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Research Article

Optimizing Propylene Glycol Purity and Profitability through Variations in Reactor Temperature and Distillation

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Abstract

Propylene glycol (PG) is a multifunctional diol widely used in food, pharmaceutical, cosmetic, and chemical industries due to its favorable physicochemical properties, high water solubility, and low toxicity. This study examines PG production through non-catalytic hydration of propylene oxide, focusing on the effect of reactor inlet temperature on process efficiency and economic performance. In the process, propylene oxide and water are mixed and fed into a continuous stirred-tank reactor (CSTR), followed by distillation for product purification. Temperature variations from 23.9 °C to 80 °C were analyzed to determine their impact on conversion and profitability. At 23.9 °C, the process was economically unfavorable, yielding a negative profit of –161.09 $/hour. Increasing the inlet temperature to 40 °C significantly improved conversion and distillation efficiency, resulting in a profit of 191.09 $/hour (552,689 $/year). Further temperature increases provided no additional economic benefit and increased energy demand. Therefore, 40 °C is recommended as the optimal operating condition, offering the best balance between technical performance and profitability.

Keywords: Propylene glycol; Distillation; Purity; CSTR; Temperature

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1. Introduction

Propylene glycol, or 1,2-propanediol, is a widely utilized diol compound valued for its favorable physicochemical properties. It is a colorless, odorless, hygroscopic liquid with excellent thermal stability. PG also exhibits stable density, low vapor pressure, high water solubility, and low toxicity, making it suitable for diverse product formulations. These attributes underpin its extensive use across the food, pharmaceutical, cosmetic, and chemical industries [1]. The versatility of PG arises from its broad application spectrum. In the food industry, it functions as an emulsifier, carrier for flavoring agents, and solvent for colorants. In pharmaceuticals, PG acts as a humectant and solvent in ointments, creams, and medicinal formulations due to its compatibility with various active ingredients [2]. In cosmetics, it serves as a softening and cleansing agent, dissolving compounds of differing polarity [3]. Beyond consumer products, PG is a critical feedstock for unsaturated polyester resins, epoxy resins, and polyurethanes, representing nearly 45% of global PG consumption. Other uses include antifungal formulations, lubricants in food processing, wetting agents in tobacco, and as a major component in automotive antifreeze and coolant systems [4].

Commercial production of PG primarily involves hydration of propylene oxide (PO) with water, the most established industrial route [5]. The reaction proceeds via nucleophilic addition, where water molecules attack the reactive epoxide ring, yielding the diol structure [6]:

$$C_3H_6O + H_2O \rightarrow C_3H_8O_2 \quad (1)$$

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Two main approaches are employed industrially. The non-catalytic process operates under high temperature and pressure, requiring excess water to achieve sufficient PO conversion [7]. Alternatively, catalytic hydration uses acidic catalysts such as H_2SO_4, enabling milder conditions, lower activation energy, and improved selectivity. Both methods, however, generate by-products such as dipropylene glycol (DPG) and tripropylene glycol (TPG) if reaction parameters are not carefully controlled [8]. Consequently, downstream purification is essential to ensure high-purity PG and minimize by-product contamination. Effective separation not only enhances product quality but also reduces wastewater loads and improves overall process economics. Among available techniques, distillation remains the most widely applied method in industrial practice [9].

Previous studies have largely focused on improving catalyst performance, optimizing operating conditions, and modelling the kinetics of propylene oxide hydration [7], while research on separation and purification processes remains limited. Distillation, the most widely used industrial separation method, faces significant challenges due to the close boiling points and strong intermolecular interactions among propylene glycol, water, and by-products. These factors make purification more complex and energy intensive. Inefficient purification not only reduces the quality of the final product but also increases wastewater treatment loads and operational costs [9]. This research gap highlights the need for separation strategies that can enhance propylene glycol purity while minimizing the presence of higher-molecular-weight glycols in the product stream. Therefore, the present study aims to analyze and optimize the separation of propylene glycol from its reaction mixture to achieve high-purity output with reduced by-product formation, focusing specifically on improving the performance of distillation-based purification systems.

