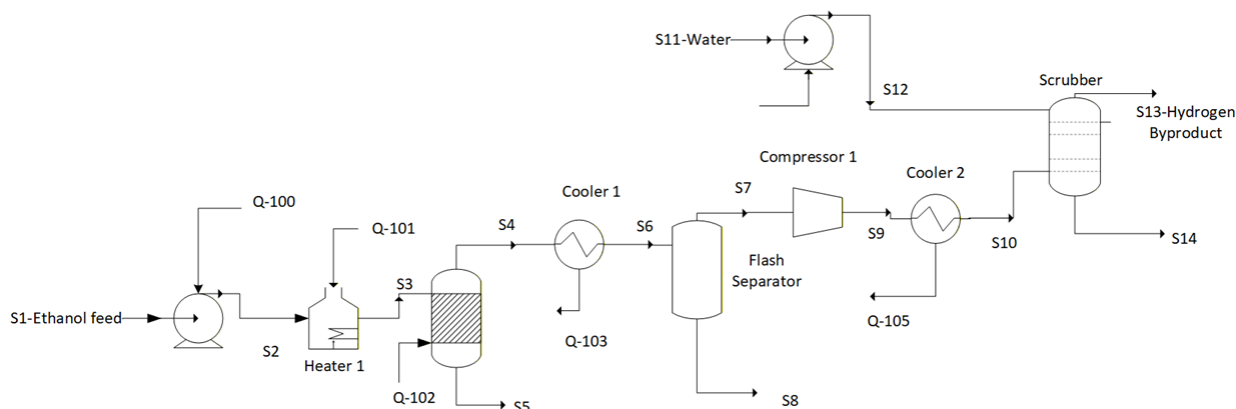


Figure 1. Unmodified process flow diagram to be modified [9].

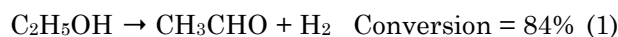
due to its high selectivity and operation under moderate temperature and pressure conditions. In general, acetaldehyde production involves four main stages: ethanol dehydrogenation, phase separation, hydrogen recovery, and acetaldehyde purification [16]

The process begins with ethanol as the feedstock, which is pressurized using Pump 1 and preheated in Heater 1 before entering the reactor. Ethanol dehydrogenation is conducted at approximately 340 °C and 300 kPa to provide sufficient activation energy for efficient cleavage of C–H and O–H bonds, as the reaction is endothermic and requires heat input to achieve high ethanol conversion [17]. At lower temperatures, the reaction rate decreases significantly and may lead to undesirable side reactions [18]. Moderate pressure helps maintain stable gas-phase acetaldehyde density and provides adequate residence time to enhance conversion without requiring excessively high temperatures [19]. This operating condition aligns with Le Chatelier’s principle, as an endothermic reaction with a positive enthalpy change shifts its equilibrium toward the formation of acetaldehyde and hydrogen when temperature is increased.

Inside the reactor, the dehydrogenation process produces acetaldehyde and hydrogen as gaseous products. Upon exiting the reactor, the product stream is cooled and separated into acetaldehyde, unreacted ethanol, water, and hydrogen using a flash separator. The acetaldehyde-rich stream undergoes further purification to achieve high purity, while the hydrogen-rich stream is directed to the hydrogen recovery section. This stream is compressed and cooled to adjust its temperature and pressure before entering the scrubber, where water is used as the absorbing medium to remove compounds other than hydrogen. Water is selected based on solubility principles: acetaldehyde and ethanol exhibit high solubility in water due to their polarity and hydrogen-bonding capability, whereas hydrogen is nearly insoluble, enabling effective separation [20].

