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RESEARCH ARTICLE

Refinery Off-Gas as Feed to a Hydrogen Production Facility: Performance Lifting of the Steam Reforming Technique

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Abstract: Refinery off-gas is one of the major causes of air pollution, where its reuse, through channeling into other plant setups to recover some of its constituent gases (via a steam reforming technique), is described as one of its best handling measures. A nominal off-gas containing 2.898% hydrogen (H_2), 83.794% methane, 1.505% carbon dioxide, 1.103% nitrogen, 10.6% sulfur, and 0.1% argon was fed to a plant to produce 37.52 kg of H_2. To lift the performance of the multiple interconnected process units enhancing the generation of H_2, temperature and pressure in the reactors were manipulated against the heat duty and H_2 yield, where it was found that the two dependent variables are sensitive to changes made during Aspen Plus sensitivity analysis. Replacing some process units also shows significant improvement in the recovery of H_2 gas. Adequate control of the synthesis process as exemplified in this work will lead to smooth realization of the target end-product which is of high economic value, basically looking at its potential for the manufacture of other useful materials it is already known for.

Keywords: hydrogen production, synthesis gas, petroleum refining, steam reforming, refinery off-gas, light hydrocarbons

1. Introduction

Hydrogen (H_2) is a diatomic gas that is colorless, odorless, tasteless, non-toxic, non-corrosive, and non-metallic. It is also regarded as a perfect gas across a wide range of temperatures and high pressures. It has a low density, being also the second lowest, in terms of boiling and melting points, second only to helium (Abe, 2005; Panda, 2020). Below its boiling point of 20K (−423° F; −253°C), it remains a liquid but solid below its melting point of 14K (–434°F; –259°C) and atmospheric pressure (Fichtner & Idrissova, 2010). Hydrogen can be generated from a range of raw materials, such as biomass and water with input from renewable energy sources (such as sunlight, wind, wave, or hydropower), as well as fossil and renewable feedstock, such as natural gas and coal (Bal, 2013; Zannah et al., 2023). Also, it can be produced from any hydrocarbon fuel since H_2 is one of its main constituents or fuel processing technologies in general (Imperiyka et al., 2017) – and other alternative sources such as biomass and water (H_2O) through gasification and electrolysis, respectively. Using fuel technologies, the methodology involves the conversion of materials such as ammonia (NH_3), methanol (CH_3OH), methane (CH_4), and gasoline into rich stream of H_2 through different reforming techniques. There are three principal techniques used to produce H_2 from hydrocarbon fuels (El-Shafie et al., 2019; Walden, 2022): namely, steam-methane reforming (SMR), autothermal reforming, and partial oxidation. Among them, SMR is the best way to

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*Corresponding author: Abdulhalim Musa Abubakar, Department of Chemical Engineering, Modibbo Adama University, Nigeria. Email: abdulhalim@mau.edu.ng go based on the following reasons: it has the highest H_2 yield of all reforming strategies, it is currently the simplest and least expensive method of H_2 production, it has the highest efficiency (65–70%), it is the safest due to the lower operating temperature of the SMR technique, and cumulatively, its disadvantages are easier to overlook or address (Holladay et al., 2009; Olateju et al., 2017). Other techniques of separating H_2 from refinery off-gas, like pressure swing adsorption (PSA), membrane separation (MS), and cryogenic distillation (CD), are vividly explained in the literature, where cost and purity of the product recovery (i.e., H_2) are two major factors that must be considered in choosing a particular technique (Benson & Celin, 2018; Faraji et al., 2005; Hussain, 2023; Key & Malik, 2010; Mehra, 1988; Mperiju et al., 2023). In terms of purity, MS < CD < PSA, according to literature sources (Benson & Celin, 2018; Hussain, 2023; Mendez et al., 2000).

Increased demand for clean fuels will be a solid motivation to build new refineries having greater conversion and off-gas treatment capacity (Faraji et al., 2005). In addition to being used to remove metals, sulfur, and nitrogen (N_2) from various petroleum fractions, H_2 is desirable for the conversion and processing of heavy petroleum fractions into lighter products. The quality of the refined crude oil will also influence the demand for H_2 in refineries. Due to the fact that the catalytic reforming unit provides the majority of the H_2 needed for production, heavier crude oils will result in higher H_2 demand as well as stricter product quality requirements (Fahim et al., 2010; Mivechian & Pakizeh, 2013). This is because, it finds application in NH_3, polymer, and resin production; hydrocracking for desulfurization in refineries; annealing (heat treatment of processed metal to restore ductility after deformation); and a replacement to today's uses of natural gas in areas such as cooking (in stoves), boilers, catalytic heater devices, central heating furnaces along with a well-organized decentralized cogeneration applications for joint electricity, and heat/cold manufacture. Hydrogen is needed in large amounts in oil refining industries because it plays a vital role in the petroleum refineries and is also used to produce low sulfur fuels, specifically from refinery gases which is its primary source (Drnevich & Herzog, 2006; Mivechian & Pakizeh, 2013; Shahraki et al., 2005). Hydro-conversion is a term used to describe the entirety of dissimilar processes in which hydrocarbons reacts with H_2 (hydro-processing), such as hydrotreating, hydrocracking, and hydrogenation (Hussain, 2023; Speight, 2016). Hydrocracking entails the catalytic cracking of feedstock into products with lower boiling points by reacting them with H_2, while hydrogenation is used when aromatics are saturated by H_2 to produce the corresponding naphthene. Hydrotreating describes the process of removing sulfur, N_2, and metal impurities in the feedstock by H_2 in the presence of a catalyst (Bricker et al., 2015; Mendez et al., 2000). About 2/3 of H_2 is supplied by the onsite steam-methane reformers at refineries (Yuan et al., 2022).

