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Generator analysis and comparison of working fluids in the organic Rankine cycle for biomass power plants using Aspen Plus software

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ABSTRACT

The organic Rankine cycle utilizes low-temperature heat (flue heat) in power plants to produce electrical power. Several factors, including the working fluid's temperature and pressure, influence the efficiency of an organic Rankine cycle. This research method includes calculations using the gasification method in calculating electrical energy in PLTBM and calculating the experimental results of a series of organic Rankine cycles by taking into account the temperature and pressure of the working fluid using Aspen Plus Software, which is analyzed using statistical methods. The results of research using the gasification method in PLTBM fuel produced power of 27,279.38 MW/year for coconut shells, 6,489.66 MW/year for rice husks, and 532.62 MW/year for corn cobs. For the organic Rankine cycle series, rice husk waste produces the largest power of 8,336.67 kW, for coconut shells of 569,723.95 kW. For corn cobs of 358,639.63 with an efficiency value of organic working fluid in R-22 of 25.37% and the R-32 organic working fluid of 11.92% at a temperature of 125 °C in coconut shell waste, it can be concluded that the temperature of the working fluid has more influence on the efficiency of the organic Rankine cycle than the pressure of the working fluid.

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1. INTRODUCTION

The level of energy demand in Indonesia is increasing along with the rapid development of technology, which is also concerned with electrical and other energy. Electricity is a basic need in life and has a very important role in society. Regarding the provision of electricity to the community, in Indonesia, the percentage level of electricity supply still needs to be 100 percent. Where the source of electrical energy can be obtained from power plants, which generally in Indonesia use conventional power plants powered by fossil fuels, continuous use of fossil fuels can result in a reduction in available fossil content, resulting in the emergence of biomass power plants fueled by organic and non-organic waste products. In obtaining electrical energy from the generator, the electrical energy source at the power plant produces waste heat, which can generally be used to produce electrical energy even though it has very little electrical efficiency. The residual results from waste heat in biomass power plants produce electrical energy known as the organic Rankine cycle (ORC). ORC is a cycle that converts a low-temperature heat source into electrical energy [1]-[3].

According to earlier research on the original design of the Rankine organic cycle system using burning corn cob biomass waste as a heat source, the potential power generated by burning maize cobs might be utilized as a low-temperature heat source to generate electrical energy. According to ORC, the maximum theoretical turbine power is 8.5 kW, thermal efficiency is 10.3%, and 101.1 hectares of maize must be planted annually [4]. In the meantime, other earlier studies used the Aspen Advanced System for Process Engineering Plus software to compute the thermodynamic properties of the organic working fluid and simulate the cycle properties to discuss the recovery of waste heat in the organic Rankine cycle and the features of low-temperature waste heat recovery from the thermodynamic system of a power plant. The impact of the heat source input temperature, flow rate, net power output, and evaporator output temperature on the thermal efficiency and net power output can be determined by comparing the thermal properties of the heat source side and the fixed organic working fluid side based on various heat source parameters [5]. Previous research further concerns identifying and analyzing refrigerants as working fluids for the organic Rankine cycle for applications in Indonesia. The research carried out the selection of refrigerant as an ORC fluid with low-pressure operating parameters and a low-temperature heat source capable of providing efficiency values that are not much different from medium pressure, namely 20 bar in ORC applications, while based on the criteria, the best specific power was obtained from R-236fa with operating parameters, pressure 10 bar, evaporator temperature 90 °C with a value of 11,396 KJ/kg [6].

Other earlier studies focused on flat plate solar collectors used in organic Rankine cycle (ORC) power plants. It discusses the organic Rankine cycle (ORC) system, a novel power plant. The ORC generator system uses operating fluids and solar energy sources. The heating fluid, which is water, is heated by solar power and is responsible for evaporating the working fluid, which can evaporate at high pressure and low temperatures. In order for it to turn the turbine shaft, a generator is used to generate power. The ORC generator's output for the working fluid system design was 13.61 kW and a 6-bar pump's lowest power by pump outlet pressure was 5.03 kW. The generating system design simulation produces power approaching 10 kW with a pump outlet pressure of 11.38 kW and a 5-bar pump. The flat collector of the solar plate system gets 191.92 W of energy and an efficiency of 9.8% [7]. According to other earlier studies on the geothermal organic Rankine cycle, the use of the cycle to generate electricity was first examined from geothermal sources, where the selection of organic fluids and geothermal energy sources was examined for various ORC configurations and operating conditions. Maintaining the long-term effectiveness of geothermal augmentation in reservoir systems through the use of a hybrid optimization technique, and reviewing energy efficiency and energy exergy, considering economic indices and levelized electricity costs [8].