### 3.2. Thermodynamics Review

A thermodynamic assessment is conducted to determine key parameters such as the reaction enthalpy change ( $\Delta H$ ), Gibbs free energy ( $\Delta G$ ), and the equilibrium constant ( $K$ ) for the process unit under consideration. Evaluating the enthalpy change provides insight into whether the reaction is exothermic (heat-releasing) or endothermic (heat-absorbing), which is critical for the efficient design of reactors and heat exchangers [21]. Similarly, the calculation of Gibbs free energy is essential for assessing the spontaneity of the reaction and its reversibility, as  $\Delta G$  determines the thermodynamic feasibility of product formation. This parameter is directly linked to the equilibrium constant, which predicts the reaction direction and supports optimization strategies to enhance conversion efficiency while minimizing unnecessary energy consumption within process equipment [22]. The stoichiometry of the ethanol dehydrogenation reaction is expressed as follows:



Standard heat of reaction at 298K ( $\Delta H^\circ_{298\text{K}}$ ) [23] is calculated based on standard heat of formation (Table 1):  $\Delta H^\circ_{298\text{K}} = \sum \Delta H_f^\circ \text{ product} - \sum \Delta H_f^\circ \text{ reactant} = (\Delta H_f^\circ \text{ CH}_3\text{CHO} + \Delta H_f^\circ \text{ H}_2) - (\Delta H_f^\circ \text{ C}_2\text{H}_5\text{OH})$ . Based on the standard heat of reaction calculation, the resulting value of  $\Delta H^\circ_{(298 \text{ K})}$  is 68.8 kJ/mol. This positive enthalpy change indicates that the ethanol dehydrogenation reaction is endothermic, meaning that it proceeds by absorbing heat.

Gibbs energy ( $\Delta G^\circ_{298\text{K}}$ ) is calculated as follow:  $\Delta G^\circ_{298\text{K}} = \sum \Delta G_f^\circ \text{ product} - \sum \Delta G_f^\circ \text{ reactant} = (\Delta G_f^\circ \text{ CH}_3\text{CHO} + \Delta G_f^\circ \text{ H}_2) - (\Delta G_f^\circ \text{ C}_2\text{H}_5\text{OH})$ . From this

Table 1. The value of  $\Delta H_f^\circ$  and  $\Delta G_f^\circ$  of compounds.

Compounds	Molecular Formula	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)
Ethanol	C <sub>2</sub> H <sub>5</sub> OH	-235	-167.7
Acetaldehyde	CH <sub>3</sub> CHO	-166.2	-133
Hydrogen	H <sub>2</sub>	0	0

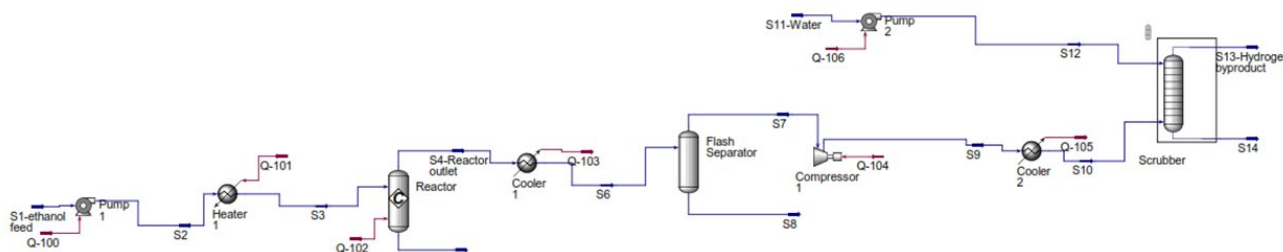


Figure 2. Unmodified/basic process flow diagram from HYSYS simulation.

calculation, the standard Gibbs free energy change at 298 K ( $\Delta G^\circ_{298\text{ K}}$ ) was determined to be 33.7 kJ/mol.

Equilibrium constant ( $K_2$ ) in the standard state can be calculated as follow:

$$\Delta G^\circ_{298\text{ K}} = -RT \ln K ; \ln K_2 = -\frac{\Delta G^\circ_{298\text{ K}}}{RT}$$

From this calculation, the value of  $K_2$  was calculated to be  $8.0774 \times 10^5$ .

Equilibrium constant ( $K_1$ ) at reaction temperature  $T = 340\text{ }^\circ\text{C}$ :

$$\ln \frac{K_1}{K_2} = \frac{-\Delta H_R^\circ}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

Based on the equilibrium constant ( $K_1$ ) calculation for the ethanol dehydrogenation reaction to acetaldehyde, the resulting value of  $8.1937 \times 10^{-5}$  indicates that  $K_1 < 1$ , signifying a very low equilibrium constant. This suggests that the reaction proceeds reversibly and that the equilibrium strongly favors the reactant side. Under such conditions, achieving high acetaldehyde conversion requires a substantial supply of thermal energy to maintain thermodynamically favorable operating conditions. Consequently, the integration of heat exchangers within the process flowsheet becomes an essential strategy for enhancing overall energy efficiency. Thus, the equilibrium constant analysis provides a strong thermodynamic basis

for implementing heat-integration measures, which ultimately contribute to reducing the total net energy required for acetaldehyde production.