2. Methods

2.1 Process Simulation in Propylene Glycole Production

The reaction studied is a non-catalytic reaction between propylene oxide and water to produce propylene glycol, represented by the following Equation (1). The standard enthalpy of formation ($\Delta H^{\circ}_{298\,K}$) of the reaction at a pressure of 1 bar and a temperature of 298 K can be determined from the data provided in Table 1.

$$\Delta H^{\circ}_{298\,K} = \Delta H_{f\,product} - \Delta H_{f\,reactant} \quad (2)$$

$$\Delta H^{\circ}_{298\,K} = \Delta H^{\circ}_{f\,C_3H_8O_2} - (\Delta H^{\circ}_{f\,C_3H_6O} + \Delta H^{\circ}_{f\,H_2O})$$

$$\Delta H^{\circ}_{298\,K} = -421.5\ \text{kJ/mol} - (-92.76\ \text{kJ/mol} - 241.8\ \text{kJ/mol}) = -86.94\ \text{kJ/mol}$$

The Arrhenius equation is used to calculate the reaction rate of propylene glycol, and the frequency factor value is 16.96×10^{12} as shown in Equation (3).

$$k = 16.96 \times 10^{12} e^{\frac{-76000}{R.T}} \quad (3)$$

The basic process model for propylene glycol production via the hydration of propylene oxide was developed using Aspen HYSYS V11. Aspen HYSYS is a process simulator widely used for conceptual design, process control, optimization, and operational monitoring across various industries. Through this simulation, a comprehensive understanding of the process behavior is obtained, covering feed mixing, reactor-phase reactions, and product purification stages [12].

The initial stage of the simulation begins with the preparation of two feed streams, namely propylene oxide and water. These streams are mixed in a mixer to produce a homogeneous mixture before entering the reactor, ensuring more stable and easily analyzed operating conditions. The resulting mixture is then directed into a CSTR, selected because it represents ideal mixing conditions in which composition and temperature are assumed to be uniform throughout the reactor [13]. Within the CSTR, the non-catalytic hydrolysis of propylene oxide takes place, and the reactor effluent is analyzed to determine the conversion and the resulting composition of propylene glycol [14]. Simulation results indicate that the purity of propylene glycol produced in the reactor does not yet meet market specifications, necessitating an additional separation unit in the form of a distillation column. During the purification stage, variations in the reflux ratio are applied to identify the operating conditions that yield the most effective separation [15].

In addition, the operating conditions are modified by increasing the reactor inlet temperature from the initial value to evaluate the effect of temperature on the resulting propylene glycol purity. In the second stage of the methodology, a simulation of the propylene glycol

Table 1. The value of $\Delta H^{o}_{f,298K}$ [11].

Compound	Molecular Formula	$\Delta H^{o}_{f,298K}$ ($\frac{kJ}{mol}$)
Propylene oxide	C_3H_6O	-92.76
Water	H_2O	-241.8
Propylene glycol	$C_3H_8O_2$	-421.5

production process was carried out with a focus on evaluating the effect of varying the reactor inlet temperature [16]. The simulated process involves the non-catalytic hydrolysis reaction between propylene oxide and water. The operating conditions were modified by increasing the reactor inlet temperature from the initial value of 23.9 °C to 30 °C, 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. These variations were applied to assess the influence of temperature on the resulting propylene glycol purity. The equation used to calculate total net energy [17], is as follows:

$$Total\ Net\ Energy = QReboiler\ (\text{kW}) - QCondensor\ (\text{kW}) \quad (4)$$

In the process configuration, the two main feed streams propylene oxide and water were first modeled as material streams in Aspen HYSYS V11. The streams were then directed to a mixer to produce a homogeneous mixture prior to heating. This homogeneity is essential to ensure that both the heating process and the reaction proceed consistently throughout all stages.

