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Comparative analysis of energy, exergy and economic performance in biomass gasification: a process simulation study

Pakon Sakdee, Siramon Srihorkaew and Somboon Sukpancharoen*

Department of Agricultural Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand

*Corresponding author.
Email address: sombsuk@kku.ac.th

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Abstract

Thailand possesses substantial biomass waste from industrial and agricultural sectors, which can be converted into chemicals and fuel through gasification, a thermochemical process that transforms biomass into fuel gas. This study examined five biomass types: rice straw, rice husks, corn cobs, rubber wood, and sugarcane bagasse, employing thermodynamic, energy, exergy, and economic analyses to assess investment viability through biomass gasification process modeling using ASPEN PLUS V12.1 software. The analysis evaluated the impact of operational variables such as gasification temperature, steam-to-biomass ratio (S/B), and equivalence ratio (ER) on process efficiency. Results indicated that increased gasification temperatures positively affected hydrogen production, with optimal temperatures ranging from 800-900°C, an optimal steam-to-biomass ratio of 1, and an ideal equivalence ratio between 0.1-0.2. Energy and exergy analyses revealed varying equipment efficiencies: decomposition units achieved 54-71% and 38-42%, coolers reached 58-75% and 54-75%, and gasifiers attained 87-96% and 68-76%, respectively, while other equipment exceeded 80% efficiency in both analyses. Economic analysis demonstrated high potential for rice straw, corn cobs, and sugarcane bagasse due to short payback periods and positive Net Present Values (NPV), whereas rice husks proved economically unfavorable with negative NPV and extended payback periods exceeding project timelines. The study's benefits include reduced prototype plant construction costs, improved production planning, and time savings by eliminating trial-and-error approaches in biomass selection for gasification processes.

Keywords: Biomass, Gasification, Energy, Exergy, Economics

1. Introduction

Climate change and greenhouse gas emissions have become major global challenges. The United Nations has called on all countries to accelerate measures to reduce greenhouse gas emissions in order to control the increase in the average global temperature to no more than 2°C [1]. As population growth and economic development continue to drive up energy demand [2], hydrogen energy has gained attention as an alternative environmentally friendly energy [3], because it can be applied in various industries without causing pollution [4]. The European Union has set a target for renewable energy usage of 32% by 2030, with biomass as the most important renewable energy source [5]. The gasification process at a temperature between 750-900°C has been proven to be effective in converting biomass into synthetic gas [6-7]. For Thailand, several studies have shown that biomass from the agricultural sector, especially bagasse and rice husks, High potential for energy production [8-9].

Despite extensive research on biomass gasification, previous studies have primarily focused on individual biomass feedstocks under specific conditions, lacking a comprehensive comparison of multiple biomass types within a unified framework. Moreover, thermodynamic evaluations, particularly exergy assessments, have often been limited, and economic feasibility studies have been largely overlooked. This study addresses these gaps by systematically analyzing five different biomass types under identical gasification conditions, integrating energy-exergy-economic (3E) analysis, and providing insights into optimal process conditions. These contributions offer a more holistic understanding of biomass gasification performance, which is critical for improving process efficiency and guiding industrial applications.

Several studies have focused on biomass gasification modeling using Aspen Plus. Kombe et al. [10] developed a three-phase simulation model for air gasification of rice husk, incorporating syngas purification and Response Surface Methodology (RSM) for multi-objective optimization. Their study demonstrated that optimal hydrogen production was achieved at temperatures between 820–1090°C and an equivalence ratio (ER) of 0.06–0.10. However, their model primarily focused on energy analysis and did not comprehensively assess exergy losses or economic feasibility. To address these limitations, this study integrates an energy-exergy-economic (3E) analysis to provide a holistic evaluation of biomass gasification efficiency and viability.

This study focuses on developing a gasification process model for five types of biomasses: rice straw, rice husk, corn cob, rubber wood, and sugarcane bagasse using the ASPEN PLUS V12.1 program, along with analyzing the thermodynamic efficiency of the process in terms of energy, exergy, and economic value. The results of this study will help add value to agricultural waste, reduce the cost of developing a pilot plant, support efficient production and investment planning, and promote the development of renewable energy and reduce the environmental impact of agricultural waste management in the country.

