Analysis of Organic Rankine Cycle on Power Plant Fueled Rice Husk

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***Abstract*— The electrical energy requirement can be obtained from alternative energy sources replacing fossil fuels such as biomass energy in the form of rice husks. Rice husk as one source of biomass energy is still poorly utilized. According to the Indonesian Department, the biggest waste in rice mill is rice husk. It reaches about 20-30% of grain weight. Rice husk with a high percentage can cause environmental problems. In this paper, the writers conducted an analysis of Organic Rankine Cycle (ORC) on power plant fueled rice husk. ORC has a working principle similar to the rankine cycle but uses organic working fluid not water. The use of organic working fluid reduces the required heat energy supply due to the low boiling point of the fluid. The writers determine the cycle parameters to produce a system with a 500 kW-1 MW output power using the organic working fluid R245FA. System analysis is performed based on simulation using software Ebsilon Professional. The system designed to produce output power reaches 589,379 kW with 15.9 % system efficiency.**

Keywords—rice husk, organic rankine cycle, Ebsilon Professional

I. Introduction

The availability of fossil fuels and their use as the main fuel for power generation in Indonesia is not matched by the increasing population growth in Indonesia. The solution for this condition is to use alternative energy sources. This alternative energy source is expected to be a substitute fuel that is environmentally friendly, effective, efficient, easily accessible to the public and can be updated so that it does not have the potential to run out. One alternative energy source in is biomass energy [1].

Biomass consists of all biological materials derived from living organisms or living organisms. Biomass for energy can include a wide range of materials, such as: native wood, derived from forestry, arboricultural activities or from wood processing; agricultural produce, from harvesting or agricultural processing; industrial and product waste, from manufacturing and industrial processes; food waste, food and beverage manufacture, preparation and processing, and post consumer waste; household and city waste; and manure. Indonesia is an agrarian country so it is not difficult to obtain agricultural waste as a source of biomass energy [2].

One of the biomass found in Indonesia is rice husk. Utilization of rice husk as an alternative fuel in power plants in Indonesia is still in the process of research. Studies related to energy potential, economic potential, and potential of electric energy generated by rice husk increased by about 36.8% over 12 years or an average increase of about 3.1% per year. Potential rice husk in 22 provinces has a total profit of 12.76 × 106 tons / year equivalent to 6.62 × 106 tons of coal equivalent to 3.68 × 106 tons of oil. The potential capacity of a power plant can generate about 5,664 MW with approximately 49,622 GWh of electrical energy. This potential is equivalent to 50% of the energy needs of coal in Indonesia in 2011, which is about 99,312 GWh [3].

In this research, the writers conducts a small-scale power plant analysis with a capacity of 500kW-1 MW using biomass fuel (rice husk). The development of biomass by using Organic Rankine Cycle technology (ORC). ORC has a working principle similar to the rankine cycle but uses organic working fluid not water. The use of organic working fluid reduces the required heat energy supply due to the low boiling point of the fluid. The efficiency of ORC is lower than the rankine cycle and the required operational cost of ORC is lower than the rankine cycle.

II. Fuel Power Plant

A. Potential of Rice Husk as Raw Material of Biomass

Rice husk is a hard layer covering *kariopsis* consisting of two hemispheres called *lemma* and *palea* that are interlocked. In the process of rice milling the husks will separate from the grain of rice and become waste material or waste milling, which if left will pollute the surrounding environment. In terms of chemical composition, rice husk contains some important chemical elements, according to DTC-IPB chemical content of chaff consisting of carbon (charcoal) 1.33%, hydrogen 1.54%, oxygen 33.64% and silica 16.98%. With the chemical composition of the husk can be used for various purposes including as raw material in chemical industry, as a building material and as a source of heat energy in various human needs, high enough cellulose content can provide a uniform and stable burning. The husk has a density of 125 kg / m3, with a calorific value of 1 kg husk of 3,300 kilo calories [4].