3. Results and Discussion

3.1. Process Simulation before Modification

In the production of propylene glycol via the hydrolysis of propylene oxide, the materials used are propylene oxide and water. Both feed components enter the system under identical initial conditions 1.1 atm and 23.9 °C with a mass flow rate of 5000 kg/h. These two streams are then mixed in a mixer (MIX-100) to produce the feed stream for the reactor (CSTR-100). The reactor operates at 1.1 atm and 22.2 °C, with the temperature decreasing slightly due to the mixing of propylene oxide and water. The process simulation results prior to modification are presented in Figure 1.

3.2. Process Simulation after Modification

To maximize the purity of propylene glycol, two process modifications were implemented (Figures 2 and 3) in which the addition of a separation unit in the form of a distillation column and the adjustment of the reactor feed temperature (CSTR-100-2). The distillation column (T-101) was introduced with a series of reflux ratio variations of 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, and 9.5. Simulation results indicate that the optimum reflux ratio is 1.5, which increases the purity of propylene glycol from 54.49% to 99.58% (Table 2).

The second modification involved adjusting the reactor feed temperature (CSTR-100-2) from the initial 23.9 °C to 30 °C, 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C (Figures 4 and 5). These variations were applied to evaluate the influence of temperature on the resulting propylene glycol purity, using an optimum reflux ratio of 3.5. Temperature adjustment was carried out using a heater (E-100), where the mixed stream was heated to the specified operating temperatures. The heater ensures that the mixture enters the reactor at the correct temperature, enabling a more accurate assessment of temperature effects on reaction rate and conversion [18]. Once the desired temperature was reached, the stream was fed into the CSTR (CSTR-100-2). Based on these modifications, the optimum reactor feed temperature was determined to be 40 °C, the propylene glycol purity is 99.95% (Tables 3 and 4).

The equation used to calculate the profit of the CSTR prior to the distillation step, under various reactor inlet temperature increases, is as follows [19,20]:

$$Profit = Total\ Income - Total\ Cost \quad (5)$$

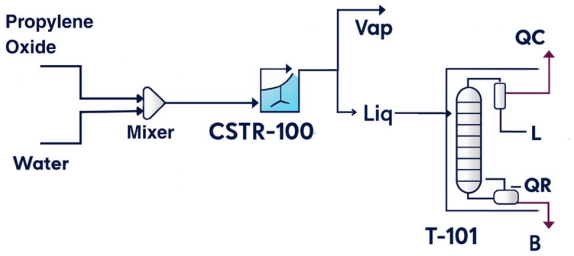

Figure 2. Modified process with distillation.

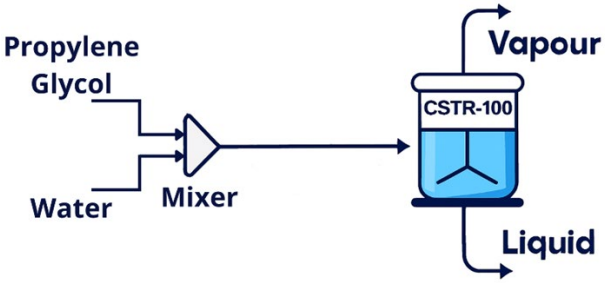

Figure 1. Unmodified process without distillation.

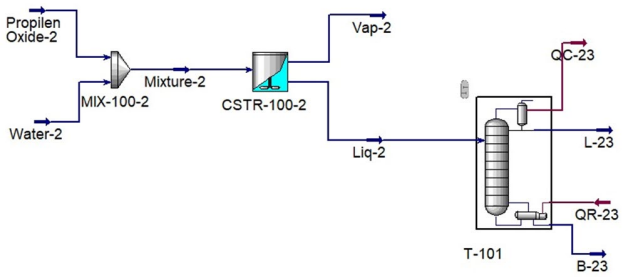

Figure 3. Process simulation of modified process with distillation.