Based on the background of previous research that has been explained, the contribution of this research is analyzing the comparison of the organic Rankine cycle (SRO) in power plants fueled by corn, coconut, and rice plant waste. The researcher aims to find the efficiency value of the working fluid using refrigerant types R-22 and R-32. It is also important to find the value of electrical potential and the most efficient type of refrigerant and carry out Aspen Plus software simulations to determine the percentage value of the working fluid used. The potential electricity produced and the specifications of the generator used.

2. METHOD

This research was carried out in several stages, as seen in Figure 1. This research compares three types of fuel, namely rice waste [9]-[13], coconut waste [14]-[16], and corn waste [17]-[19], as well as the temperature of the evaporator heating water (50 °C–125 °C). Next, get the value of the cycle efficiency and power produced by the fuel using the gasification method. Corn, rice, and coconut trash are the fuel biomass employed in this simulation of the organic Rankine cycle system for power generation. The biomass fuel composition data utilized in the study are shown in Table 1. Aspen Plus software is used to simulate the combustion of solid biomass fuel [20]-[23]. Then, the higher heating value (HHV) [24]-[26] and lower heating value (LHV) [27], [28] values are used in this research, and then the fuel data is input (proximate, ultimate, and heating value), as described in Table 2. Meanwhile, the organic Rankine system relies heavily on the use and choice of an appropriate working fluid, and its characteristics also influence how it is used. In this research, the working fluids used and compared were R-22 (chlorodifluoromethane/difloromonochloromethane) and R-32 (difluoromethane). Freon refrigerants-32 have a lower cold number index than refrigerant-22. Table 3 provides detailed working fluid specifications.

Organic Rankine cycle pump specifications vary depending on the application and working fluid used. However, they are generally based on volume flow rate, operating pressure, total head, and efficiency. Organic Rankine cycle pumps are usually made of steel or aluminum. They can also have additional features like a drive motor, control valve, and filter. The pump specifications that are generally used are shown in Table 4.

Turbine specifications in the organic Rankine cycle vary depending on the application, desired power, and available heat sources. Because the turbine is one of the most important components in the organic Rankine cycle, it functions in the expansion system, where the turbine is usually connected to a generator to produce electricity. Therefore, the turbine has several relevant specifications, as shown in Table 5. The turbine inlet pressure value for refrigerant R22 and refrigerant R32 varies depending on the system operating conditions. Generally, the turbine inlet pressure should be 200-300 psig (1379-2068 kPa) for R22 refrigerant and 220-280 psig (1516-1930 kPa) for R32 refrigerant. Turbine inlet pressure that is too low can cause the turbine to operate beyond its design, which can cause damage. A high turbine inlet pressure can cause the turbine to lose efficiency. Table 6 provides recommended turbine inlet pressure values for different operating conditions. Factors such as turbine design, speed, and refrigerant properties can also influence the turbine inlet pressure value. Turbine manufacturers usually provide specific recommendations for particular operating conditions. For a standard refrigeration system, the R22 turbine inlet pressure is typically around 180 psig (1240 kPa), and the R32 turbine inlet pressure is typically around 250 psig (1723 kPa). This pressure is high enough to ensure the turbine operates at good efficiency, but not so high that it causes it to lose efficiency.

Condenser specifications in an organic Rankine cycle vary depending on the application and specific working conditions. The condenser removes heat from the organic working fluid, which is experiencing expansion in the turbine, so that the fluid can be condensed back into liquid form to be reheated in the organic Rankine cycle, where determining the specifications can be seen in Table 7. Meanwhile, evaporator specifications in an organic Rankine cycle vary depending on the application and specific working conditions. However, some general specifications are relevant, as in Table 8.

In this simulation, a generator is used to produce electrical energy. The electrical energy produced by this generator is used as a reference for calculating the power produced by the turbine itself. Table 9 presents the generator specifications. Then, this simulation is carried out by physical modeling, where the organic Rankine cycle is created in its initial condition with its respective function. The model specifications for the SRO system series are in Table 10. Table 10 shows the component types in Aspen Plus. The organic Rankine cycle design model used for the application is the SRO model for biomass burning applications. The heat source from burning Biomass is applied using Aspen Plus software, and then the SRO system design model in the Aspen Plus software is the organic Rankine cycle system. In Figure 2, the SRO system is designed for biomass-burning applications.