### 3.3. Integrating Heat Exchanger to Optimize Energy Efficiency of Ethanol Dehydrogenation and Hydrogen Purification

Based on the simulation results, data were obtained regarding the total energy requirements for operating the ethanol dehydrogenation process through to hydrogen purification. The energy demand is expressed in terms of heat duty ( $\text{kJ}\cdot\text{h}^{-1}$ ) required and generated within the reaction system. Energy savings were evaluated by comparing the total energy consumption of the baseline (unmodified) process with that of the modified process incorporating heat exchanger integration (Figures 3 and 4). These simulation outcomes were used to quantify the reduction in energy consumption, calculate the numerical amount of energy saved through the modification, and determine the corresponding improvement in thermal efficiency. The comparative data on total energy requirements for both process configurations are presented in Table 2.

Furthermore, process simulation serves as a powerful evaluative tool, enabling comprehensive quantitative and qualitative assessment of system

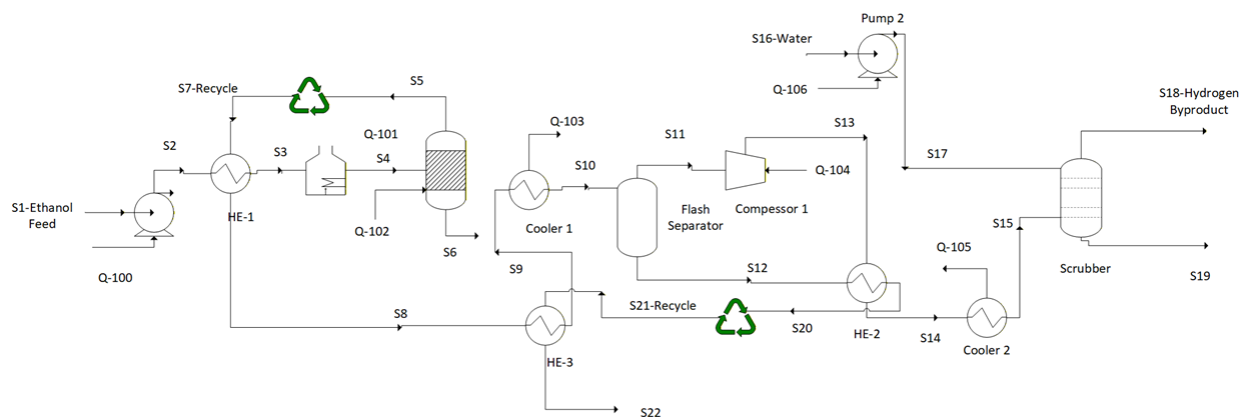


Figure 3. Modified process flow diagram to be simulated.

Table 2. Comparison of energy between the modified and unmodified processes.

Unmodified Process		Modified Process	
Heat Streams Items	Heat Flow (kJ/h)	Heat Streams Items	Heat Flow (kJ/h)
Q-100	3,267.74	Q-100-2	3,267.74
Q-101	16,402,100	Q-101-2	13,484,100
Q-102	12,724,700	Q-102-2	12,726,600
Q-103	13,585,900	Q-103-2	6,954,700
Q-104	946,124	Q-104-2	947,275
Q-105	799,494	Q-105-2	197,217
Q-106	3,819.97	Q-106-2	3,799.33
Total Heat Flow (kJ/h)	44,465,405.71	Total Heat Flow (kJ/h)	34,316,959.07
Total Energy Conserved (%)		23%	

performance before and after modification. Simulation provides critical insights into potential improvements achievable within a process, offering operational and optimization benefits that ultimately enhance overall efficiency and effectiveness.