$$Profit\ R = (Total\ Propylene\ Glycole\ Selling\ Price + Total\ Water\ Selling\ Price) - (Feed\ Cost + Heating\ Cost) \quad (6)$$

$$Total\ Propylene\ Glycole\ Selling\ Price = Price\ of\ Pure\ Propylene\ Glycole\ \left(2.47\frac{\$}{kg}\right) \times Bottom\ Flow\ Rate\ \left(\frac{kg}{h}\right) \times Composition\ of\ Propylene\ Glycole\ in\ system\ (mass\ fraction) \quad (7)$$

$$Total\ Water\ Selling\ Price = Price\ of\ Pure\ Water\ \left(2.6\frac{\$}{kg}\right) \times Bottom\ Flow\ Rate\ \left(\frac{kg}{h}\right) \times Composition\ of\ Water\ in\ system\ (mass\ fraction) \quad (8)$$

$$Feed\ Cost = Feed\ Cost\ \left(1.3\frac{\$}{kg}\right) \times Feed\ Flow\ Rate\ (kg/h) \quad (9)$$

$$Heating\ Cost = Heating\ Cost\ \left(0.005\frac{\$}{kWh}\right) \times Heater\ Duty\ (kW) \quad (10)$$

The equation used to calculate the profit of the CSTR after the distillation step, under various reactor inlet temperature increases, follows the same formulation as before but includes additional terms accounting for the performance of the condenser and reboiler, as shown below:

$$Condensor\ Cost = Condensor\ Cost\ \left(0.471\frac{\$}{kWh}\right) \times Condensor\ Duty\ (kW) \quad (11)$$

$$Reboiler\ Cost = Reboiler\ Cost\ \left(0.737\frac{\$}{kWh}\right) \times Reboiler\ Duty\ (kW) \quad (12)$$

$$Profit\ RD = (Total\ Propylene\ Glycole\ Selling\ Price + Total\ Water\ Selling\ Price) - (Feed\ Cost + Heating\ Cost + Condensor\ Cost + Reboiler\ Cost) \quad (13)$$

The equation for finding profit in a CSTR reactor before distillation at a temperature of 23.9 ℃:

$$Profit = Total\ Income - Total\ Cost \quad (5)$$

$$Profit\ R = (Total\ Propylene\ Glycole\ Selling\ Price + Total\ Water\ Selling\ Price) - (Feed\ Cost) \quad (14)$$

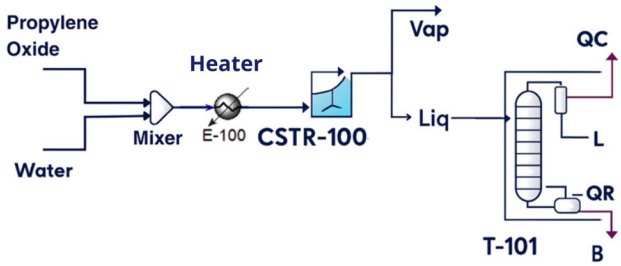

Figure 4. Modified process with distillation and increase temperature.

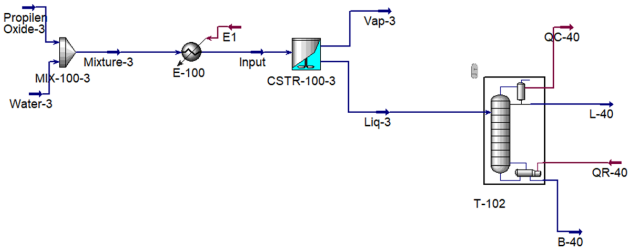

Figure 5. Process simulation of modified process with distillation and increase temperature using HYSYS.

Table 2. Process simulation result of modified process with distillation.

Reflux Ratio	Number of Trays	Purity $C_3H_8O_2$	Mass Flow $C_3H_8O_2$	QCondensor	QReboiler	Total Net Energy
1.5	20	99.58	6303	1176	1219	43
2	17	99.64	6306	1191	1233	42
2.5	16	99.66	6307	1203	1245	42
3	15	99.71	6309	1215	1259	44
3.5	15	99.73	6310	1227	1272	45
4	14	99.74	6311	1239	1285	46
4.5	14	99.76	6312	1212	1294	82
5	14	99.78	6313	1264	1310	46
5.5	13	99.80	6314	1276	1323	47
6	13	99.81	6314	1288	1336	48
6.5	13	99.82	6315	1301	1349	48
7	12	99.83	6316	1313	1361	48
7.5	12	99.85	6316	1326	1374	48
8	12	99.84	6316	1338	1387	49
8.5	12	99.84	6316	1351	1399	48
9	12	99.85	6317	1363	1412	49
9.5	11	99.86	6317	1376	1425	49