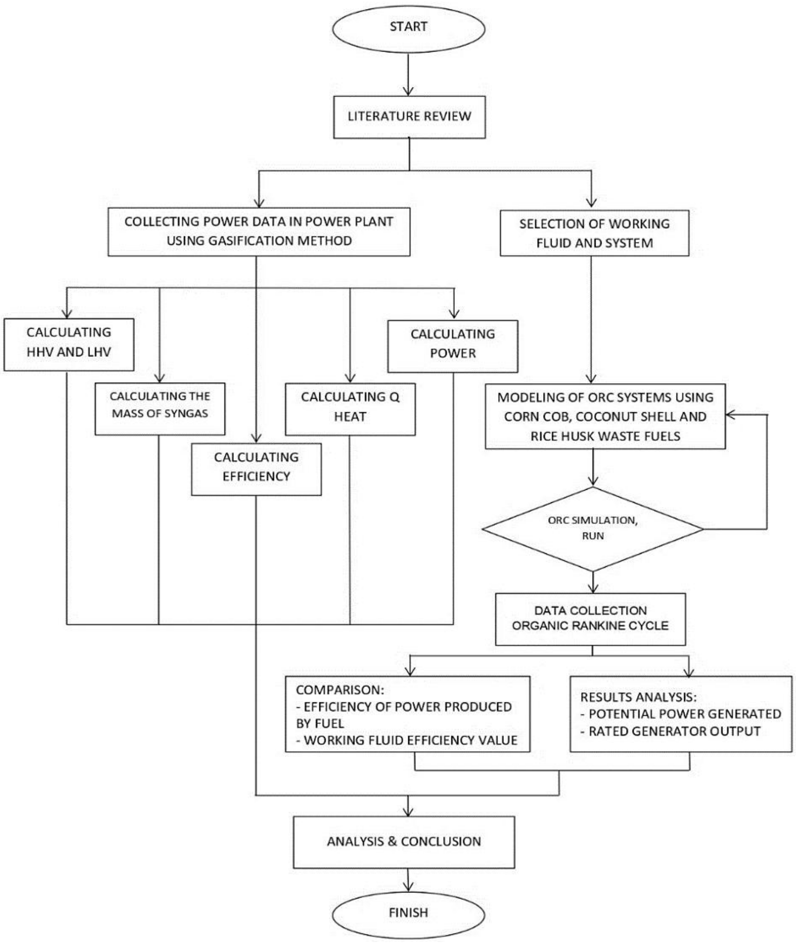

Figure 1. 24 bus equivalent EHV Indian power system

Table 1. Data from biomass fuel composition

Properties		Rice husk	Coconut shell	Corncob
Ultimate analysis (dry)	Carbon (%)	38	46.53	49.0
	Hydrogen (%)	4.55	6.34	6.0
	Oxygen (%)	32.4	34.93	44.7
	Nitrogen (%)	0.69	0.15	0.3
	Sulfur (%)	0.11	0	0.08
	Ash (%)	14	0.22	3.1
Proximate analysis (dry)	Volatile matter (%)	55.6	69.18	6.50
	Fixed carbon (%)	20.1	18.77	16.7
	Ash (%)	14	0.22	3.1
	Moisture (%)	10.3	11.77	6.50
	ρmix (kg)	0.86408	0.06006	0.63008

Table 2. HHV and LHV values of biomass waste

Biomass waste	High heating value (HHV) (kcal/kg)	Low heating value (LHV) (kcal/kg)
Rice husk	4,541.1090	4,063.0975
Coconut shell	4,780.1147	4,182.6004
Corncob	1195.029	956.0229

Table 3. Working fluid specifications

Component name	R-22	R-32
Molecular mass/MR [kg/kmol]	86.47	52.02
Boiling point/BP [°C]	-40.8	-51.7
Critical temperature/TC [°C]	96.2	78.2
Critical pressure/PC [bar]	49.9	5.8
Potential for ozone depletion/ODP	0.034	0
Global warming potential/GWP [100 year]	1700	550
Long stay in the atmosphere/LT [year]	11.9	5
Security aspect	A1	A1

Table 4. SRO pump specifications

Parameter	Unit value
Volume flow rate	0.001-10 m^3/s
Operating pressure	10-10,000 kPa
Total head	1-100 m
Efficiency	70-90%