Production of H_2 will significantly bring to the barest minimum, the frequency of fuel cell importation by several countries. This is simply because, fuel cells and other products, such as fertilizers, chemicals, ceramics, plastics, pharmaceuticals, metallurgy, glass, food, and beverages, are products of H_2. A country that produces H_2 may be able to also produce a majority of the products just listed. Based on this merit, we set an achievable objective of realizing approximately 40 kg/h of H_2, to be manufactured taking refinery off-gas as feed. Off-gases formed at refineries regularly comprise of components such as olefins, diolefins, hydrocarbons, CO, CO_2, H_2S, and various organic sulfur species – all of which are injurious to the environment and subject to ever more sterner protocols (Faraji et al., 2005). In a typical refinery off-gas, there are 28% H_2, 28% CH_4, 24% C_2^+ paraffins, 10% olefins, 3.5% N_2, 3% CO_2, and 3.5% CO, sometimes containing 25–250 ppm of sulfur (Dragomir et al., 2010). In another report by Faraji et al. (2005), % molar composition of an industrial off-gas stream flowing at 5800 kg/h at 25 and 1.2 bara contains 45.74 C_1, 5.46 C_2, 3.84 C_3, 0.98 iC_4, 0.59 nC_4, 0.18 iC_5, 0.07 nC_5, 0.04 C_6^+, 0.64 CO, 8.84 CO_2, and 33.62 H_2. Despite the fact that refinery off-gases containing minimal CO_2 cause greenhouse gas problems upon release, re-channeling them to recover CO_2, CH_4, and olefins will reduce this potential hazard to the atmosphere. As part of addressing some of these challenges, objectives of this work are to model the production of H_2 using the SMR method, describe the process, carryout and show the material and energy balances results, carryout Aspen Plus sensitivity and optimization analysis for the process, and design a scheme for adequate control of process variables. This study will enable students acquire the basic understanding of the principles of plant design, give them insight on how industries operate, and help them appreciate the chemical engineering profession, thereby facilitating the mimicking of the real-world H_2 production scenarios.

2. Method

Since Aspen Plus version 8.4 has a variety of specialized work environments and a powerful solver, it was utilized to model H_2 production employing a wide range of unit operations.

2.1. Process description

Production of H_2 from light hydrocarbons was carried out by following these steps (Fahim et al., 2010; Ibrahim, 2018): first, the steam was hydrogenated to convert the organic sulfur to hydrogen sulfide (H_2S) via a pretreatment (or desulfurization) process, before it is later adsorbed on zinc oxide. Next, steam was reformed to synthesis gas (CO + H_2); CO was converted to CO_2 using steam in a one-stage shift converter; and lastly, the H_2 produced was purified. Light hydrocarbon (C3–C7) streams from the various refining operations were fed into the steam reforming unit. The presence of sulfur compounds in these streams, such as H_2S, mercaptans, and halogenated chemicals (chlorides), may poison the nickel catalyst. To address this, the feed was prepared. A process that involves hydrogenating organic sulfur and chloride at 350–400°C (662–752°F) in the presence of a cobalt/molybdenum (Co-Mo) hydrotreating catalyst to produce H_2S and hydrochloric acid (HCl), respectively. After that, the H_2S will be absorbed in a bed of ZnO. The sulfur content of treated feed must be 0.1 ppm or below, and the chloride content must be kept to 0.5 ppm. Minimum purity limits (composition standards) for the natural gas feed are set by reformer constraints. First off, reforming is a catalytic process (Giwa & Giwa, 2013), and even minute levels of sulfur can damage the catalysts used. As a result, sulfur compounds were pretreated in R-101 using the following reaction as the mechanism: $RSH + H_2 \rightarrow RH + H_2S$, in order to operate economically. Second, non-CH_4 hydrocarbons must be changed into CH_4 hydrocarbons since reforming is basically a reaction between CH_4 and steam.

By chemically reacting CH_4 and other light hydrocarbons with steam at temperatures of 820–880°C (1508–1616°F) and pressures of 20–25 bar (294–368 psi), this process creates H_2. Nickel on an alumina support served as the catalyst in use. Light hydrocarbons were supplied into the steam reforming reactor, which consists of tubes that are loaded with a nickel catalyst and run through a furnace. The major feed used was CH_4. It was circulated through the convection area of the furnace, where it was heated to

540–580°C (1004–1076°F). The feed (which is a combination of CO, H_2, CO_2, H_2O, and CH_4) was then converted to synthesis gas by reacting with surplus steam in the radiation section of the furnace, in accordance with Reaction 1 in R-102 (Al-Dhfeery & Jassem, 2012; Cruz & Junior, 2008; Zaccara et al., 2020).

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad \Delta H = +206.16 KJ/molCH_4 \quad (1)$$

Steam-to-carbon molar ratio, which is mostly in the range of 2.5–5.0, according to Fahim et al. (2010), was specified. Reforming reactions are simply equilibrium reactions where the conversion with nickel catalyst helps the unit to get close to the highest conversion that can be accomplished at the reaction temperature and pressure. Consequently, a lot will depend on the quality of the H_2 stream produced by the unit in addition to the catalyst's catalytic activity, including the reaction's temperature, pressure, and amount of steam. Hot gas leaving the reformer tubes was cooled between the range of 650–700°F in waste heat boiler exchanger before channeling to a shift converter. In this reactor (via mechanism of Reaction 2 or water-gas shift), CO was converted to CO_2 over an iron and chromium oxide catalyst in R-103 (Al-Dhfeery & Jassem, 2012; Olateju et al., 2017).

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \Delta H = 41.150 KJ/molCO \quad (2)$$

H_2 and CO are abundant in the reformer's synthesis gas (used in Reaction 2). The H_2 content was raised via the shift reaction discussed above.

2.2. Generating stream outputs

After defining the units and feed properties in Aspen Plus following the procedure described in the previous section, the process flow diagram of the H_2 synthesis technique used was generated.

2.3. Sensitivity analysis and optimization

Inputs, including operating variables, variables that describe field conditions, and variables that include unknown or partially known model parameters, according to Giwa & Giwa (2013), may be manipulated during sensitivity analysis. In this work, yield of the product (H_2) was optimized by carrying out a sensitivity analysis on the temperature and heat duty requirements, which are the manipulated variables against H_2 yield which is the objective function, as described in Fahim et al. (2010). Other process units, such as HX-101 and HX-102 that may only be optimized if replaced with similar unit, were changed completely and the model was re-run.

2.4. Control implementation

Using Aspen Plus control features, control of the process units by specifying set points was carried out.