$$Total\ Propylene\ Glycole\ Selling\ Price = Price\ of\ Pure\ Propylene\ Glycole\ \left(2.47\frac{\$}{kg}\right) \times Bottom\ Flow\ Rate\ \left(\frac{kg}{h}\right) \times Composition\ of\ Propylene\ Glycole\ in\ system\ (mass\ fraction) \quad (15)$$

$$Total\ Water\ Selling\ Price = Price\ of\ Pure\ Water\ \left(2.6\frac{\$}{kg}\right) \times Bottom\ Flow\ Rate\ \left(\frac{kg}{h}\right) \times Composition\ of\ Water\ in\ system\ (mass\ fraction) \quad (16)$$

$$Feed\ Cost = Feed\ Cost\ \left(1.3\frac{\$}{kg}\right) \times Feed\ Flow\ Rate\ (kg/h) \quad (17)$$

The equation for finding profit in a CSTR reactor after distillation at a temperature of 23.9 ℃, using the same equation but adding for condenser and reboiler performance as follows:

$$Condensor\ Cost = Condensor\ Cost\ \left(0.471\frac{\$}{kWh}\right) \times Condensor\ Duty\ (kW) \quad (18)$$

$$Reboiler\ Cost = Reboiler\ Cost\ \left(0.737\frac{\$}{kWh}\right) \times Reboiler\ Duty\ (kW) \quad (19)$$

$$Profit\ RD = (Total\ Propylene\ Glycole\ Selling\ Price + Total\ Water\ Selling\ Price) - (Feed\ Cost + Condensor\ Cost + Reboiler\ Cost) \quad (20)$$

Based on the calculations for the CSTR reactor under variations of inlet temperature before distillation, an analysis of mass flow and product purity indicates that the optimum temperature for achieving both high purity and high mass flow is 40 °C. Subsequently, the calculated results for determining profit prior to distillation are presented in Table 5. Then the calculation is carried out to find the profit after distillation as presented in Table 6. The

Table 3. Process simulation result of modified process with distillation and increasing temperature.

Reflux Ratio	Number of Trays	Purity $C_3H_8O_2$	Mass Flow $C_3H_8O_2$	QCondensor	QReboiler	Total Net Energy
2.5	14	99.88	5462	381	554.7	173.7
3	14	99.95	5468	391.5	564.7	173.2
3.5	13	99.95	5470	400.2	573.3	173.1

Table 4. Result data before distillation for the modified system with distillation and increased temperature.

Reactor Inlet Temperature is Increased	Purity $C_3H_8O_2$	Purity H_2O	Mass Flow Bottom	Mass Flow Feed	Mass Flow Top
30	0.5646	0.4353	7447	10000	2553
40	0.7771	0.2228	5839	10000	4161
50	0.8016	0.1983	5490	10000	4510
60	0.8275	0.1725	4994	10000	5006
70	0.8556	0.1443	4207	10000	5793
80	0.8874	0.1125	2712	10000	7288

Table 5. Profit of reactor before distillation for the modified system with distillation and increased temperature.

Total Propylene Glycole Selling Price ($/h)	Total Water Selling Price ($/h)	Heating Cost ($/h)	Feed Cost ($/h)	Reactor CSTR Profit ($/h)
14415.119	5.4093	617.606	13000	802.922

Table 6. Profit of reactor after distillation for the modified system with distillation and increased temperature.

Condensor Cost ($/h)	Reboiler Cost ($/h)	CSTR Reactor and Distillation Profit ($/h)	CSTR Reactor and Distillation Profit ($/m)	CSTR Reactor and Distillation Profit ($/y)
188.494	422.522	191.906	46057.4	552688.8

calculation results for the CSTR at 23.9 °C prior to the distillation step yield the following profit values (Tabole 7). Then the calculation is carried out to find the profit after distillation as listed in Table 8. Based on the calculations for both systems, each reactor configuration yields a different profit outcome. For the reactor operating at 23.9 °C with a distillation unit, the annual profit is 552,688.8 $/year. In contrast, for the reactor with an optimized feed temperature increase to 40 °C prior to entering the reactor and followed by distillation, the annual profit becomes negative, amounting to –463,945.24 $/year.