2. Methodology

2.1 Development of a model of biomass conversion to gasification

Study the simulation process using 5 types of biomasses: rice straw, rice husk, corn cob, rubber wood, and sugarcane bagasse. The selection of biomass feedstocks in this study was based on their abundance, energy potential, and economic feasibility in biomass gasification applications. Five biomass types were chosen: rice straw, rice husk, corn cob, rubberwood, and bagasse, each representing major agricultural and industrial residues. Rice straw and rice husk are widely available by-products of rice cultivation in Southeast Asia, making them cost-effective options for large-scale gasification. Corn cob, with its high hydrogen-to-carbon ratio, has been shown to enhance syngas production efficiency. Rubberwood, commonly used in the timber industry, provides a dense biomass source with a stable combustion profile. Bagasse, a by-product of sugarcane processing, is well-known for its high-energy yield and suitability for thermochemical conversion. By incorporating multiple biomass types, this study offers a comparative analysis that reflects real-world feedstock availability and variability. Study the physical properties of biomass, proximate analysis, and chemical properties of biomass, detailed analysis (Ultimate analysis) from the research paper that has been studied. Enter the data into the biomass gasification model from the ASPEN PLUS V12.1 program, the process as shown in Figure 1 and details of the process simulation unit, as shown in Table 1. Validate the biomass conversion model from the actual research paper and compare the synthetic gas with the values from the program with an error of no more than 5%.

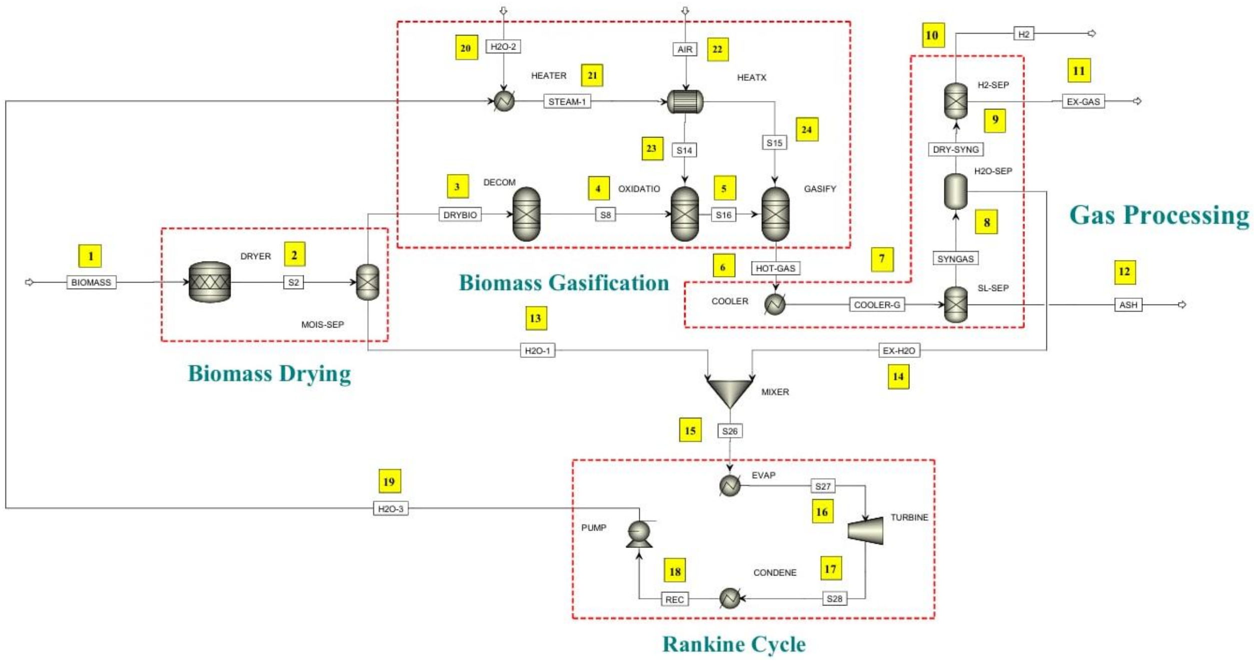

Figure 1 Process model of biomass gasification using ASPEN PLUS V12.1

2.2 Comparative analysis of the 5 types of biomass on energy, exergy and economic

2.2.1 Energy analysis

Under the assumption of steady-state and steady-state process, the energy and efficiency can be determined by using the mass and energy balance, as in Equation (1).

$$\sum M^*_{in} = \sum M^*_{out} \tag{1}$$

And considering the energy changes in the system with mass inflow and mass outflow, this equation can be described as in Equation (2).