$$\Delta H_{Unmodified} = H_{Q-100} + H_{Q-101} + H_{Q-102} + H_{Q-103} + H_{Q-104} + H_{Q-105} + H_{Q-106}$$

$$\Delta H_{Unmodified} = 44,465,405.71 \text{ kJ/h}$$

$$\Delta H_{Modified} = H_{Q-100-2} + H_{Q-101-2} + H_{Q-102-2} + H_{Q-103-2} + H_{Q-104-2} + H_{Q-105-2} + H_{Q-106-2}$$

$$\Delta H_{Modified} = 34,316,959.07 \text{ kJ/h}$$

$$\text{Energy Reduction} = \Delta H_{Unmodified} - \Delta H_{Modified}$$

$$\text{Energy Reduction} = 10,148,446.64 \text{ kJ/h}$$

$$\text{Total Energy Conserved (\%)} \text{ (Table 2)} = \frac{\text{Energy Reduction}}{\Delta H_{Unmodified}} \times 100\%$$

Energy savings were achieved by integrating three additional heat exchangers into the system. First, Heat Exchanger E-103 was installed upstream of Heater E-100 to facilitate preheating and cooling of the reactor inlet and outlet streams. Second, E-105 was positioned before Cooler E-101 to reduce the temperature of the stream prior to entering the cooling unit. Third, E-104 was placed after the separation step, between the bottom product of the flash separator and the compressed overhead stream, to cool the hydrogen-rich flow. The integration of these heat exchangers significantly reduced the energy demand for heating and cooling operations within the system.

In the baseline (unmodified) process simulation, the total energy consumption was 44,465,405.71 kJ/h, whereas the modified process incorporating heat exchanger integration required only 34,316,959.07 kJ/h. This modification resulted in an energy reduction of 10,148,446.64 kJ/h, corresponding to an energy efficiency improvement of approximately 23% compared to the unmodified process.

### 3.5. Hydrogen Purity Improvement

The production of acetaldehyde ( $\text{CH}_3\text{CHO}$ ) via ethanol dehydrogenation is an important

industrial process that not only yields acetaldehyde but also generates hydrogen as a valuable by-product. High hydrogen purity is critical for advanced applications, particularly in fuel cells and other energy technologies. Enhancing hydrogen purity while optimizing energy efficiency is essential to improve both economic viability and environmental sustainability. One effective approach to increase hydrogen purity is by adjusting the mass flow rate of the absorbent solution [24].

Prior to modification, the water absorbent flow rate was maintained at 5,200 kg/h, resulting in a hydrogen purity of 94.6%. After modification, increasing the flow rate to 6,000 kg/h improved purity to 96.3%. A further increase to 7,000 kg/h yielded 98% purity, and at 8,000 kg/h, hydrogen purity reached 99.5%. This comparison demonstrates that adjusting the absorbent solution flow rate can enhance hydrogen purity by approximately 4.9 percentage points, confirming the effectiveness of this strategy in optimizing product quality while supporting energy efficiency and sustainability. The detailed comparison is presented in Table 3.

### 3.6 Cost of Energy Consumption for Ethanol Dehydrogenation and Hydrogen Purification

Energy consumption is a critical determinant of efficiency and sustainability in ethanol dehydrogenation and hydrogen purification processes. The implementation of heat integration strategies using heat exchangers (HE) enables recovery of residual heat from hot streams and its utilization to meet the heating requirements of cold streams. This approach reduces dependence

Table 3. Comparison of absorbent solution mass flow rate on hydrogen purity.