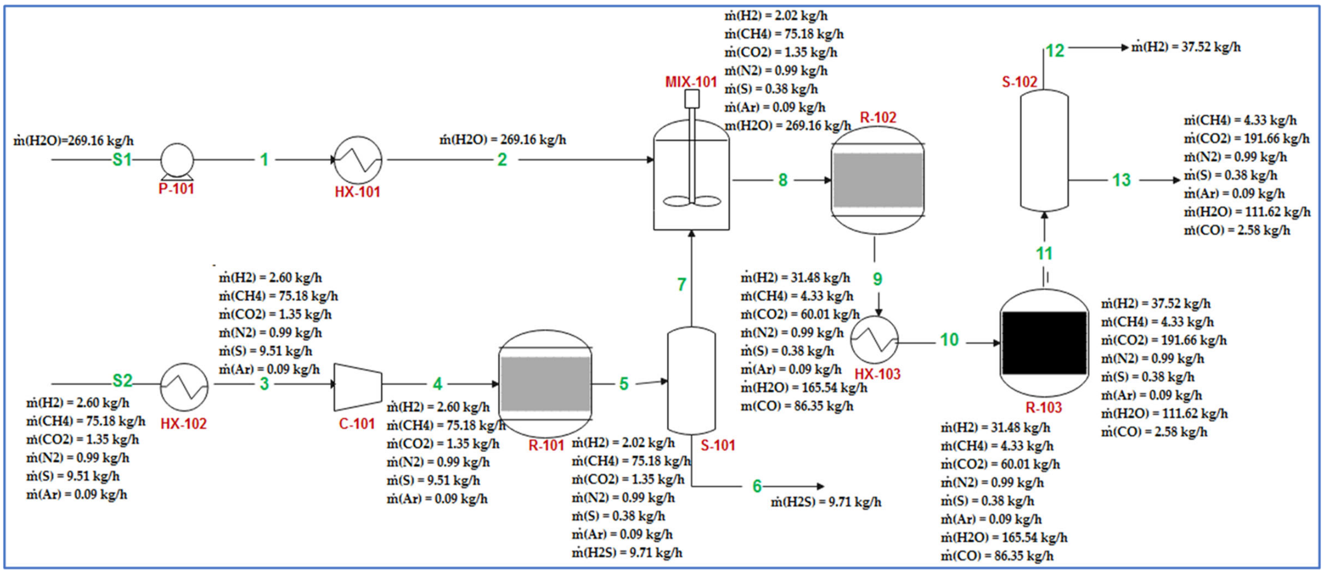
3. Results and Discussion

3.1. Balanced process flow diagram

Eleven units comprising of a pump (P-101), heat exchangers (HX-101, HX-102, and HX-103), compressor (C-101), reactors (R-101, R102, and R-103), mixer (MIX-101), and separators (S-101 and S-102) interconnected using 13 streams, resulted in the process outputs shown in Figure 1.

Energy balance is crucial for a H_2 production plant for several reasons: an energy balance allows for the assessment of the overall energy efficiency of the H_2 production plant. It helps identify areas where energy losses or inefficiencies occur, enabling plant operators to implement measures for optimization. By understanding the energy flows within the system, the plant can target improvements in energy conversion, utilization, and recovery, leading to enhanced overall efficiency. Energy is a significant cost factor in H_2 production. An energy balance helps quantify and analyze energy consumption throughout the plant, enabling a detailed cost analysis. By accurately tracking energy usage, plant operators can

Figure 1
Steam reforming process/mass flow diagram of hydrogen manufacture



identify areas where energy costs can be reduced, thereby optimizing the cost-effectiveness of the H_2 production. It also aids in the efficient management of resources. By tracking energy inputs and outputs, the plant can assess the overall energy demand and ensure an adequate and reliable supply, thereby allowing for better planning and allocation of resources, such as fuel sources or electricity, optimizing their usage, and minimizing waste. Energy balance provides insights into the environmental impact of H_2 production. It helps quantify greenhouse gas emissions, energy-related pollutants, and the carbon footprint of the plant (Dolci, 2018; Leclerc et al., 2022). By identifying energy-intensive processes or areas with high emissions (e.g., H_2S from S-101 shown in Figure 2), the plant can implement strategies for emissions reduction and environmental sustainability (Zaccara et al., 2020).

In addition, an energy balance provides vital information for process control and safety considerations, as would be seen later. It allows operators to monitor and adjust energy inputs and outputs, ensuring that the plant operates within safe limits. By maintaining a balanced energy system, the risk of equipment failures, operational issues, and safety hazards can be minimized. An energy balance serves as a valuable tool for future planning and scale-up of the H_2 production plant. It provides insights into the energy requirements and constraints of the existing plant, helping in the design and optimization of larger-scale systems. Accurate energy balance data are crucial for estimating energy demands, evaluating potential expansions, and guiding strategic decision-making. In summary, an energy balance is essential for optimizing efficiency, reducing costs, managing resources, minimizing environmental impact, ensuring safety, and facilitating future planning in the H_2 production plant. It enables a comprehensive understanding of the energy dynamics within the plant, leading to more sustainable and effective operations (Ghasem & Henda, 2015). Basic illustration, destination, and/or constituents of every stream in Figures 1 and 2 are illustrated in Table 1.

Obviously, the simulation convergence is due to its attainment of a balance in material and energy flow in and out of the system as shown in Table 1; attributed to this researcher's specification of appropriate process conditions in the beginning (Ghasem & Henda, 2015).

3.2. Response analysis

Elimination and replacement of redundant equipment with alternative ones will significantly reduce the cost of production by minimizing the cost of operation and maintenance of the units in the process. Figure 2 shows the process flow diagram where both a heater and a cooler are being separately employed. The two units: HX-101 and HX-103, i.e., a heater and a cooler, respectively, are being eliminated and replaced with a heat exchanger, E-101, as shown in Figure 3.

By limiting downtime, prolonging equipment life, lowering energy and other operating expenses, and optimizing performance, successful equipment optimization specifically protects investment and enhances output. On the other hand, temperature in reformer R-102, shift converter R-103, and the pressure in both were respectively varied between 820–950, 220–500°C, and 20–25 bar. As described earlier, those parameters were manipulated against the heat duty requirements and H_2 yield as shown in Figures 4, 5, 6 and 7. Figure 4 shows the graph of temperature against heat duty and H_2 yield in the reformer (R-102), where it was observed that they both increase with increase in temperature.