$$\text{Energy} = \sum M^*_{in} h_{in} = \sum M^*_{out} h_{out} \tag{2}$$

The energy terms are defined as shown in Equation (3).

$$Q^* + \sum M^*_{in} h_{in} = W^* + \sum M^*_{out} h_{out} \tag{3}$$

Table 1 Details of the process simulation unit

Type	Blog Name	Description
RYield	DECOM	It functions to change substances whose molecular structure cannot be identified (nonconventional component) into substances with a molecular formula (conventional component) calculated from the equation of the balance of the constituent elements.
RGibbs	GASIFY	Gasification simulation
Heater	HEATER	Heat water to convert it into steam before feeding it for heat exchange.
Heater	COOLER	It functions to cool down the temperature of high-temperature water.
Heater	EVAP	It acts to increase the temperature of water to change its state into vapor and increase the pressure.
Heater	CONDEME	It functions to cool down the temperature of high-temperature water.
HeatX	HEATX	It functions as a heat exchanger before water is introduced into the gasification process.
Dryer	DRYER	It functions to heat the biomass to dry it.
Sep	MOIS-SEP	It acts to separate water from biomass.
Sep	SL-SEP	It acts to separate ash from the gasifier.
Sep	H_2-SEP	Separate hydrogen gas from waste gases such as CO, CO_2.
Fash	H_2O-SEP	Separate water from gasifier
Mixers	MIX	Combine the remaining water from the gasification process.
Compresser	TURBINE	Steam is spun into energy and the pressure in the system is reduced.
Pump	PUMP	It is the process of taking the remaining water from the system and reusing it in the heater again.
RGibbs	OXIDATIO	It functions to add oxygen to the gasification process.

Where Q* represents the net heat input rate, W* represents the input work rate, and h indicates the specific enthalpy. The formulas for Q* and W* are given in Equation (4) and (5).

$$Q^* = Q^*_{in} - Q^*_{out} \quad (4)$$

$$W^* = W^*_{in} - W^*_{out} \quad (5)$$

As in Equation (6), the energy efficiency system I is defined as the ratio of power.

$$\eta_{sys} = \frac{W^*}{Q^*} = \frac{\text{Out put}}{\text{In put}} \quad (6)$$

Where η_{sys} represents the ratio of net power.

2.2.2 Exergy analysis

Exergy is formally defined as the maximum potential work that can be done by a complete system consisting of both the system locally and its surrounding environment. Once the system reaches equilibrium with its surroundings, the inflow and outflow of control quantities are dominated by three types of exchange processes: work, heat, and mass transfer, which are given by the exergy formulae in Equations (7) and (8). The exergy of the current in state "i" can be written as

$$e_{xi}=[(h- h_0)-T_0(s- s_0)] \quad (7)$$

Including the relevant exergy change rates

$$E_{xi}=m_i[(h- h_0)-T_0(s- s_0)] \quad (8)$$

Where E_{xi} is exergy energy

2.2.3 Economic analysis

The index in the economic return analysis to decide whether the project to produce hydrogen gas compounds and electricity is interesting for investment or not will consider the following 3 index values.

1) Payback period (PB)

It is the period that the business receives the return and returns the investment. The payback period is a criterion that takes into account the period that the net benefit from the operation (the total profit received each year, which is the net profit after deducting taxes, interest, and depreciation of assets) equals the initial investment cost of the project. That is, the number of years that the benefit is worth the investment cost is considered. Therefore, if the operation results in the benefit being worth the amount of money invested quickly (fast payback period), it is good because the investment risk is low, allowing investors to use the money that is withdrawn to invest to find benefits in other businesses in the future, as in Equation (9).

$$\text{Payback period} = \text{Initial investment cost} / \text{Average net annual return} \quad (9)$$

2) Net present value

It is the difference between the present value of the benefit throughout the project's life and the present cost throughout the project's life. This is to assess the value of the project to see if it will receive a return that is worth the investment or not. If the net present value obtained is positive or greater than zero, it is considered a worthwhile investment, meaning that it will make a profit. However, if the net present value is less than zero, it means that the project under consideration will not provide a return that is worth the investment because the value of the return is less than the present value of the capital. This criterion is therefore used to help in deciding whether to accept or reject the project, as in Equation (10).