Mass Flow Rate (kg/h)	Hydrogen Purity (%)
5200	94.6
6000	96.3
7000	98
8000	99.5

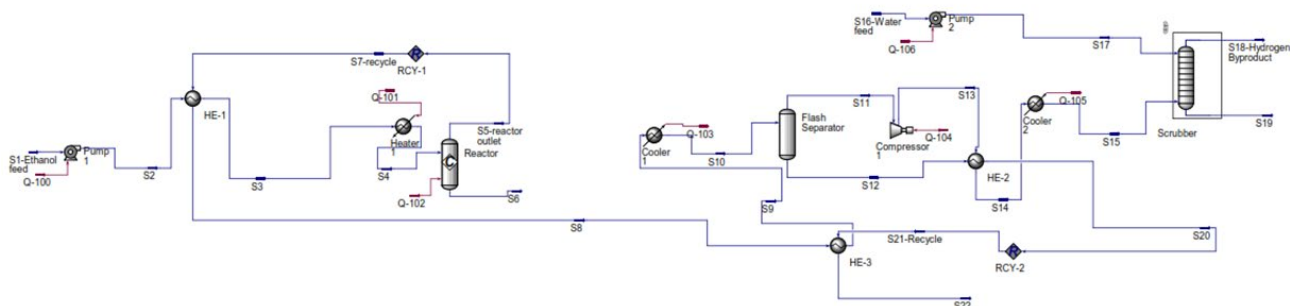


Figure 4. Modified process simulation using Aspen HYSYS.

on external utilities such as fuel and electricity, thereby lowering overall energy demand and creating opportunities for waste heat recycling, where excess thermal energy is reutilized within the system to support other operations. Through this integration, heat exchangers contribute to cost reduction and improved process performance [25].

The impact of heat integration on operational costs was quantified by converting energy demand from kJ/h to kWh, followed by cost estimation based on electricity tariffs and currency exchange rates. The energy conversion was performed using the following relation:

$$E_{kWh} = \frac{E_{kJ/h} \times 1000}{3.6 \times 10^6}$$

$$\text{Cost per hour (Rp)} = E_{kWh/h} \times \text{Electricity rate (Rp/kWh)}$$

$$\text{Monthly cost (Rp)} = \text{Cost per hour (Rp)} \times 24 \times 30$$

$$\text{Monthly cost (USD)} = \frac{\text{Monthly cost (Rp)}}{15,600}$$

Using an electricity tariff of Rp 1,444.70 per kWh and an exchange rate of Rp 15,600 per USD, the unmodified process with an energy demand of 44,465,405.71 kJ/h corresponds to 12,351.5 kWh, resulting in an estimated monthly cost of approximately USD 824,000. In comparison, the modified process incorporating heat exchanger integration requires 34,316,959.07 kJ/h, equivalent to 9,532.5 kWh, reducing the monthly cost to about USD 635,000. This improvement represents a cost saving of nearly 22.8%, confirming that heat integration significantly decreases both energy consumption and operational expenditure. A detailed comparison of energy demand and associated costs is presented in Table 4.

#### 4. Conclusion

Based on the simulation results, the integration of three heat exchangers reduced the overall energy requirement from 44,465,405.71 kJ/h to 34,316,959.07 kJ/h, corresponding to an energy recovery of 10,148,446.64 kJ/h. According to the Total Energy Conserved (%) calculation, this modification increased process efficiency by 23%. In parallel, increasing the water flow rate in the absorber unit improved hydrogen purity from 95% to 99.5%, representing an enhancement of approximately 4.5 percentage points. From an economic perspective, the reduction in energy consumption lowered monthly operating costs from USD 824,000 to USD 635,000, yielding total cost savings of 22.8%. Overall, the combined integration of heat exchangers and optimization of absorbent flow rate resulted in significant improvements in energy efficiency, product quality, and cost reduction in the acetaldehyde production process via ethanol dehydrogenation. These findings demonstrate the effectiveness of process intensification strategies in achieving sustainable and economically viable chemical manufacturing.

#### Credit Author Statement

Author Contributions: M. A. Biantoro: Conceptualization, Software and Editing, Resource, Data Curation, Visualization, Validation, Review and Editing, Methodology; E. P. Prawira: Investigation, Writing Draft Preparation, Data Curation, Review, Resource, Formal Analysis; F. N. Yusuf: Investigation, Resource, Writing Draft, Project Administration, Formal Analysis, Review, Resource, Methodology; M. F. Mujahid: Conceptualization, Investigation, Resource, Economic analysis, Review and Editing, Data Curation; H. A. Rahim: Conceptualization, Writing Draft, Review and Editing, Data Curation, Resource, Methodology, Validation. All authors have read and agreed to the published version of the manuscript.

Table 4. Comparison of cost energy between the modified and unmodified processes.

Process Condition	Energy (kJ/h)	Energy (kWh/h)	Monthly Cost (USD)
Unmodified Process	44,465,405.71	12,351.5	USD 824,000
Modified Process	34,316,959.07	9,532.5	USD 635,000
Saving			22.8%

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