Table 5. Specifications turbine

Parameter	Unit value
Type	Isotropic
Pressure	12 and 17 bar

Table 6. Organic fluid turbine inlet pressure value

Operating conditions	Turbine inlet pressure (psig)	
	R-22	R-32
Inlet temperature 120 °F (48.9 °C)	200-250	220-250
Inlet temperature 140 °F (60.0 °C)	250-300	250-280
Inlet temperature 160 °F (71.1 °C)	300-350	280-310
Inlet temperature 180 °F (82.2 °C)	350-400	310-340
Inlet temperature 200 °F (93.3 °C)	400-450	340-370
Inlet temperature 220 °F (104.4 °C)	450-500	370-400
Inlet temperature 240 °F (115.5 °C)	500-550	400-430
Inlet temperature 260 °F (126.6 °C)	550-600	430-460

Table 7. Condenser specifications

Parameters	Unit value
Condensation temperature	27-100 °C
Condensation pressure	10-10,000 kPa
Mass flow rate	1-10 kg/s
Condensation efficiency	90-95%

Table 8. Evaporator specifications

Parameter	Unit value
Evaporation temperature	50-150 °C
Evaporation pressure	10-10,000 kPa
Mass flow rate	1-10 kg/s
Evaporation efficiency	80-95%

Table 9. Generator specifications

Parameter	Unit value
Number of units	1
Phase	3 phase
Frequency	50 Hz

Table 10. Model component types in Aspen Plus

Component name	Type	Code
Pump	Pump	Pump
Evaporator	Heater	EVP
Condenser	Heater	CDS
Turbine	Turbine	TRB

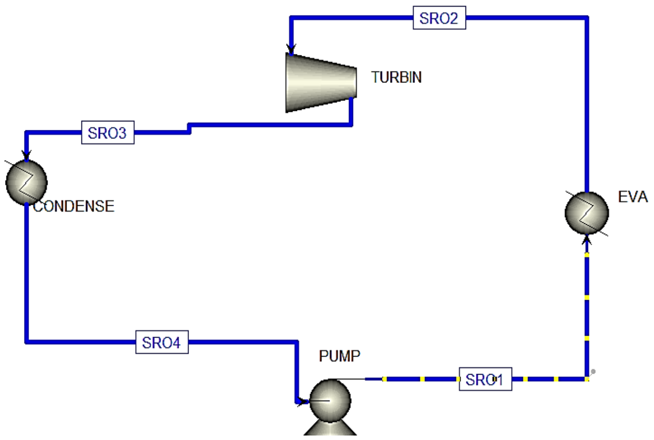

Figure 2. SRO system design biomass burning application

3. RESULTS AND DISCUSSION

3.1. Calculation results from biomass fuel

The data obtained calculates the electrical power produced by a power plant using biomass fuel and the gasification method. The calculation is based on waste data as of 2020 in the Deli Serdang district, as shown in Table 11. As can be seen in Table 11, the gasification method is used to determine the power yield in biomass power plants from three biomass fuels, namely rice husks, coconut shells, and corn cobs. The resulting power data is 27,279.38 MW/year for coconut shells, 6,489.66 MW/year for rice husks, and 532.62 MW/year for corn cobs. The percentage efficiency of waste use using the gasification method for rice husks is 77.31%. In comparison, for coconut shell waste, the percentage value of waste use efficiency is 55.31%, and for corn cob waste, the percentage value of waste use efficiency using the gasification method is 50.41%. This data can be seen in Figure 3, which shows the efficiency and power of electricity generation using the gasification method.

3.2. Calculation results from biomass fuel

The gasification calculation results show that this biomass gasification system has good conversion efficiency, producing syngas gas with high energy content. The gasification method aims to analyze the biomass gasification process and evaluate the performance of the system being developed. The gasification method calculates the mass of syngas gas, gas flow rate, and thermal efficiency. So, it can produce power for the energy produced and the efficiency obtained.

Table 11. Biomass fuel gasification

Biomass name	Production (ton)	ρ $\boldsymbol{mix}$ (kg)	Mynges (ton)	Q heat (MJ)	Power (MW/year)	Efficiency (%)
Coconut shell	3,909,357.5	0.06006	2,347,910.11	982,057.88	27,279.38	55.31
Rice Husk	66,544.7	0.86408	57,499.94	233,627.86	6,489.66	77.31
Corncob	31,258.22	0.63008	19,717.68	18,850.55	532.62	50.41

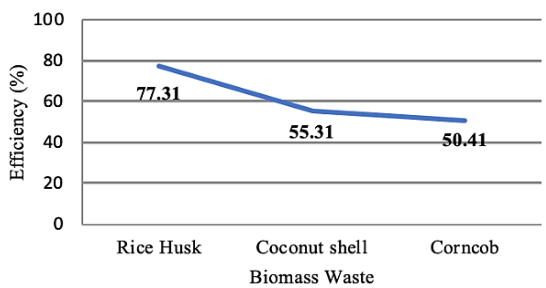

Figure 3. Efficiency and power of electricity generation using the gasification method