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \quad (10)$$

3) Internal rate of return (IRR)

It is a discount rate that makes the net present value equal to zero. This rate is a measure of the ability of the investment to generate income that is equal to the investment for that purpose. It is the rate that will make the return equal to the expenses that are the present value. The criteria for making the decision is to compare the value of the internal rate of return with the discount rate. If the internal rate of return obtained is higher than the discount rate, it can be concluded that the project should be considered, as in Equation (11).

$$\sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+IRR)^t} = 0 \quad (11)$$

Where B_t = the net cash flow in each year
C_t = the net cash flow in each year
i = WACC, short for Weighted-Average Cost of Capital, which means the average cost of the business. If we are going to do any business, how much will the cost be (set to 10%/y)
IRR = the internal rate of return (IRR)
t = the year of the project
n = the age of the project

3. Results and discussion

3.1 Model validation

From the model validation results, the results are close to the experimental values and Jayah et al. [11] developed a downdraft gasifier model utilizing pyrolysis and gasification sub-models to predict syngas composition and process efficiency. The model was validated against experimental data, achieving an error margin of ±5.8%. This study highlights the impact of biomass particle size, moisture content, and pressure drop across the fuel bed on gasifier performance and Striugas et al. [12] investigated the performance of a downdraft gasifier for various biomass feedstocks, focusing on the effects of pressure drop across the fuel bed and biomass particle size on gasification efficiency. The experimental results demonstrated that automated control systems enhance gasification performance by regulating air supply and ash removal. This study provides key insights for developing adaptive gasifiers capable of processing multiple biomass types. From the comparison of gas composition between the model and the experiment of the biomass gasification process combined with carbon dioxide capture, as shown in Table 2, it was found that the simulation results were close to the experiment. The total error of the synthetic gas (Syngas) value was not more than 5%. When considering the average error of the data, it was found to be acceptable. The values from the simulation using the Aspen Plus program were very close to the experiment, so it is confident that the model can be applied to improve the process to be more efficient than before.

Table 2 Comparison results of gas composition (volume %) between experiment and simulation

Gas	Test	Model [11]	Error (%)	Test	Model [12]	Error (%)
H_2	17.20	16.59	0.61	16.40	17.75	1.35
CO	19.60	20.74	1.14	22.60	22.36	0.24
CH_4	1.40	0.01	1.39	4.80	0.01	4.79
CO_2	9.90	9.80	0.10	11.05	10.41	0.64
N_2	51.90	52.87	0.97	44.90	49.47	4.57

3.2 Energy analysis

From the results of the model, in the chemical process and the study of energy use, energy transfer, and energy loss in the system, focusing on better monitoring of energy use in the system and being able to make improvements efficiently to make the process more energy-saving and worthwhile, and to improve energy efficiency to make the operation as efficient as possible, which will be simulated with 5 types of biomass: rice straw, rice husk, rubber wood, corn cobs, sugarcane bagasse, there will be an analysis of energy efficiency in each machine in the process simulation, as shown in Figure 2.

From Figure 2, it shows the energy efficiency graph of each machine in the operation unit of all 5 types of biomass, namely rice straw, rice husk, rubber wood, corn cobs and bagasse. It was found that the efficiency of the dryer equipment was 93-95%. Each type of biomass was not different because the dryer machine reduces the moisture content in the biomass raw materials by using heat to evaporate water from the biomass, which is a process that uses little energy, so the efficiency values are not much different. The value that affects is the moisture content.