Rice husks have great potential to be used as raw materials for biomass production. The resulting chemical can be converted into biofuel and the heat that can be generated from the combustion process can be used as a source of electricity or heating the room. The calculation of raw materials of biomass from can be done with mass balance approach which is different for each raw material. Fig 1 shows the biomass balance in the rice industry [4].

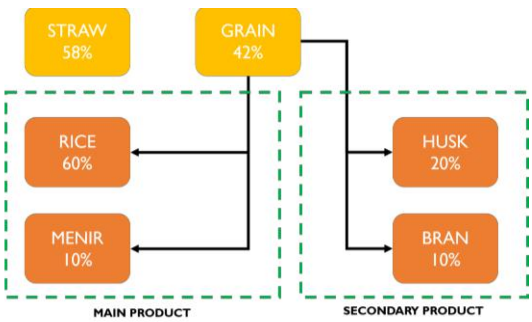

Fig. 1. Biomass Balance in the Rice Industry

B. Fuel Conditions in Testing

The condition of the fuel sample in the test of calorific value, the proximate analysis and the ultimate analysis consists of three conditions such as dry-ash free base, air dried base, and as fired or as received conditions. The dry-ash free base condition is a condition of the fuel sample in a state free of water content and ash at all. Prior to testing, the sample is heated until the water content is inherently out of the sample at temperatures above 100°C. The sample must be thoroughly cleaned so ash content is not included in the mass fraction to calculate the sample heat of the combustion sample. The sample contains only burning substances, carbon, and volatile substances [5].

The condition of the air-dried base is a condition of the fuel sample in a clean state of the water content, but still has an inherent water content. Prior to testing, the sample experiences drying at ambient temperature for a certain time so that only the outer water of the sample evaporates. The sample still contains burning substances, carbon, volatile substances, ash, and inherent water. The as received condition is a condition of the fuel sample in the state as it is when taken from the source. Before tested, the sample did not undergo any treatment. The sample is still intact so it contains burning substances, carbon, volatile substances, ash, outer water, and inherent water [5].

C. Calorific Value

The calorific value test is performed using bomb calorimeter. The bomb calorimeter is a device used to measure the amount of heat (calorie value) liberated at complete combustion (in excess O2) of a compound, foodstuff, fuel or specifically used to determine the heat of combustion reactions. The combustion reaction that takes place inside the bomb will produce heat and is absorbed by water and bombs because no heat is wasted into the environment [5].

The calorific value of fuel is expressed in the value of Higher Heating Value (HHV) and Lower Heating Value (LHV). Higher Heating Value is the energy content released per unit mass through the entire fuel combustion. The fuel temperature prior to combustion and residue after combustion shall have a temperature of 25°C at pressure 1 atm. Carbon and sulfur combustion must be fully oxidized to produce carbon dioxide and sulfur dioxide. Oxidation of nitrogen is not allowed in the combustion process (DIN 51900). Lower Heating Value is a Higher Heating Value minus the heating value and evaporation of the water contained in the fuel. Theoretically, the heat that reduces the value of combustion energy is to heat water from the initial temperature of 25^oC until it reaches 100^oC and converts water to vapor at a temperature of 100°C. After that, the combustion gas exhaust temperature will reach 900^oC, so that the water vapor will heat up to reach 900^oC [5].

D. Proximate Analysis and Ultimate Analysis

Proximate analysis was done to find out moisture, volatile matter, ash, and fixed carbon content.

- Moisture

Moisture is water that is physically bound in the sample. The moisture content can be determined by calculating the weight loss of the sample after heating at 105^oC. The heating lasts until there is no more mass changes in the sample. The moisture content is the ratio between the mass lost during heating to the mass before heating [6].

- Volatile matter

Volatile matter comprises of flammable gases and steam condensation such as tar, CO2 gas and H2O. Testing is done by heating the sample up to 900^oC. The volatile matter content is the ratio between the mass of volatile matter lost during heating to the mass of the sample before heating [6].