Heat duty of R-102 increases with an increase in temperature, suggesting that the reactor is operating under an endothermic reaction or process, based on Figure 4. An endothermic reaction or process absorbs heat from the surroundings to proceed. In such a scenario, raising the temperature of the reactor provides the necessary energy to drive the endothermic reaction or process (Mostafa et al., 2020; Overwater et al., 2013). As the temperature

Figure 2

Energy flow in the streams after hydrogen production simulation with Aspen Plus: unoptimized process flow diagram

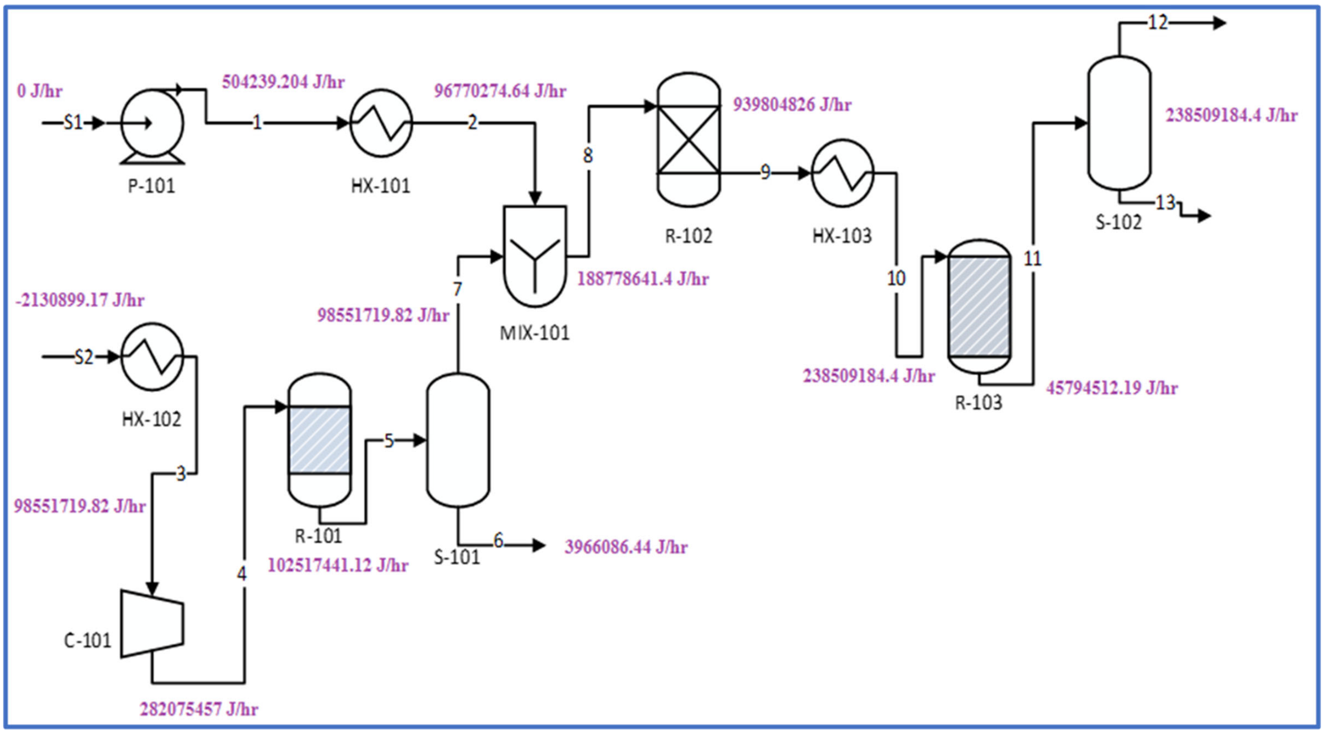
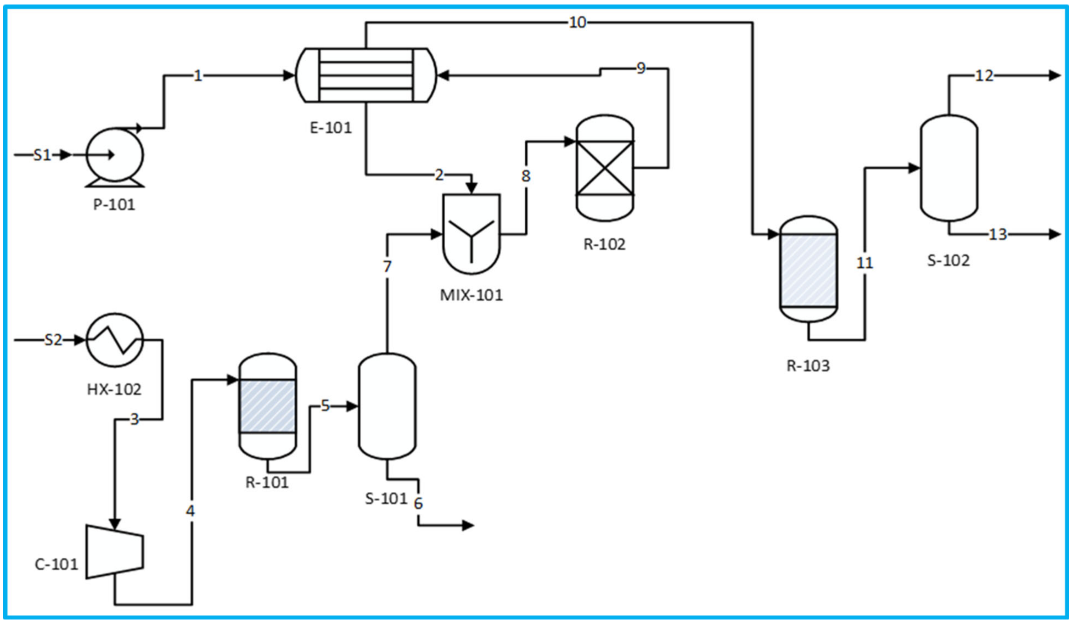


Table 1
Stream functions and units nomenclature

No.	Units	Name	Feed stream flow rate (kg/h)		Exit stream flow rate (kg/h)	
1.	P-101	Water pump	S1: 269.16		1: 269.16	
2.	HX-102	Heat exchanger	S2: 89.72		3: 89.72	
3.	HX-101	Heat exchanger	1: 269.16		2: 269.16	
4.	C-101	Natural gas compressor	3: 89.72		4: 89.72	
5.	R-101	Pre-reformer	4: 89.72		5: 89.72	
6.	S-101	H_2S remover	5: 89.72		6: 9.71	7: 80.01
7.	MIX-101	Gas mixer	2: 269.16	7: 80.01	8: 349.17	
8.	R-102	Steam reformer	8: 329.17		9: 349.17	
9.	HX-103	Heat exchanger	9: 349.17		10: 349.17	
10.	R-103	Shift converter	10: 349.17		11: 349.17	
11.	S-102	Hydrogen separator	11: 349.17		12: 37.52	13: 311.65

Note: S1, S2 and integer numbers in Column 4 and 5 represent streams

Figure 3
Optimized process flow diagram of hydrogen production



increases, more heat is required to sustain the reaction, resulting in an increased heat duty. It is worth noting that maintaining higher temperatures in a reactor can have several implications. To maintain the correct temperature, more energy may be needed, which could raise running expenses. Moreover, higher temperatures can also impact the kinetics and equilibrium of the reaction, affecting its overall performance and selectivity. Thus, careful consideration and optimization are necessary to balance the benefits and drawbacks of operating at higher temperatures (especially) in R-102. Normally, control architectures (as would be explained later) are designed based on whether a reactor is endothermic or exothermic (McQuillan et al., 2023). According to McQuillan et al. (2023), endothermic reactions are easier to control. Meanwhile, in Figure 5, the graph shows how heat duty increases with increase in temperature as H_2 yield remains constant over the range of temperature analyzed.