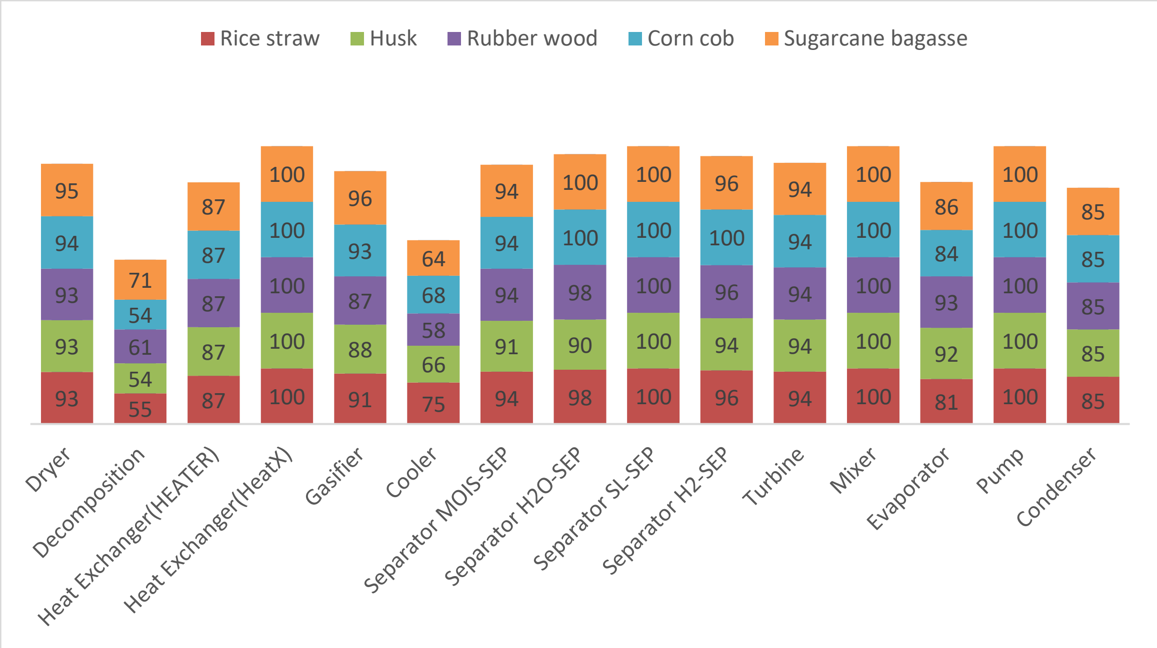

Figure 2 Energy efficiency of each machine

Decomposition has an efficiency of 54-71%. It can be seen that each type of biomass has a very different efficiency value. Although working under the same conditions, the decomposition machine functions to separate complex compounds into smaller molecules. The principle is to use heat or a catalyst to break chemical bonds to separate substances. The different values are the quantitative analysis (Proximate analysis) and the detailed analysis (Ultimate analysis), in which the molecules of the compound that have the most effect are volatile matter (VM), carbon (C), hydrogen (H). The higher the value of all three, the higher the efficiency. And the higher the moisture content and volatile matter in these fuels Loss of energy in the process

Heat Exchanger (HEATER) has an efficiency of 87%. Each type of biomass is not different because the temperature difference of the hot and cold lines is the same. It is not related to biomass.

Heat Exchanger (HeatX) has an efficiency of 100%. Each type of biomass is not different because the temperature difference of the hot and cold lines is the same. It is not related to biomass.

Gasifier has an efficiency of approximately 87-96%. Each type of biomass is different because the machine has a function. Convert solid fuel to fuel gas. The principle uses high heat and limited oxygen to cause a chemical reaction. The different values are proximate analysis and ultimate analysis. The elements that mainly affect the chemical reaction are Carbon (C), Oxygen (O), Hydrogen (H), respectively.

Cooler has an efficiency of approximately 58-75%. Each type of biomass is different because the machine has a function. Reduce the temperature of the fluid or material. The principle of extracting heat by transferring it to a cooler medium. The efficiency is lower than other machines. Because the temperature difference of the hot and cold lines is very different because syngas from the gasification process has a temperature of up to 800°C and then drops to 25°C, causing the cooler to have a much lower efficiency. Proximate analysis moisture high humidity will increase the cooling load of the cooler and ultimate analysis Carbon (C), Hydrogen (H), Oxygen (O) impact affects the specific heat of the material to be cooled, affecting the efficiency.

Separator MOIS-SEP has an efficiency of approximately 91-94%. Each type of biomass is not different because the machine has a function to separate moisture from the mixture. The principle uses condensation or adsorption to separate water. It does not use much energy.

Separator H2O-SEP has an efficiency of approximately 90-100%. Each type of biomass is not different because the machine has a function to separate water from the mixture. The principle may use distillation and filtration. It does not use much energy.

Separator SL-SEP has an efficiency of 100%. Each type of biomass is not different because the machine has a function to separating solid particles from liquids. Principles using gravity, filtration or centrifugal force not much energy is used.

Separator H2-SEP has an efficiency of about 94-100%. Each type of biomass is not different because the machine has the function of separating hydrogen from mixed gas. Principle using membranes or alternating pressure adsorption not much energy is used.

Turbine has an efficiency of 94%. Each type of biomass is not different because the machine has the function of converting kinetic energy of the fluid into mechanical energy. Principle using rotating blades to create mechanical work. Biomass with high carbon and hydrogen will increase the efficiency of the turbine in producing energy. While biomass with high moisture content and high ash content will reduce efficiency.

Mixer has an efficiency of 100%. Each type of biomass is not different because the machine has the function of mixing various substances together. Principle using mechanical agitation to create consistent mixing not related to biomass.