3.2.1. Mynges value calculation

The composition of the syngas produced during the experiment was measured and analyzed. This includes the content of CO, H_2, CH_4, CO_2, and other gases. Calculations were carried out to determine the efficiency of converting biomass into syngas gas. The test results obtained data on the density of the mix and the total production of rice husk waste. The mass of rice husk syngas is:

$\rho\ mix$	= 0.86408
Production	= 66,544.7
Myngas	= $\rho\ mix$ × production
Rice husk	= 0.86408 × 66,544.7
	= 57,499.94

The test results obtained data on mix density and total coconut shell waste production. The mass of coconut shell syngas is:

$\rho\ mix$	= 0.60060
Production	= 3909357.5
Myngas	= $\rho\ mix$ × production
coconut shell	= 0.06006 × 3,909,357.5
	= 2,347,960.11

The test results obtained data on the density of the mix and the total production of coconut cob waste. The mass of corncob syngas is:

$\rho\ mix$	= 0.63008
Produksi	= 31,258.22
Myngas	= $\rho\ mix$ × production
Corncob	= 0.63008 × 31,258.22
	= 1,9717.68

3.2.2. Calculation of Q calorific value

The thermal efficiency of gasification is calculated by comparing the heat produced with the heat used to gasify the biomass. This is a key parameter that measures the overall efficiency of the process. The results of the calculations obtained data on the mass of syngas gas and the lower heating value of rice husk waste, so the thermal value of rice husk is:

Myngas	= 57,499.94 tons
LHV	= 4,063.0975 kcal/kg
Q heat	= myngas × LHV
Rice husk	= 57,499.94 × 4,063.0975
	= 233,627.86 MJ

The results of the calculations obtained data on the mass of syngas gas and the lower heating value of coconut shell waste, so the thermal value of coconut shell is:

Myngas	= 234,796.01 tons
LHV	= 4,182.6004 kcal/kg
Q heat	= myngas × LHV
Coconut shell	= 23,4796.01 × 4771.2715
	= 98,2057.88 MJ

The results of the calculations obtained data on the mass of syngas gas and the lower heating value of corncob waste, so the thermal value of corncob is:

Myngas	= 19,717.68 tons
LHV	= 956.0229 kcal/kg
Q heat	= myngas × LHV
Corncob	= 19,717.68 × 675.5568
	= 18,850.55 MJ

3.2.3. Calculation of power values

In calculating the power produced by the biomass gasification method, you can use the basic formula for calculating the electrical power produced by gas, as in (1).

$$\text{Power (kw)} = \frac{\text{Gas energy (MJ)}}{\text{operational time (hours)}} \quad (1)$$

Operational time = 1 kWh = 3.6 × 10^6 joules. The calculation results obtained, data on thermal heat value and operational time value (1 kWh) on rice husk waste, produce power in (2).

Q (thermal value of gas energy) = 233,627.86 MJ

$$P = \frac{Q}{W} \quad (2)$$

Rice husk $= \frac{233{,}627.86}{3.6 \times 10^6\ \mathrm{J}}$
= 6,489.66 MW/year

The calculation results obtained, data on thermal heat value and operational time value (1 kWh) on coconut shell waste, produce power of:

Q (thermal value of gas energy) = 982,057.88 MJ
Coconut shell $= \frac{982{,}057.88}{3.6 \times 10^6\ \mathrm{J}}$
= 27,279.38 MW/year

The calculation results obtained, data on thermal heat value and operational time value (1 kWh) on corncob waste, produce power of:

Q (thermal value of gas energy) = 18,850.55 MJ
Corncob $= \frac{18{,}850.55\ \mathrm{MJ}}{3.6 \times 10^6\ \mathrm{J}}$
= 523.62 MW/year

3.2.4. Calculation of efficiency values

The entire system's overall efficiency in converting biomass into gas includes gasification and electricity generation. Overall efficiency can be calculated by comparing the amount of initial biomass production with the total value of the mass of syngas gas obtained. The calculation results compare biomass production data with the mass of syngas gas in rice husk waste, which produces efficiency values in (3).