Figures 6 and 7 depict the profile of pressure variation against H_2 yield and heat duty requirement in reactors, R-102 and R-103, respectively.

Technically, heat duty of R-102 and R-103 decreases with an increase in pressure (Figures 6 and 7), suggesting that R-103 operates under an exothermic reaction or process (Bekat & Inal, 2015; Lu et al., 2023). An exothermic reaction releases heat to the surroundings as it proceeds. When the pressure is increased, it can have several effects on the exothermic reaction and the heat duty of the two reactors. Increasing the pressure can cause the reaction to shift towards the reactant side, depending on the stoichiometry and thermodynamics of the reaction. This shift can result in a decrease in the heat duty as fewer products are formed, leading to less heat release. Changes in pressure can influence the reaction rate. In some cases, increasing the pressure can enhance the reaction rate, leading to a more rapid consumption of reactants and thus reducing the heat duty. Higher pressure can impact heat transfer mechanisms within R-102 and R-103. Increased pressure can improve heat conduction or convection, allowing heat to dissipate more effectively. This efficient heat transfer can reduce the temperature rise and, consequently, the heat duty.

Figure 4
Sensitivity curve of R-102 to variation in temperature

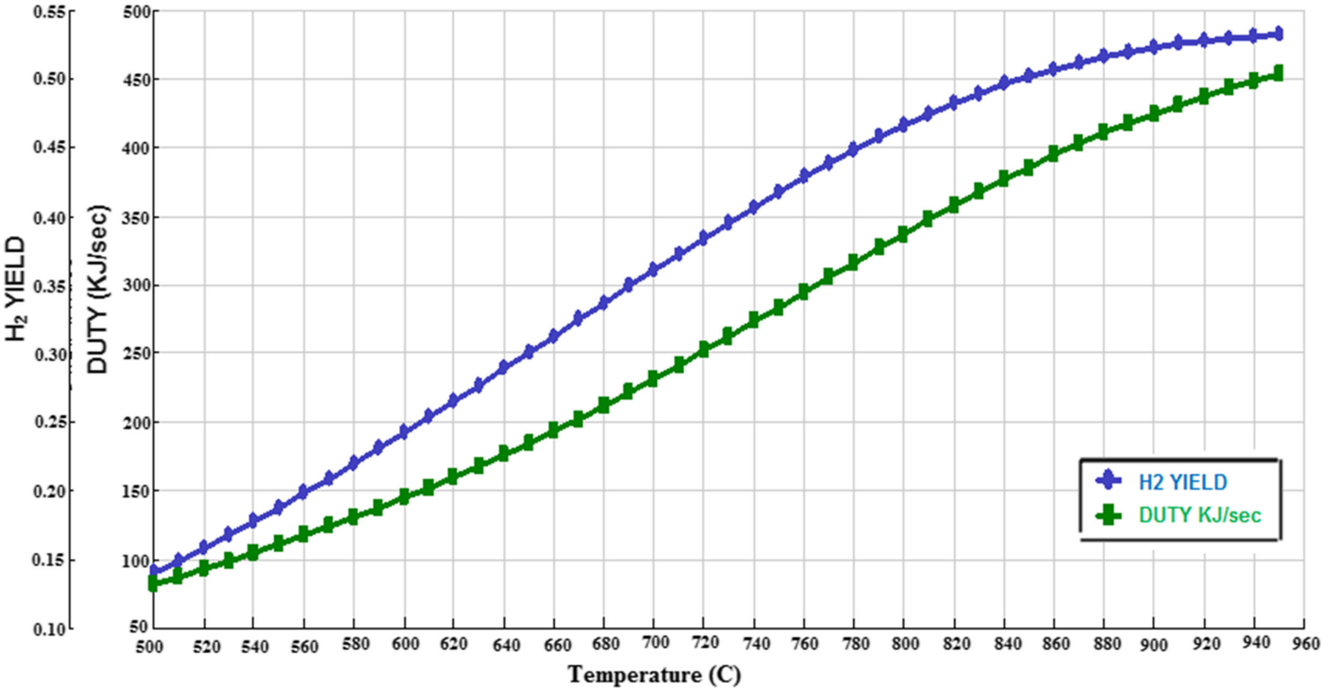


Figure 5
Linear sensitivity diagram of R-103 on varying the temperature

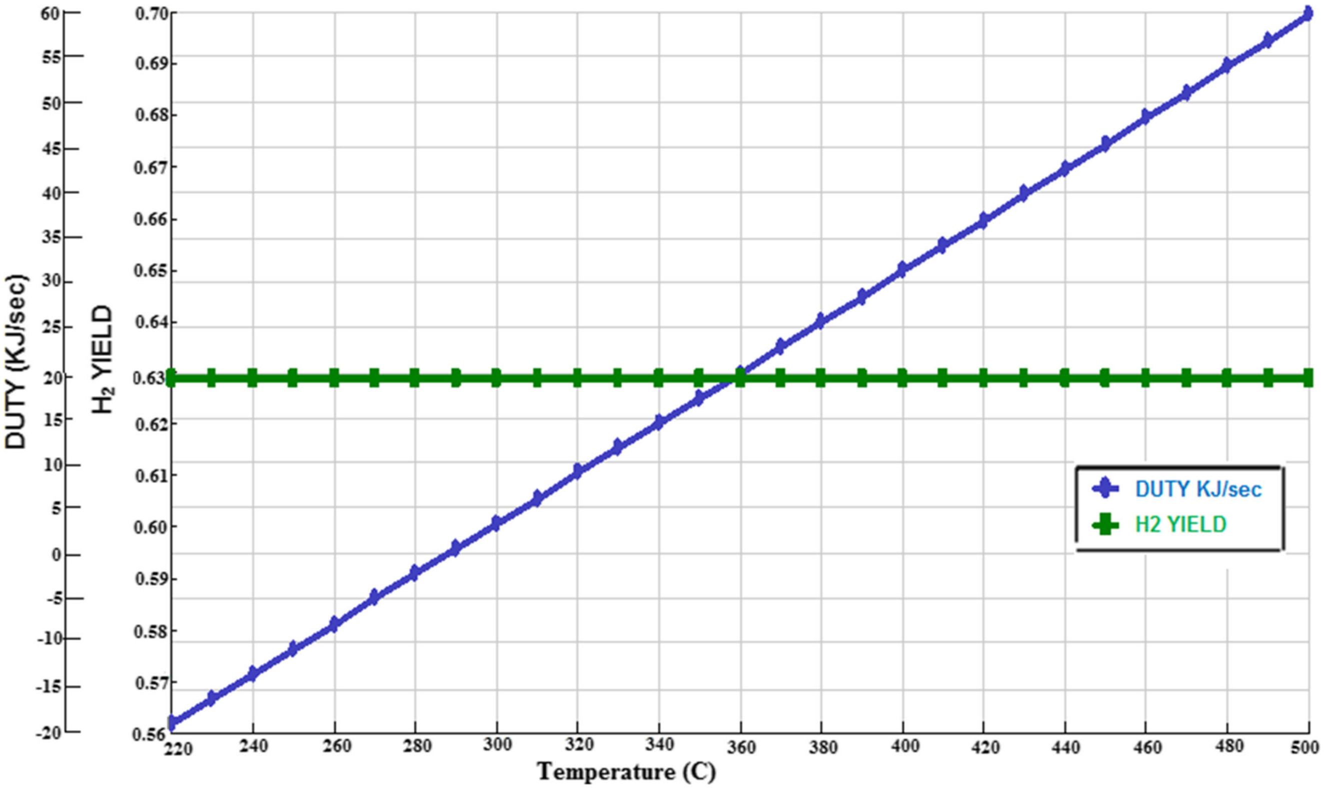


Figure 6
Sensitivity linear diagram of R-102 after pressure manipulation

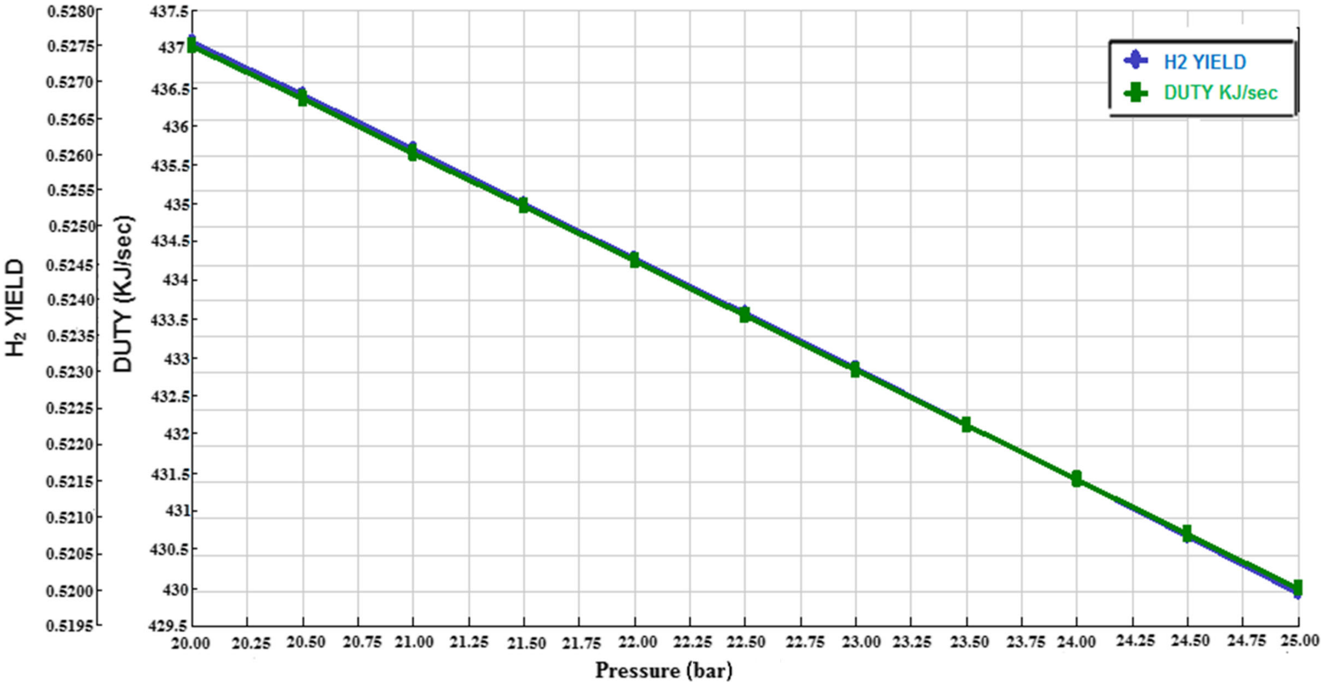
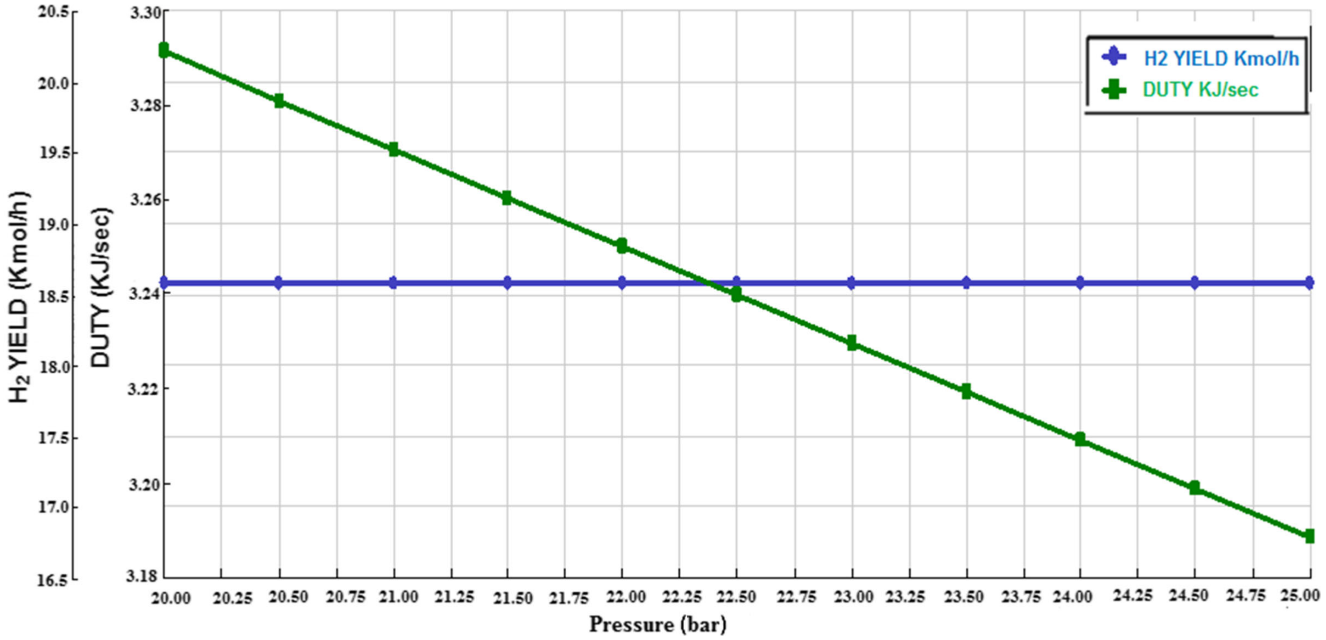