Evaporator has an efficiency of about 81-93%. Each type of biomass is different because the machine has the function of changing liquid into vapor. Principle heating the liquid to boiling point the difference is the quantitative analysis (Proximate analysis) and the detailed analysis (Ultimate analysis). % Volatile matter (VM) Higher values such as bagasse (74.98%) and rubberwood (80.10%) indicate volatile matter, which may result in excess heat in the evaporator. When these substances evaporate, the excess heat must be dealt with. % Carbon (C) and Hydrogen (H) The values of Carbon and Hydrogen, such as in rubberwood (50.60% and 6.50%, respectively), affect the amount of energy released in the form of biomass fuel. Higher carbon will result in more energy, but moisture and volatile matter must also be dealt with in the process. % Oxygen (O) High oxygen in some such as rice straw (48.54%) increases the moisture content in the biomass, which requires more energy for the evaporator to evaporate the water.

Pump efficiency is 100%. Each type of biomass is not different because the machine has the function of increasing pressure and moving the liquid. Principle Use a mechanical mechanism to add energy to the liquid not related to biomass

Condenser has an efficiency of 85%. Each type of biomass is not different because the machine has the function of changing the vapor into a liquid. The principle is to reduce the temperature of the vapor below the distillation point.

The energy analysis revealed that the decomposition and cooler units are the two most critical components in terms of energy loss. The decomposition unit plays a crucial role in breaking down biomass into volatile gases and char, which are then converted into syngas in the gasification process. However, this stage also contributes to significant energy dissipation due to the endothermic nature of pyrolysis reactions, which absorb heat from the system.

The cooler unit is responsible for reducing the syngas temperature before utilization, which unavoidably leads to thermal energy losses. The results indicate that heat recovery strategies, such as integrating a heat exchanger, could enhance overall system efficiency by utilizing the waste heat from the cooling process.

3.3 Exergy analysis

Exergy analysis from the results of the model, which has chemical processes and studies of energy use, energy transfer, and energy loss in the system, focuses on better monitoring of energy use in the system and can be improved effectively to make the process more energy-saving and worthwhile, and improve energy efficiency to make the operation as efficient as possible. The test will be simulated with 5 types of biomass: rice straw, rice husk, rubber wood, corn cobs, and sugarcane bagasse. The exergy efficiency of each machine will be analyzed in the process simulation, as shown in Figure 3.