LHV = 4,063,097.5 kcal/ton
HHV = 4,541,109.0 kcal/ton
M syngas = 574,99.94 tons
M biomass = 66,544.7 tons

$$\% = \frac{M\ syngas\ x\ LHV}{M\ biomassa\ x\ HHV}\ x\ 100\% \quad (3)$$

Rice husk $= \frac{57{,}499.94\ x\ 4{,}063{,}097.5}{66{,}544.7\ x\ 4{,}541{,}109.0}\ x\ 100\%$
= 77.31%

The calculation results compare biomass production data with the mass of syngas gas in coconut shell waste, which produces efficiency values for coconut shells.

LHV = 4,182,600.4 kcal/ton
HHV = 4,541,109.0 kcal/ton
M syngas = 234,796.01 tons
M biomass = 3,909,357.5 tons
Coconut shell $= \frac{2{,}347{,}960.11\ \ x\ 4{,}182{,}600.4}{3{,}909{,}357.5\ \ x\ 4{,}541{,}109.0}\ x\ 100\%$
= 55.31%

The calculation results compare biomass production data with the mass of syngas gas in corncob waste, which produces efficiency values for corncob.

LHV = 956,022.9 kcal/ton
HHV = 1,195,029.0 kcal/ton
M syngas = 19,717.68 tons
M biomass = 31,288.22 tons
Corncob $= \frac{19{,}717.68\ x\ 956{,}022.9}{31{,}288.22\ \ x\ 1{,}195{,}029.0}\ x\ 100\%$
= 50.41%

3.3. Simulation results of the organic Rankine cycle

3.3.1. Data analysis of R-22 refrigerant

The analysis was carried out by varying the temperature and pressure conditions to the actual conditions based on the organic working fluid used, namely R-22. This is done to obtain the characteristics and efficiency of using the organic working fluid formed. The following calculation can be carried out to find the efficiency of the working fluid. It is known that the heat input of the organic working fluid R22 at a temperature of 50 °C is 179.78, so it can be calculated as (4).

$$\text{Energy Efficiency} = \left|\frac{W_t - W_p}{Q_{in}}\right| = \left|\frac{-60-5}{179.78}\right| = 0.36 \quad (4)$$

From the calculation results above, the energy efficiency for the rice husk fuel type is 0.36%. Calculations for other types of fuel and at other temperatures can be seen in Table 12, which is a table of test results for the organic Rankine cycle of R-22 refrigerant. As described in Table 12, the highest efficiency occurs in coconut shell biomass fuel with a temperature of 125 °C at 25.37%. Figure 4 shows a graph of the efficiency value of the organic Rankine cycle in R-22 organic fluid.

3.3.2. Data analysis of R-32 refrigerant

The analysis was carried out by varying the temperature and pressure conditions to the actual conditions based on the organic working fluid used, namely R-32. This is done to obtain the characteristics and efficiency of using the organic working fluid that is formed. This can be seen in Table 13, a table of test results for the organic Rankine cycle of refrigerant R-32. This is done to obtain the characteristics and efficiency of using the organic working fluid formed. The following calculation can be carried out to find the efficiency of the working fluid. It is known that the heat input of the organic working fluid R32 at a temperature of 50 °C is 273.34, so it can be calculated as (4).

$$\text{Energy Efficiency} = \left|\frac{58-(-3)}{179.78}\right| = 0.22$$

From the calculation results above, the energy efficiency for the rice husk fuel type is 0.22%. For calculations of other types of fuel and at other temperatures, see Table 13, which is a table of test results for the organic Rankine cycle of R-32 refrigerant. As described in Table 13, the highest efficiency occurs for coconut shell biomass fuel at 125 °C, at 11.92%. Next, Figure 5 shows the efficient SRO value for R-32 organic fluid.

Table 12. Test values of the R-22 organic Rankine cycle series

Biomass name	Temperature	Density (kg/s)	Q evaporator (kJ/s)	Q condenser (kJ/s)	W pump (kW)	W turbine (kW)	η efficiency (%)
Rice husk	50 °C	22	3,926.1800	-3,871.5213	5	-60	0.36
	75 °C	22	3,950.4718	-3,765.9009	25	-209	1.37
	100 °C	22	3,899.6399	-3,648.6287	44	-295	2.07
	125 °C	22	4,353.1918	-3,993.9811	64	-423	3.10
Coconut shell	50 °C	180	32,123.2983	-31,676.102	44	-491	2.98
	75 °C	180	32,321.9997	-30,811.9004	203	-1713	8.88
	100 °C	180	31,906.0997	-29,852.3989	362	-2416	16.96
	125 °C	180	35,616.9987	-32,677.9991	521	-3460	25.37
Corncob	50 °C	144	25,698.5993	-25,340.7995	35	-393	2.38
	75 °C	144	25,857.6014	-24,649.5002	162	-1370	9.01
	100 °C	144	25,524.9015	-23,882.0012	290	-1932	13.57
	125 °C	144	28,493.5981	-26,142.4001	417	-2768	20.30

