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Research Article

Improving Energy Efficiency with Reusage Outlet Stream of Heat Exchanger for Formaldehyde Production from Methanol

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Abstract

Formaldehyde is one of the chemical products that has an important role in various industries with the percentage of global production consistently increasing over the past ten years. However, the production of formaldehyde requires considerable energy consumption. The purpose of this study is to examine other alternatives to improve energy efficiency in the formaldehyde production process. This study focuses on the reutilization of heat generated from the heat exchanger to minimize the net energy generated. The process modification was simulated using Aspen HYSYS and the net energy comparison between the original and modified process was calculated using the net-energy formula. The results show that the Net-Energy (NE) value for the original process is 18,839,836 kJ/h while for the modified process it is 4,123,000 kJ/h. This result shows that the modified process is efficient to reduce Net-Energy and can increase energy efficiency in the formaldehyde production process through the methanol dehydrogenase process.

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Keywords: Formaldehyde; Modification Process; Heat Exchanger; Energy Efficiency; Net-Energy

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1. Introduction

Formaldehyde remains one of the most important chemicals produced in the world today due to its unparalleled reactivity and versatility [1]. Formaldehyde (CH_2O) or commonly known by the trade name formalin is a chemical compound that has an important role in the world economy [2]. This compound is generally sold as a raw material used to produce plastics, polymers, resins, and textiles [3]. This compound is widely used in various industries, especially in the chemical industry because it has favorable chemical-physical properties, such as high stability, good reactivity, high purity, colorless, flammable and has an affordable price [4].

Formaldehyde production was first carried out in Europe on a small scale and the development of production for industrial scale was first carried out in 1910 [5]. In recent years, the demand for formaldehyde has reached 30 MT per year and is expected to continue to increase in demand by 5% per year [6]. In 2011, Indonesia was included in the 10 countries with the most formaldehyde production in the world with the first rank occupied by China which produced 11 MT of formaldehyde [7].

In general, formaldehyde can be produced through several methods, one of which is by dehydrogenation of methanol which will produce valuable by-products in the form of hydrogen.

$$CH_3OH \rightarrow CH_2O + H_2 \quad \Delta H = 84\ \text{kJ/mol} \qquad (1)$$

The methanol used in this process is made from fossil raw materials using a mixture of CO_2, H_2, and a small amount of CO_2 at pressures of 50-100 bar and temperatures of 200-300 °C [9]. The

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methanol dehydrogenation process is carried out by passing a mixture of methanol gas, steam and air with the addition of a catalyst in a bed carried out under certain pressure process conditions and temperatures of 560 to 700 ºC. [10]. On an industrial scale, the formaldehyde yield generally ranges from 82-92% [11]. However, this process has shortcomings because it often requires the consumption of large amounts of methanol and large amounts of energy [12].

Therefore, this study will modify the methanol dehydrogenation process to reduce the net energy used. This modification is done to improve the energy efficiency of formaldehyde production in the heat exchanger using Aspen HYSYS. This modification is proven to reduce the net energy during the formaldehyde production process.

2. Methods

In order to improve the energy efficiency of the methanol oxidation process, simulations were conducted using Aspen HYSYS. The process uses a plug flow reactor with the reaction occurring under non-isothermal conditions. This reactor is supported with a heat exchange to remove the heat generated from the exothermic reaction. During the reaction, a large amount of energy generated can be utilized for the next process [13].

In this modification, methanol is heated through three stages before entering the reactor to ensure optimal conditions for the reaction. In the first stage at E-100, the water temperature is raised to 180 °C to approach the ideal reaction conditions and utilize the residual heat from the system. Next, in the second stage at E-105, the water temperature is lowered to 126.5 °C to maintain process stability and avoid unwanted initial reactions. In the third stage, at E-103, the water temperature is again raised to 150 °C, ensuring that the methanol is ready to enter the reactor at a temperature suitable for the exothermic reaction. The heat efficiency of basic and modified process can be compared using net energy calculation as follows:

$$NE = E_{\mathrm{P}} - E_{\mathrm{C}} \qquad (2)$$

where, NE is net-energy (kJ/h), E_{P} is energy produced (kJ/h), and E_{C} is energy consumed (kJ/h) [14]. The effect of this modification process is studied in this article.