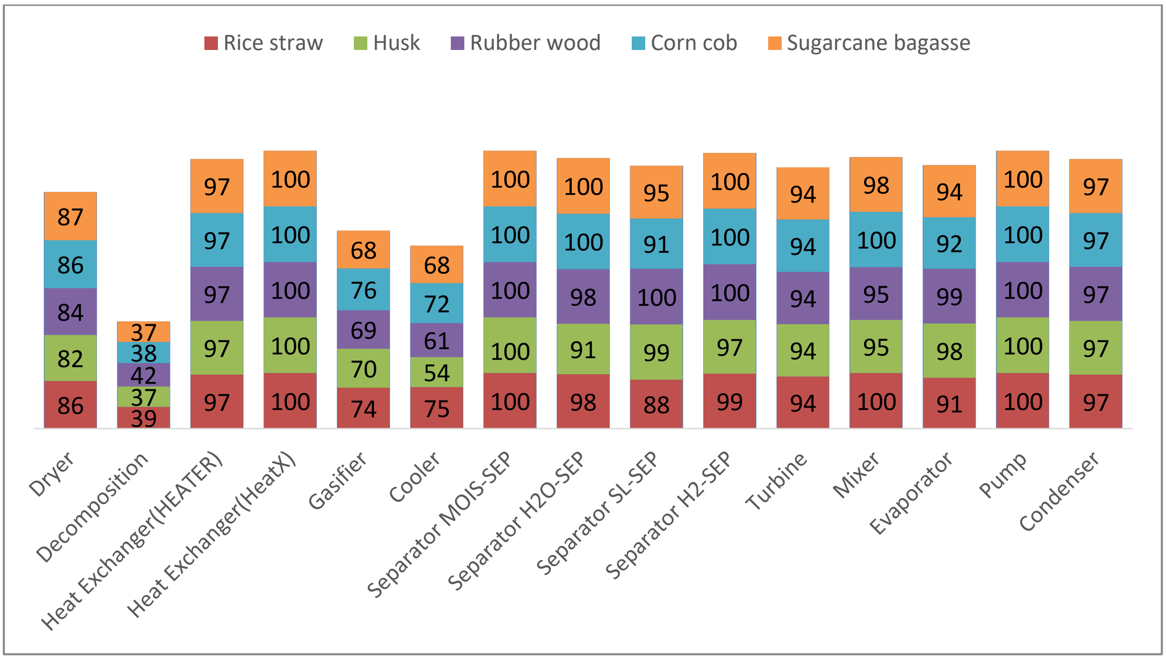

Figure 3 Exergy efficiency of each machine

From Figure 3, it shows the exergy efficiency graph of each machine in the operation unit of all 5 types of biomass. It was found that the efficiency of each machine of each type of biomass is not different. It was found that the dryer device has an efficiency of 82-87%. Each type of biomass is not very different because the dryer machine reduces the humidity in the biomass raw materials by using heat to evaporate water from the biomass, a process that extracts energy that can be converted to work under specified conditions. There is an energy loss in the system that can be reused efficiently.

Decomposition has an efficiency of 37-42%. Each type of biomass is different because the decomposition machine functions to separate complex compounds into smaller molecules. The principle is to use heat or a catalyst to break the chemical bonds in the separation of substances. All biomass works at the same conditions. The difference is in the quantitative analysis (Proximate analysis) and the detailed analysis (Ultimate analysis), which the molecules of the compound that have the most effect are Carbon (C), Oxygen (O), Hydrogen (H), respectively. Therefore, there is an energy extraction that can be converted to work in a given condition. There is an energy loss in the system that can be reused efficiently.

Heat Exchanger (HEATER) has an efficiency of 97%. Each type of biomass is not different because the temperature difference of the hot and cold lines is the same.

Heat Exchanger (HeatX) has an efficiency of 100%. Each type of biomass is not different because the temperature difference of the hot and cold lines is the same.

Gasifier has an efficiency of about 68-76%. Each type of biomass is different because the machine has a function. Convert solid fuel to fuel gas. Principle use high heat and limited oxygen to cause a chemical reaction. The difference is the quantitative analysis (Proximate analysis) and the detailed analysis (Ultimate analysis) with the elements that mainly affect the chemical reaction, namely Carbon (C), Oxygen (O), Hydrogen (H), respectively.

Cooler has an efficiency of about 54-75%. Each type of biomass is different because the machine has the function of reducing the temperature of the fluid or material. The principle of extracting heat by transferring it to a cooler medium. The efficiency is lower than other machines because the temperature difference between the hot and cold lines is very different.

MOIS-SEP separator has an efficiency of 100%. Each type of biomass is not different because the machine has the function of separating moisture from the mixture. The principle of using condensation or adsorption to separate water. It does not use much energy.

H2O-SEP Separator has an efficiency of about 91-100%. Each type of biomass is not different because the machine has the function of separating water from the mixture. The principle of using distillation, filtration, it does not use much energy.

SL-SEP Separator has an efficiency of about 88-100%. Each type of biomass is not different because the machine has the function of separating solid particles from liquids. Principles using gravity, filtration or centrifugal force not much energy is used.

Separator H2-SEP has an efficiency of about 97-100%. Each type of biomass is not different because the machine has the function of separating hydrogen from mixed gas. Principle using membrane or alternating pressure adsorption not much energy is used.

Turbine has an efficiency of 94%. Each type of biomass is not different because the machine has the function of converting kinetic energy of the fluid into mechanical energy. Principle using a rotating blade to create mechanical work. Synthetic gas obtained from high-quality biomass (from high carbon and hydrogen) will have a high exergy value because the energy that can be used from the gas is more. Which will increase the efficiency of the turbine in producing energy.

Mixer has an efficiency of about 95-100%. Each type of biomass is not different because the machine has the function of mixing various substances together. Principle using mechanical agitation to create a consistent mix. Because it does not use a high amount of heat energy, it has a high exergy efficiency.

Evaporators have an efficiency of about 91-99%. Each type of biomass is not very different because the evaporator evaporates water from biomass, which is a process that uses heat energy to change the liquid into vapor. It is noticeable that all biomass has a higher exergy value than energy. This is because in this process, the loss of mechanical energy and other losses not related to heat energy are usually low, allowing the total amount of energy put in to be used in the evaporation process efficiently. Therefore, exergy, which measures the actual energy that can be used in this process, is higher than energy, which has a small loss of energy in this step. And the evaporator usually works in conditions where the temperature of the liquid to be evaporated is relatively high. When energy is used in a system that has a higher temperature than the surrounding area, the loss of exergy will be less because the temperature difference between the system and the environment is not very high. That makes the exergy value, which measures the actual energy that can be used, tend to be higher than energy, which includes the energy that is lost. Results of proximate analysis and ultimate analysis show that the higher the % Oxygen (O) of biomass, the lower the exergy efficiency of the evaporator.