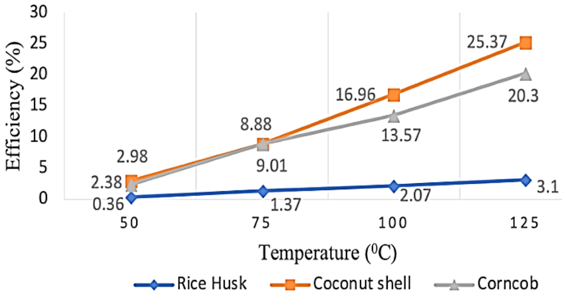

Figure 4. Efficiency of the organic Rankine cycle (SRO) in R-22 organic fluid

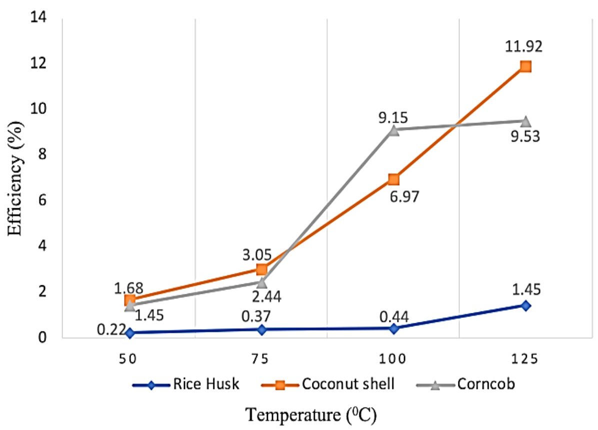

Figure 5. Efficiency of the organic Rankine cycle (SRO) in R-32 organic fluid

Table 13. Test values of the R-32 organic Rankine cycle series

Biomass name	Temperature	Density (kg/s)	Q evaporator (kJ/s)	Q condenser (kJ/s)	W pump (KW)	W turbine (KW)	η efficiency (%)
Rice husk	50 °C	22	5,959.9516	-6,015.0206	-3	58	0.22
	75 °C	22	5,916.9113	-5,836.3992	9	-90	0.37
	100 °C	22	5,902.6720	-5,836.3992	23	-90	0.44
	125 °C	22	5,749.4393	-5,459.8216	38	-327	1.45
Coconut shell	50 °C	180	48,763.1990	-4,9213.7992	-23	437	1.68
	75 °C	180	48,411.1017	-4,7752.4008	75	-734	3.05
	100 °C	180	47,820.4991	-4,6413.6003	192	-1599	6.97
	125 °C	180	47,040.9002	-4,4671.2007	308	-2678	11.92
Corncob	50 °C	144	39,010.6011	-3,9371.0008	-18	379	1.45
	75 °C	144	38,728.8001	-3,8201.8997	60	-587	2.44
	100 °C	144	38,256.3993	-3,7130.8995	154	-1279	9.15
	125 °C	144	37,632.7001	-35,695.1328	247	-2142	9.53

3.4. Selection of generator specifications

An organic Rankine cycle generator is a power-generating device that generates electricity using an organic working fluid. Like a traditional steam generator, this Rankine cycle generator uses an organic working fluid with a lower boiling point than water. A turbine and a pump are the two primary parts of an organic Rankine cycle generator. The pump is used to return the working fluid to the evaporator, and the turbine transforms the heat energy of the fluid into mechanical energy. Synchronous and asynchronous generators can be used in a power plant's organic Rankine cycle circuit. Therefore, the synchronous generator can be utilized when choosing a generator for this study. The turbine's mechanical energy is used to drive the synchronous generator before being transmitted to the generator, transforming the mechanical energy into electrical energy. The working principle of a synchronous generator is based on the principle of electromagnetic induction. In this principle, if a piece of electrically conducting wire changes in a magnetic field, the wire will form an electromotive force (EMF). The rotation of the turbine shaft rotates the rotor in a synchronous generator, where the rotor is an electromagnet that rotates in the stator coil. When the rotor rotates, there is an intersection of magnetic lines of force between the rotor and the stator, which induces voltage (EMF) in the stator coil. The induced voltage has a frequency of 50 Hz with a certain speed on generators in Indonesia. The synchronous generator, equipped with a rotor rotation control system, ensures a constant speed even with varying loads. This stability is achieved by connecting the synchronous generator to an automatic voltage regulator (AVR) in the exciter system. The exciter produces DC for the field winding in the rotor of the synchronous generator. The AVR, detecting the generator output voltage, signals the exciter to adjust the rotor field current, thereby ensuring a stable output voltage and frequency for distribution. Therefore, in this research, Table 14 displays the specifications of synchronous generators used in organic Rankine cycles. Several types and brands of synchronous generators are commonly used in organic Rankine cycles, including those made by ABB, General Electric (GE), Siemens, Mitsubishi, Hitachi, Fuji Electric, Hyundai Heavy Industries (HHI), and Doosan Skoda.