- Ash

Ash is the impurities contained in the sample. Ash is the burning residue of the moisture sample test and volatile matter [6].

- Fixed Carbon

Fixed carbon is the solid carbon content of the sample. In other words solid carbon is a 100% reduction with moisture percentage, volatile matter and ash [6].

Another method for knowing the element content in the sample is the ultimate analysis. This analysis produces values in the form of mass fractions in elements of carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulfur (S). In general, the results of the ultimate analysis are in the dry basis [5].

III. Organic Rankine Cycle

Organic Rankine Cycle (ORC) is a modification of the rankine cycle. In ORC, the boiling point of this cycle is lower so that water is not suitable for use as a working fluid. Therefore, silicone oil, hydrocarbon, and fluorocarbon are used which have low boiling point as the working fluid of water substitute. The working fluid used in this study is R245FA which is the working fluid of hydrofluorocarbon. The ORC cycle is a steam cycle in which this cycle uses an organic working fluid (refrigerant). ORC uses evaporator as a heat absorption site. In this cycle we do not use the place or tool for the combustion process so that will not be formed emissions of air pollution caused by combustion process [7].

Shortly, there are four processes in this Organic Rankine Cycle. The states are identified by number as described in Fig. 2.

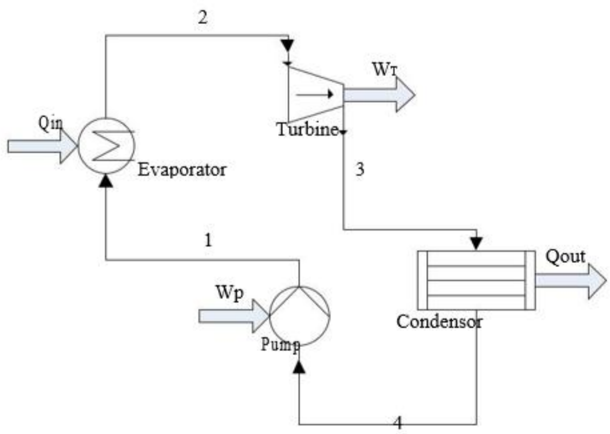

Fig. 2. Simple Cycle of Organic Rankine Cycle

- Process 1-2: the pressure of working fluid is increased by pumping it to a higher pressure state

- Process 2-3 : the high pressure working fluid is heated at constant pressure to dry saturated vapor state
- Process 3-4 : the dry saturated vapor expand through a turbine which coupled with a generator to generate electric power
- Process 4-1: the working fluid enters a condenser where it is condensed at a constant pressure to saturated liquid state.

IV. Characteristic Of Rice Husk

Based on the results of laboratory analysis, the results of testing the calorific value of rice husks, proximate test results from rice husk (moisture, ash, volatile content and fixed carbon) and ultimate test results from rice husk (C, H, O, N, S, Cl). Tests of calorific values using bomb calorimeters. The calorific value based on the test is 3,505.42 cal / gr or 14,676.4861 kJ / kg. The value of this heat is still in the value of Higher Heating Value (HHV) then it needs to be converted into Lower Heating Value (LHV). Based on the basic theory of lower heating value, the amount of heat required to heat and evaporate the water content is (under 1 atm pressure conditions) TABLE I gives the value of vaporing heat of water at pressure 1 atm.