Pump has 100% efficiency. Each type of biomass is not different because the machine has the function of increasing pressure and moving liquid. Principle use mechanical mechanism to add energy to the liquid.

Condenser has 97% efficiency. Each type of biomass is not different because the machine has the function of changing vapor into liquid. Principle reduce temperature.

Exergy analysis provides deeper insight into the irreversibilities within the system, highlighting areas where improvements can be made. The decomposition unit exhibited the highest exergy destruction (37–42%), primarily due to chemical reaction irreversibilities and heat losses to the surroundings. This aligns with previous studies, such as Gani et al. [5], which reported significant exergy destruction in pyrolysis-dominated stages.

Similarly, the cooler unit experienced an exergy efficiency range of 54–75%, reflecting substantial losses due to rapid temperature reduction. The high exergy loss in this stage suggests that optimizing the cooling process such as by utilizing regenerative heat exchange could significantly improve the system’s exergy efficiency.

3.4 Economic analysis

3.4.1 Payback Period (PB)

Analysis revealed that the payback periods for hydrogen gas compound and electricity production from rice straw, rubber wood, corn cobs, and bagasse were 4, 4.4, 3.8, and 3.4 years respectively, as shown in Table 3. This means the cash flow received from operations will equal the investment cash flow within 4 years, 4 years and 5 months, 3 years and 10 months, and 3 years and 5 months, respectively. These relatively fast payback periods indicate low-risk projects attractive for investment. However, rice husk demonstrated a payback period longer than the project implementation timeline, making it unsuitable for investment.

3.4.2 Net Present Value (NPV)

The study of annual cash flows for rice straw, rubber wood, corn cobs and bagasse yielded Net Present Values of 54,550,244, 31,560,339, 76,999,666 and 125,184,958 baht, respectively, as shown in Table 3. Rice husks resulted in a negative net present value upon project completion, indicating it should not be pursued. The positive NPV values for the other biomass types demonstrate that these projects are viable investment opportunities, as their returns exceed investment costs.

3.4.3 Internal Rate of Return (IRR)

The results of the study found that the internal rate of return of biomass, rice straw, rubber wood, corn cobs and bagasse, which are equal to 15.02, 12.98, 16.93 and 20.83%, respectively, as shown in Table 3, means the return that makes the net present value throughout the project equal to the initial net cash investment. It is greater than the discount rate, indicating that the project can be decided to accept the hydrogen gas compound and electricity production. As for the biomass that is rice husks, the internal rate of return during the project period is negative, which is not worth investing.

Table 3 Payback time (PB), Net Present Value (NPV), and Internal Rate of Return (IRR)

Biomass	PB (Year)	NPV (Baht)	IRR
Rice straw	4	54,550,244	15.02%
Rice husk	-	-	-
Rubber wood	4.4	31,560,339	12.98%
Corn cob	3.8	76,999,666	16.93%
bagasse	3.4	125,184,958	20.83%

4. Conclusions

This study aligns with previous biomass gasification research, finding optimal hydrogen production at ER values of 0.06-0.10, with the Aspen Plus model demonstrating high accuracy, and confirming that biomass physical characteristics significantly impact syngas composition. The research extends beyond operational parameters to comprehensive energy-exergy-economic (3E) analysis, revealing that Decomposition units had the lowest efficiency due to solid-to-gas state transformations, followed by Coolers (due to 775°C temperature differentials) and Gasifiers (converting mixed states to 99% gas), while other equipment maintained >80% efficiency. Economic assessment identified high potential for rice straw, corn cobs, rubber wood, and bagasse, whereas rice husks proved economically unfavorable with negative NPV and extended payback periods. These findings have significant industrial and agricultural applications, suggesting that optimizing parameters (800-900°C temperature, S/B ratio of 1) enhances hydrogen production efficiency, implementing heat recovery systems in Cooler units reduces thermal losses, and utilizing agricultural residues enables decentralized energy production with bagasse and corn cobs identified as the most cost-effective biomass options for commercial-scale gasification projects.

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