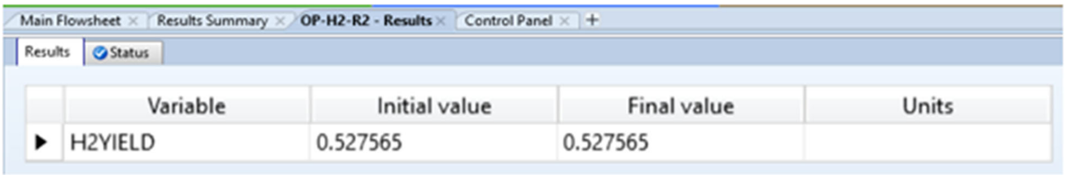
Figure 7
Sensitivity linear relationship of R-103 after pressure manipulation



3.3. Optimization outcome

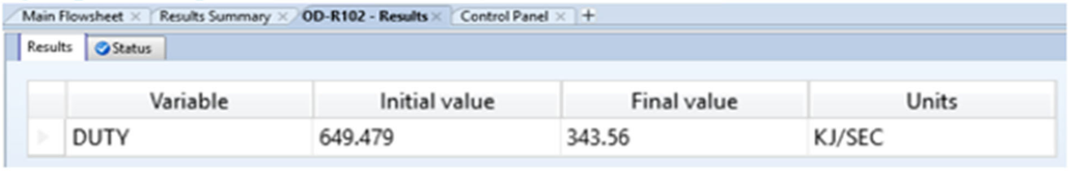
Flexible feature of Aspen Plus was used to evaluate the optimum operating values. Result of the optimization on R-102 showed that input operating conditions are at their optimum values of 920 and 20 bar, producing H_2 yield of 52.7% as shown in Figure 8(a). Further optimization conducted with respect to heat duty requirement in R-102 (Figure 8(b)) showed a decrease in the objective function (heat duty requirement) which has decreased the H_2 yield. R-103 optimization result with respect to H_2 yield showed that the operating condition is already at its optimum value, i.e., 300 and 20 bar with H_2 yield of 62.8% as shown in Figure 8(c). Lastly, optimization run with respect to heat duty requirement of R-103 is shown in Figure 8(d),

Figure 8
Hydrogen yield and heat duty optimization in R-102 and R-103



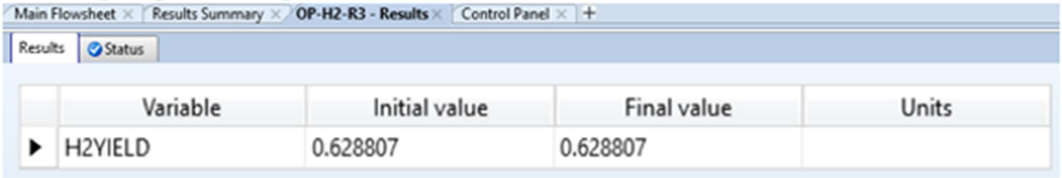
	Variable	Initial value	Final value	Units
▶	H2YIELD	0.527565	0.527565	

(a) Hydrogen Yield Optimization in R-102



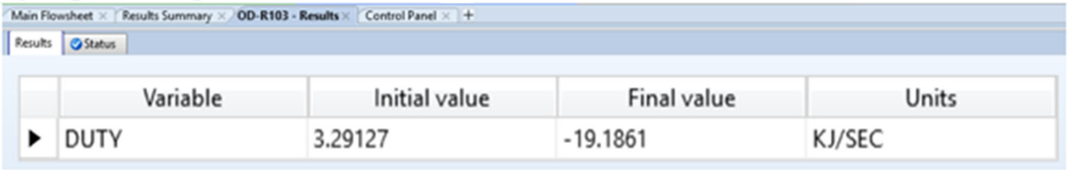
	Variable	Initial value	Final value	Units
	DUTY	649.479	343.56	KJ/SEC

(b) Heat Duty Requirement Optimization of R-102



	Variable	Initial value	Final value	Units
▶	H2YIELD	0.628807	0.628807	

(c) Hydrogen Yield Optimization in R-103



	Variable	Initial value	Final value	Units
▶	DUTY	3.29127	-19.1861	KJ/SEC

(d) Heat Duty Requirement Optimization of R-103

where it depicts a decrease in heat duty requirement in the unit, influencing the H_2 yield. Figure 8 shows that heat duty varies with pressure and temperature manipulations, which is same with depictions in Figures 5, 6 and 7, thereby pointing to an optimal/final value.

3.4. Control architecture

There are hundreds or even thousands of control loops in a typical processing plant, such as a chemical factory or an oil refinery. One aspect of the process is controlled by each control loop, such as the flow, level, or temperature (Abubakar et al., 2023). Process performance deviates from its ideal state if the control loop is improperly planned and tuned. Equipment will break down sooner and the process will cost more to run. The detection of sensor, valve, and tuning issues is crucial for the efficient operation of each control loop. Objective of implementing control in this process is to ensure optimal performance of the process units. Hence, inlet and outlet temperature for the reactors (R-101, R-102, and R-103) and the heat exchangers (HX-101, HX-102, and HX-103), respectively, were specified a set point (McMillan, 2014; McQuillan et al., 2023). The six set points for the units listed in that order are 903, 272, 300, 26, 15, and 920°C. Figure 9 shows the control scheme process diagram for H_2 manufacture from refinery off-gas.