4. Conclusions

Regarding process performance and economic feasibility, a modification was made to the reactor inlet temperature. At a temperature of 23.9 °C with a distillation configuration, the profit obtained was –161.09 $/h, indicating that this condition is not economically viable for operation. The negative profit suggests that reaction and separation efficiency at this temperature remain inadequate, resulting in higher energy consumption. Conversely, when the reactor inlet temperature increased to 40 °C with the same distillation configuration, profit rose significantly to 191.09 $/h, equivalent to 552.689 $ per year on an annual operational basis. This improvement demonstrates that a moderately higher temperature setting can enhance conversion efficiency and support distillation performance, making the overall process more profitable. Based on these results, it can be concluded that the reactor inlet temperature is a critical parameter in optimizing propylene glycol production. Among the tested conditions, operation at 40 °C delivers the best technical and economic performance and is therefore recommended as the most feasible operating condition.

CRedit Author Statement

Author Contributions: F K.D.A Anditariani: Resources, Data Curation, Writing, Review and Editing, Supervision; D.A.D. Lestari: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing Draft Preparation, Visualization, Software, Project Administration; J.F. Putri: Conceptualization, Methodology, Investigation Validation, Writing, Review and Editing, Data Curation; L.H. Fauzia: Conceptualization, Methodology, Investigation Validation, Investigation, Resources, Writing, Review and Editing, Validation. P.S. Prastica: Investigation, Validation, Writing, Review and Editing, Data Curation, Resources. All authors have read and agreed to the published version of the manuscript.

References

[1] Alshbuki, E. (2023). Simulation of The Optimum Operating Conditions for A Propylene Glycol Production Unit Using Aspen Hysys Software. *Journal of Pure & Applied Sciences*, *22*(3), 120–123. DOI: 10.51984/jopas.v22i3.2758

[2] Okolie, J.A. (2022). Insights on production mechanism and industrial applications of renewable propylene glycol. *ISCIENCE*, *25*, 104903. DOI: 10.1016/j.isci.2022.104903

[3] Pemberton, MA., Kimber, I. (2023). Propylene glycol, skin sensitisation and allergic contact dermatitis: A scientific and regulatory conundrum. *Regulatory Toxicology and Pharmacology*, 138. DOI: 10.1016/j.yrtph.2023.105341

[4] Duggan, K., Ijaz, M.K., McKinney, J., Maillard, J.Y. (2024). Reviewing the evidence of antimicrobial activity of glycols. *Journal of Applied Microbiology*, 135. DOI: 10.1093/jambio/lxae071

[5] Wordu, A.A., Wosu, C.O. (2019). CSTR Design for Propylene Glycol Chemical Production. *International Journal of Latest Technology in Engineering. 8(2).*

Table 7. Profit of reactor before distillation for the modified system with distillation.

Total Propylene Glycole Selling Price ($/h)	Total Water Selling Price ($/h)	Feed Cost ($/h)	Reactor CSTR Profit ($/h)
13444.316	4.083	13000	448.399

Table 8. Profit of reactor after distillation for the modified system with distillation.

Condensor Cost ($/h)	Reboiler Cost ($/h)	CSTR Reactor and Distillation Profit ($/h)	CSTR Reactor and Distillation Profit ($/m)	CSTR Reactor and Distillation Profit ($/y)
187.411	422.079	-161.092	-38662.1	-463945.24

[6] Fendu, E.M., Nicolae, M. (2020). Synthesis and simulation of a distillation columns system for the propylene glycols mixtures separation. *Engineering Reposrts, 3(4),* 1-20. DOI: 10.1002/eng2.12301