TABLE I. The Value of Warming and Vaporizing Heat of Water (in 1 ATM Pressure)

Parameter	Value
h (enthalpy) at temperature 25 ^oC	104.93 kJ/kg
h at 100 ^oC and x (vapor quality)= 0	418.99 kJ/kg
Warming heat of water from 25 ^OC to 100 ^OC:	314.06 kJ/kg
h at 100 ^OC and x=0	418.99 kJ/kg
h at 100 ^OC and x=1	2,675.50 kJ/kg
Vaporizing heat of water at 100 ^OC	2,256.51 kJ/kg
h at 100 ^OC and x=1	2,675.50 kJ/kg
h at 900 ^OC and x=1	4,398.10 kJ/kg
Warming heat of water vapor from 100 ^OC to 900 ^OC	1,722.60 kJ/kg

The value of this calor is still in the value of Higher Heating Value (HHV) then it needs to be converted into Lower Heating Value (LHV). Lower Heating Value (LHV) is a Higher Heating Value (HHV) minus the heating value of calor and evaporation of the water contained in the fuel. Theoretically, the heat that reduces the value of combustion energy is the heat to heat water from the initial temperature of 25^OC until it reaches 100^OC and converts water to vapor at a temperature of 100^OC. After that, the combustion gas exhaust temperature will reach 900^OC, so that the water vapor will heat up to reach 900^OC. The calculation data is obtained from the property table of water.

LHV = 14,676.4861 kJ/kg - (314.06 kJ/kg + 2,256.51 kJ/kg + 1,722.60 kJ/kg) = **10,383.3161 kJ/kg**

Based on the results of rice husk samples test in Solid and Hazardous Toxic Waste Laboratory Bandung Institute of Technology obtained the results of proximate and ultimate test of rice husk samples in TABLE II.

TABLE II. Result of Proximate and Ultimate Test

No	Parameter	Unit	Method	Result
Proximate Analysis				
1	Moisture	%	ASTM D 2216-98	11.60
2	Ash	%	ASTM D 2216-98	20.23
3	Volatile Matter	%	ASTM D 2216-98	2.64
4	Fixed Carbon	%	ASTM D 2216-98	65.53
Ultimate Analysis				
1	Carbon	%	ASTM 3172-3175	36.54
2	Hydrogen	%	ASTM 3172-3175	5.32
3	Oxygen	%	ASTM 3172-3175	38.63
4	Nitrogen	%	ASTM 3172-3175	0.46
5	Sulfur	%	ASTM 3172-3175	0.06
6	Chlorine	%	ASTM 3172-3175	0.089

V. Results of System Simulation

In this paper, the system will simulate with parameters as shown in TABLE III.

TABLE III. Initial Parameters of ORC System

Parameter	Unit	Value
Thermal oil pressure	bar	10
Thermal oil temperature	^oC	265
Thermal oil mass flow rate	kg/s	17.4
Fuel mass flow rate	kg/s	0.66
Turbine inlet pressure	bar	20
Turbine efficiency	%	90
Condenser pressure	bar	1.85
Condenser cooling water pressure	bar	1
Condenser cooling water temperature	^oC	26
Pump efficiency	%	75
Working fluid mass flow rate	kg/s	15.15

The working fluid used for the system is R245FA (1,1,1,3,3-pentafluoropropane, CF3CH2CHF2). R245FA is a type of hydrofluorocarbon working fluid that has been used by various companies and researches. R245FA includes a dry working fluid having a steady isentropic saturation curve (positive T-s) curve. R245FA is suitable for generating power at low-medium level. The GWP (Greenhouse Warming Potential) value of the working fluid of R245FA is already at the safe limit of 1,000, but this can still be tolerated because of the isolation of the working fluid on the system. The working fluid of R245FA has an ODP (Ozone Depletion Potential) = 0 value, this fluid does not contribute to the depletion of the ozone layer. This working fluid does not have toxic properties, corrosive properties and flammability so it is safer to use on the system.

The result of simulation system using Ebsilon Professional software obtained the condition of temperature, entropy, pressure and enthalpy for each process in cycle, output power and efficiency. The result of system simulation is represented in TABLE IV and *T-s* curve in Fig. 3.