In this research, generator output calculations were carried out in an organic Rankine cycle using R-22 and R-32 working fluids. Calculations were carried out using the classic organic Rankine cycle. In this study, rice husk waste using the organic working fluid R-22 had an efficiency value of 0.36%, with heat entering the fluid of 3926.1800 kJ/s. Then, the resulting generator output power is calculated using (5).

$$Q = 3926{,}1800 \text{ kJ/s} \Rightarrow 3926{,}1800 \text{ kW}$$

$$\eta = 0.36\%$$

$$P = \eta \times Q \tag{5}$$

$$P = 0.36\ \% \times 3926.18 = 1426.38 \text{ kW}$$

So, for this research data, the output value of the rice husk waste generator at a temperature of 50 °C for the R-22 organic working fluid is 1,426.38 kW. Further data results can be seen in Table 15. The power was obtained from the organic Rankine cycle series in the Aspen Plus software.

Table 14. Test values of the R-32 organic Rankine cycle series

Parameter	Value	Parameter	Value
Output power	10 kW – 10 MW	Round	1,500 rpm – 3,000 rpm
Frequency	50 Hz	Rotor speed	1,500 rpm – 3,000 rpm
Voltage	400 V – 15 kV	Working fluid temperature requirements	0 °C – 180 °C
Power factor	0.85 – 0.9		

Table 15. The power obtained by a series of organic Rankine cycles

Biomass name	Temperature	Density (kg/s)	Power R-22 (kW)	Power R-32 (kW)
Rice husk	50 °C	22	1,426.38	1,311.19
	75 °C	22	5,412.15	2,189.25
	100 °C	22	8,072.25	2,597.17
	125 °C	22	13,494.89	8,336.67
Coconut shell	50 °C	180	95,727.40	81,922.17
	75 °C	180	287,019.27	147,653.86
	100 °C	180	541,127.29	333,308.88
	125 °C	180	903,603.03	569,723.95
Corncob	50 °C	144	611,62.64	56,565.37
	75 °C	144	232,976.97	94,498.27
	100 °C	144	346,372.89	350,045.97
	125 °C	144	578,419.87	358,639.63

4. CONCLUSION

After carrying out simulations and analyzing the results, several conclusions can be obtained, namely: First, the electrical energy produced by biomass power plants using the gasification method based on agricultural waste data from Deli Serdang district in 2020 is 6,489.66 MW/year for rice husks with an efficiency value of 77. 31%, and 27,278.38 MW/year for coconut shells with an efficiency value of 55.31% and 532.62 MW/year for corn cobs with an efficiency value of 5%. Second, the organic Rankine cycle (SRO) simulation results on rice husk waste biomass fuel showed that the greatest efficiency was on the R22 organic working fluid of around 3.10% and the R32 organic working fluid of 1.45% and on shell waste biomass fuel. Coconut obtained the greatest R22 organic working fluid efficiency of around 25.37%. In the R32 organic working fluid of 11.92%, then in Corncob waste biomass fuel, the greatest efficiency was obtained in the R22 organic working fluid of around 20.10% and organic working fluid R32 of 9.53%. From the results obtained, it can be proven that the sensitivity to low temperatures in R-22 organic fluids in achieving energy efficiency is low. In contrast, for R-32 organic fluids, the sensitivity to low temperatures in achieving energy efficiency is high. Third, the type of generator used is a synchronous generator where for the organic working fluid R-22, the largest generator output value is 903,603.03 kW for coconut shell waste with a temperature of 125 °C and the smallest generator output value is 1,426.38 kW for waste. The temperature of rice husks is 50 °C. In comparison, for the organic working fluid R-22, the largest generator output value is 569,723.95 kW for coconut shell waste with a temperature of 125 °C, and the smallest generator output value is 1,311.19 kW for rice husk waste temperature of 50 °C.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author, [YS], on request.

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