3. Results and Discussion

3.1 Comparison Between Basic and Modified Process

The process of formaldehyde production from methanol simulated in unmodified process and modified process. HYSYS simulation of the modified process and process flow diagram of the modified process are shown in Figures 1 and 2, respectively. Meanwhile, the HYSYS simulation and process flow diagram of the unmodified process can be seen in Figures 3 and 4, respectively. The difference between both

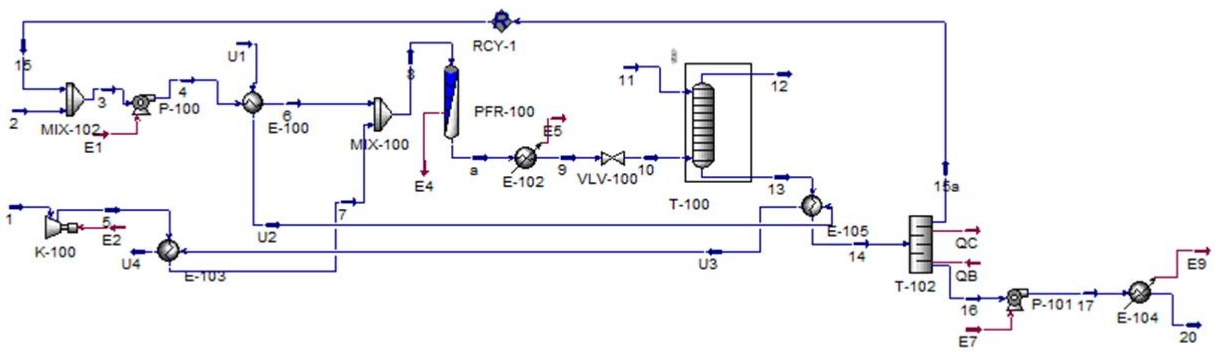

Figure 1. Simulation using Aspen HYSYS of modified process

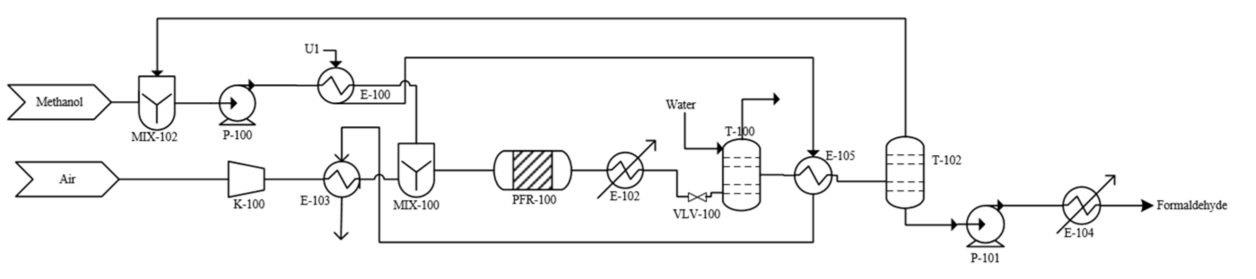

Figure 2. Process flow diagram of modified process

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processes can be seen in the modified process there reusage of heat, namely from U2 to heat the components in the heat exchanger E-105, while the reusage of heat from U3 to cool the heat exchanger in E-103. The purpose of modified process is to increase energy efficiency of entire system and increase conversion in system. Because in the basic process obtained high energy requirements and low conversion.

3.2 Energy Balance and Mass Balance Results

The modified process is shown in Figures 1 and 2 in which there is heat exchanger E-100 without steam U2. Energy from U2 reusage in E-105 with flow rate input 7.673 × 10^4 kg/h to heat from temperature of 80.18 ˚C to temperature 102 ˚C. Energy output from E-105 is reusage in E-103 with flow rate input 7.673 × 10^4 kg/h to cool from temperature of 169 ˚C to 150 ˚C. The heat required in E-105 and E-103 of 0.008 × 10^9 kJ/h.

3.3 Heat Transfer Fluid Recycle

The dehydrogenation of formaldehyde requires multiple heat transfer stages to effectively manage the heating and cooling processes. This process is generally performed in a fixed bed reactor at temperatures between 650-720 °C, producing a considerable amount of heat due to its exothermic nature, as reflected by a negative ΔH. To enable these processes, a heat transfer fluid is required, utilizing heat exchangers [16,19].

In the unmodified process, there is no heat recycle caused the energy waste from heating and cooling processes in the heat exchanger. The absence of a heat recovery system also requires additional heat sources to reheat the reactor feed, resulting in increased energy consumption [17]. In contrast, in the modified process, the cold fluid produced in E-100 is reused for the heat exchangers in E-103 and E-105. This continuous cycle ensures more efficient energy utilization to reduce waste [17].