TABLE IV. INITIAL PARAMETERS OF ORC SYSTEM

Process	T (^{o}C)	s (kJ/kgK)	P (bar)	h (kJ/kg)
1	32.118	1.142	20	242.43
2	122.786	1.803	20	486.673
3	51.557	1.817	1.85	447.122
4	31.122	1.14	1.85	240.602
Output Power				**589.379 kW**
Efficiency				**15.9%**

The output power of 589,379 kW is obtained with a fuel supply of 0.66 kg/s. Fuel consumption for power generation of 589,379 kW is

$$\text{Fuel Consumption} = \frac{0{,}66\ \frac{kg}{s}\ \text{x}\ 3.600}{589{,}379\ \text{kW}} = 4.03\ \text{kg/kWh}$$

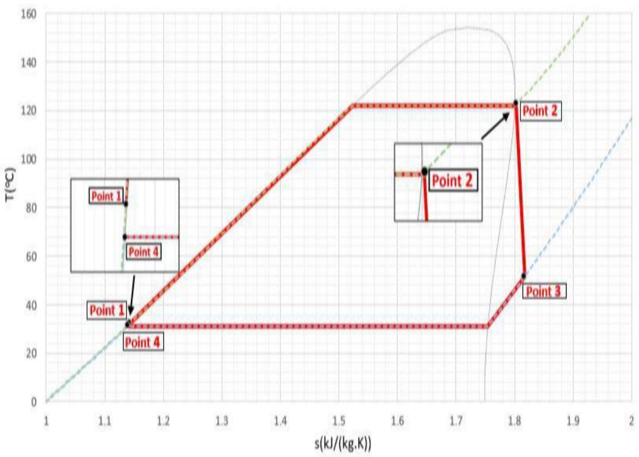

Fig. 3. T-s curve of the system

VI. CONCLUSION

Based on the research, it is concluded that:

- Rice husk can be an alternative fuel to replace fossil fuels in power plants using organic rankine cycle technology in terms of calorific value, proximate test results, ultimate test results and rice husk potential in Indonesia.
- System analysis is performed based on simulation using software Ebsilon Professional. The system designed to produce output power reaches 589,379 kW with 15.9 % system efficiency.

REFERENCES

[1] I. P. Kusuma, “Studi Pemanfaatan Biomassa Limbah Kelapa Sawit sebagai Bahan Bakar Pembangkit Listrik Tenaga Uap di Kalimantan Selatan (Studi Kasus Kabupaten Tanah Laut),” Proceeding Tugas Akhir. Surabaya: Institut Teknologi Sepuluh Nopember, 2010, pp. 1.

[2] J. J. Robert, A. M. Cassula, P. O. Prado, R. A. Dias, and J. A. Balestieri, “Assessment of Dry Residual Biomass Potential for Use as Alternative Energy Source in The Party of General Pueyrredon,” Argentina Renewable and Sustainable Energy Reviews, 2014, pp. 2-3.

[3] M. Anshar and F. N. Ani, “The Utilization Potential of Rice Husk as an Alternative Energy Source for Power Plants in Indonesia,” Advanced Materials Research, 2013, pp. 7.

[4] A. Tajali, “Panduan Penilaian Potensi Biomassa sebagai Sumber Energi Alternatif di Indonesia,” Jakarta: Penabulu Alliance, 2015.

[5] Y. Prakasa, “Analisis Karakteristik Pembakaran Sampah Kota Bandung untuk PLTS Babakan,” Proceeding Tugas Akhir. Bandung: Institut Teknologi Bandung, 2014, pp.16-20.

[6] A. Sudrajad, I. Rosyadi, & D. M. Nurdin, “Uji Ultimat dan Proksimat Sampah Kota untuk Sumber Energi Alternatif Pembangkit Tenaga,” Proceedings Seminar Nasional. Banten: Universitas Sultan Ageng Tirtayasa, 2014, pp. 2-3.

[7] A. H. Pamungkas and A. B. Putra, “Studi Variasi Flowrate Refrigerant Pada Sistem Organic Rankine Cycle Dengan Fluida Kerja R-123,” Proceeding Tugas Akhir. Surabaya: Institut Teknologi Sepuluh Nopember, 2013, pp. 1-2.