[7] Ariyanto, E., Yusmartini, E.S., Robiah, R., Ardianto, F. (2024). Simulation Study of Propylene Glycol Formation from Propylene Oxide and Water: Effect of Reactor Type, Reactant Ratio, Temperature, and Reactor Configuration. *Indonesian Journal of Fundamental and Applied Chemistry*, *9*(1), 26–34. DOI: 10.24845/ijfac.v9.i1.26

[8] Akyalcin, S. (2017). Kinetika hidratacije propilen-oksida u prisustvu heterogenog katalizatora. *Chemical Industry and Chemical Engineering Quarterly*, *23*(4), 573–580. DOI: 10.2298/CICEQ170203011A

[9] Hu, S., Li, J., Wang, Q., Yang, W. (2022). Design and optimization of an integrated process for the purification of propylene oxide and the separation of propylene glycol by-product. *Chinese Journal of Chemical Engineering*, *45*, 111–120. DOI: 10.1016/j.cjche.2021.04.012

[10] Azad, T., Torres, H.F., Auad, M.L., Elder, T., Adamczyk, A.J. (2021). Isolating key reaction energetics and thermodynamic properties during hardwood model lignin pyrolysis. *Physical Chemistry Chemical Physics, 23(37)*, DOI: 10.1039/d1cp02917g.

[11] Yaws, C.L. (1997). Handbook of chemical compound data for process safety : comprehensive safety and health-related data for hydrocarbons and organic chemicals : selected data for inorganic chemicals. Gulf Pub. Co.

[12] Valverde, J.L., Ferro, V.R., Giroir-Fendler, A. (2023). Automation in the simulation of processes with Aspen HYSYS: An academic approach. *Computer Applications in Engineering Education*, *31*(2), 376–388. DOI: 10.1002/cae.22589

[13] Cherkasov, N., Adams, S.J., Bainbridge, E.G.A., Thornton, J.A.M. (2022). Continuous stirred tank reactors in fine chemical synthesis for efficient mixing, solids-handling, and rapid scale-up. *Reaction Chemistry and Engineering, 8*, 266–277. DOI: 10.1039/d2re00232a

[14] Li, M.R., Gu, G.G., Yue, T.J., Ren, W.M., Lu, X.B. (2024). CO2-assisted hydration of propylene oxide to produce propylene glycol: Accessing high selectivity using a jet loop reactor. *Journal of CO2 Utilization*, *80*. DOI: 10.1016/j.jcou.2024.102684

[15] Olivier-Maget, N., Berdouzi, F., Murillo, C., Gabas, N. (2021). Deviation propagation along a propylene glycol process using dynamic simulation: an innovative contribution to the risk evaluation. *Journal of Loss Prevention in the Process Industries*, 70, 104435. DOI: 10.1016/j.jlp.2021.104435.

[16] Sun, P., Zhang, W., Yu, X., Zhang, J., Xu, N., Zhang, Z., … Jin, X. (2022). Hydrogenolysis of Glycerol to Propylene Glycol: Energy, Tech-Economic, and Environmental Studies. *Frontiers in Chemistry*, *9*. DOI: 10.3389/fchem.2021.778579

[17] Shao, Y., Xiao, H., Chen, B., Huang, S., Qin, F.G.F. (2018). Comparison and analysis of thermal efficiency and exergy efficiency in energy systems by case study. *Energy Procedia*, *153*, 161–168. DOI: 10.1016/j.egypro.2018.10.081

[18] Muranaka, Y., Maki, T., Nakayoshi, D., Ota, M., Mae, K. (2024). Temperature control strategy for safer and heat-efficient operations in a catalytic flow reactor. *Chemical Engineering Journal*, *491*. DOI: 10.1016/j.cej.2024.152029

[19] Restrepo, J.B., Paternina-Arboleda, C.D., Bula, A.J. (2021). 1,2—propanediol production from glycerol derived from biodiesel's production: Technical and economic study. *Energies*, *14*(16). DOI: 10.3390/en14165081

[20] Chong, D.J.S., Foo, D.C.Y., Putra, Z.A. (2023). A reduced order model for triethylene glycol natural gas dehydration system. *South African Journal of Chemical Engineering*, *44*, 51–67. DOI: 10.1016/j.sajce.2023.01.001.