3.4 Improving Energy Efficiency by Reducing Net Energy

From the simulation, data of the total energy required by the system can be obtained. The data is presented by the heat flow within the system. This method, serves as a model for how much energy can be conserved compared to the unmodified process [18,20]. From there, the energy saved by the modified process can be calculated mathematically. Table 1 shows the heat stream for both unmodified and modified processes.

$$EP_{Unmodified} = H_{E1} + H_{E2} + H_{E3} + H_{E4} + H_{E5} + H_{E6} + H_{E7} + H_{E9} + H_{13} + H_{Qc} + H_{Qb}$$
$$EP_{Unmodified} = 1.884 \times 10^7 \text{ kJ/h}$$
$$EC_{Unmodified} = H_{11}$$
$$EC_{Unmodified} = 1.637 \times 10^2 \text{ kJ/h}$$
$$NE_{Unmodified} = E_P - E_C$$
$$NE_{Unmodified} = 18{,}839{,}836 \text{ kJ/h}$$

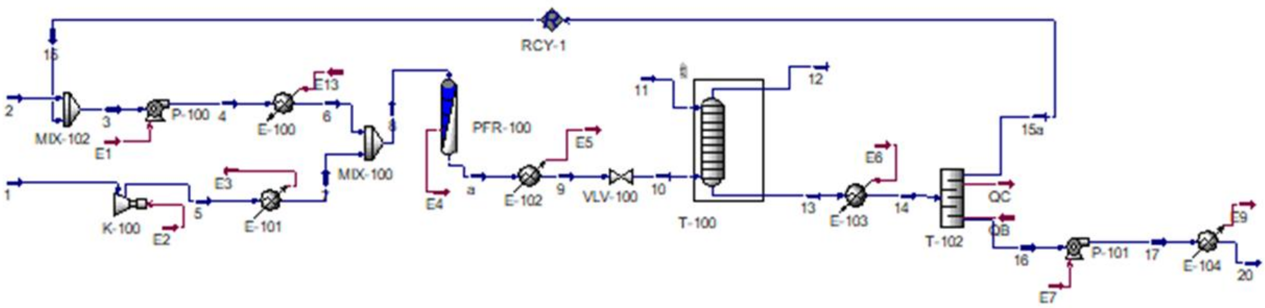

Figure 3. Simulation using Aspen HYSYS of unmodified process

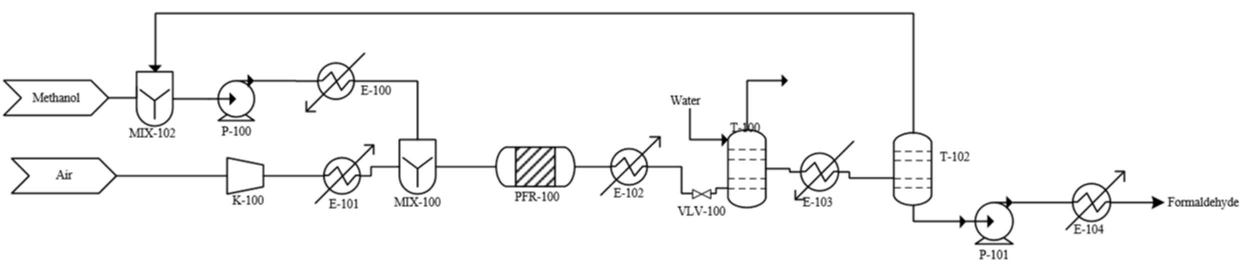

Figure 4. Process flow diagram of unmodified process [15]

$EP_{Modified} = H_{E1} + H_{E2} + H_{E4} + H_{E5} + H_{E7} + H_{E9} + H_{Qc} + H_{Qb}$

$EP_{Modified} = 6.601 \times 10^6$ kJ/h

$EC_{Modified} = H_{11} + H_{U1}$

$EC_{Modified} = 2.478 \times 10^6$ kJ/h

$NE_{Modified} = E_P - E_C$

$NE_{Modified} = 4.123 \times 10^6$ kJ/h

Energy reduction $= 18{,}839{,}836 \frac{kJ}{h} - 4.123 \times 10^6$ kJ/h

Energy reduction $= 14{,}716{,}836$ kJ/h

$\%\text{Energy Efficiency} = \frac{NE_{Unmodified} - NE_{Modified}}{NE_{Unmodified}} \times 100\%$

Therefore, %Energy Efficiency = 78.12%

4. Conclusion

The heat transfer fluid looping system for heating and cooling process improves the heat efficiency of the formaldehyde production through the methanol dehydrogenase process. The results show that the Net-Energy (NE) value for the original process is 18,839,836 kJ/h. For the modified process, the Net-Energy value is 4,123,000 kJ/h which increases energy efficiency by 78.12%. It can be seen that the net energy value of modified process is much lower and closer to zero than the basic process. The looping process in the heat exchange fluid allows for better energy efficiency due to the process of releasing and receiving energy in the system which can be mutually utilized in each processes.

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Table 1. Net-Energy (NE) of processes simulation

Simulation	E_p (kJ/h)	E_c (kJ/h)	Net Energy (*NE*) (kJ/h)
Unmodified	1.884×10^7	1.637×10^2	18,839,836
Modified	6.601×10^6	2.478×10^6	4,123,000

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