Symbols and instruments (Prokop et al., 2020) to automate the H_2 recovery in high amount and ensure an easy operation of the system by process engineers are as shown in Table 2.

Controls are implemented for reactors to control either pressure or temperature (Messaouda & Dumitru, 2012). Temperature control is very important to operating cost, production rate, and product quality. As an example, the control architecture aims at controlling the inlet temperature to R102. TT measures outlet temperature from MIX-101 as measured variable = 272°C. An electric signal from TT is sent to the feedback controller in the form of temperature control. TC is specified a set point = 867°C which then directs the final control element to respond. Measured variable for a heat exchanger is the temperature of the exit stream as shown in Table 2. For MIX-101, a proportional–integral–derivative (PID) controller was chosen because of its robustness and simplicity in tuning parameters. FT senses the flow into the column and measures it. FC is short for feed rate controller. It receives signal from FT, compares it with the given set point, and makes appropriate corrections to it after which it sends a signal to I/P. I/P responds by sending pneumatic signal to the final control element for appropriate action. Overall, the controller compares the measured value to the intended value (set point), calculates an appropriate output signal, and sends it to an I/P where it is converted into an equivalent pneumatic (air) signal that is consistent with the control value (Luyben, 1973; Roffel et al., 2006).

4. Conclusion

Precisely, 89.72 kg of refinery off-gas and 269.16 kg of water were fed into the production process, which yields 37.52 kg/h of H_2, 9.71 kg H_2S, and 311.65kg waste gas. Two parameters of optimization (i.e., equipment and operating condition) were targeted; where the elimination and replacement of units made, minimized the energy requirement of the process. Operating

Figure 9
Piping and instrumentation diagram

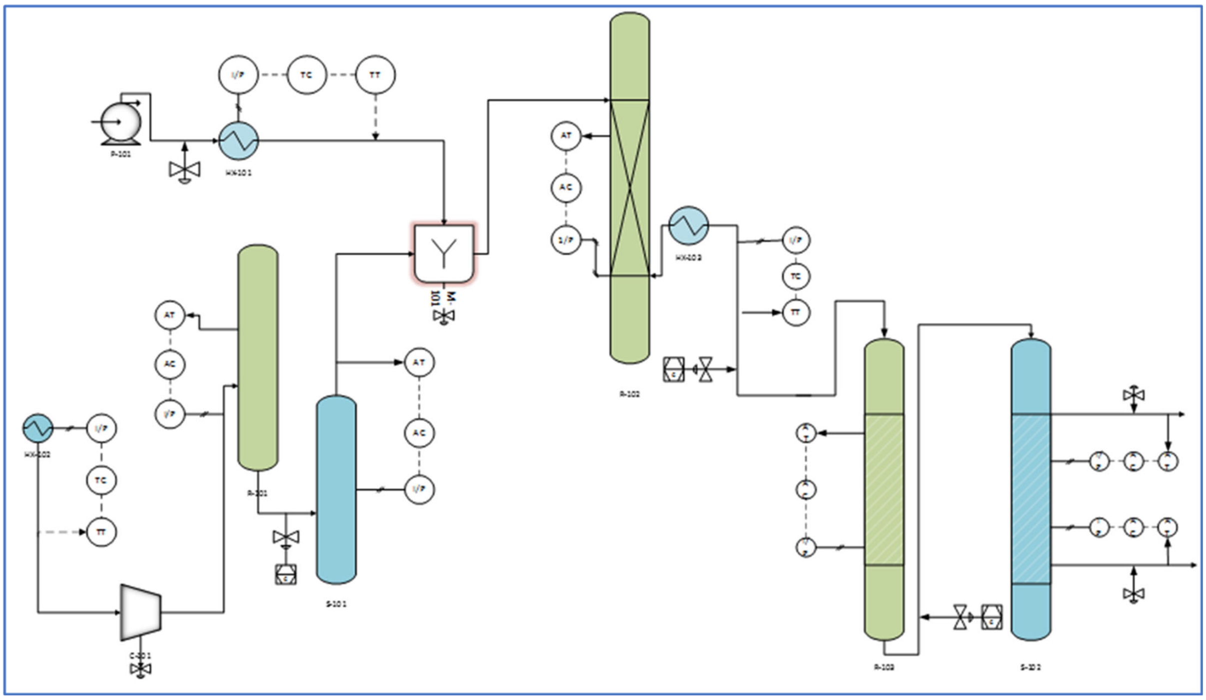


Table 2
Definition of control instruments and parameters

Symbol	Instrument	Description	Quantity
AC	PID controller	Controls the composition of the mixture	6
AT	Transducers	Measure the composition of the mixture	6
C	Computer	Computer-based detector	3
FC	PID controller	Controls the flowrate of the mixture	1
FT	Flow transmitter (flowmeter)	Measures the flowrate of the stream	1
I/P	Current-to-pressure transducer	Converts electric signal to pneumatic signals	9
TC	PID controller	Temperature controller	3
TT	Censor (thermometer)	Temperature transmitter	3

conditions of the two key units were analyzed using Aspen Plus V8.4 by running sensitivity analysis over a range of temperatures for both units. In terms of maximizing H_2 yield, the two units are running at their ideal temperature and pressure. It is recommended to run multivariable optimization on the two units by defining their H_2 yield and heat duty requirements simultaneously as objective functions as well as their temperature and pressure. It is observed that varying R-102 and R-103 temperatures (between 820 and 950°C) influences the heat duty and points to the need for an additional energy to be absorbed (endothermic process), which is easier to control. Reasons for implementing control in this work include maintaining optimal operating conditions, maximizing H_2 production efficiency, minimizing energy consumption, and ensuring safe and stable plant operation. Advanced process control, that entails implementing advanced control techniques such as model predictive control or fuzzy logic control to optimize the performance of the H_2 production plant, may be a good idea for future studies. Other likelihood for future execution is the development of an operator training simulators using Aspen Plus to train operators on plant operations, emergency scenarios, and abnormal situations. Simulators can help operators gain experience in a safe and controlled environment.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that supports the findings of this study is openly available with zannahabba154@gmail.com, and would be shared upon request via email.

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