Journal of Metals, Materials and Minerals, Vol.19 No.2 pp.9-14, 2009.

Exergetic and Thermoeconomic Analyses of the Rice-Husk Power Plant in Thailand

Prachuab PEERAPONG[1] and Bundit LIMMEECHOKCHAI[2*]

[1]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailan
[2]Sirindhorn International Institute of Technology, Thammasat University, Pathumthani, Thailand

Abstract

The purpose of this study is to analyze a rice husk power plant, and consider the efficiency of the power plant through both the first law and the second law of thermodynamics. The energetic and exergetic performance criteria such as thermal efficiency, exergy efficiency, and exergy loss have been found to be useful methods in design, evaluation, optimization and improvement of thermal power plants. The exergetic efficiency of a power plant shows that the boiler is the major component contributing to total loss, with its exergetic efficiency of 30%, while the steam turbine has the exergetic efficiency of 76%. The study also evaluates the economic consideration of a rice-husk fired power plant for heat and power production. The capacity of the plant is 576 tons paddy/day. The total load of thermal energy consumption is 1,062 MJ/ ton paddy and the electrical energy consumption of the rice mill is 6,518 MWh/year. The total capital cost of the rice husk-fired cogeneration is US$ 1.2 million (1 US$=35 Baht). The capacity of the back pressure steam-fired boiler is 18 tons/hour of steam and 25 bar (absolute), 400°C. The rice-husk fired cogeneration can generate power of 1,432 kW_e. Economic analyses in terms of net present value (NPV), simple pay-back period (PBP), and internal rate of return (IRR) are also evaluated. Results show that the rice husk-fired cogeneration has NPV of US$ 0.303 million /year, PBP of 3.7 years and IRR of 27%. Results of the study also show that rice husk-fired cogeneration is beneficial to power generation.

Key words: Rice-husk fired power plant, Exergetic efficiency, Thermoeconomic analysis, Electricity generation.

Introduction

Thailand, celebrated as an agricultural country, is one of the world leading producers of paddy rice. Rice husk, a by-product from the milling process, is annually generated at approximately 5 million tons or equivalent to 7.5×10^7 GJ.(14,15) Taken into account as a widely available, CO_2-neutral fuel source, containing high heating value of about 15 MJ/kg, rice husk is a renewable energy resource with high potential. Over the last 10-15 years, rice husk has been utilized widely in Thailand for steam–fired power plants, and combined heat and power or cogeneration power plants.(13) However, the conventional steam-fired cogenerations worldwide are used to covert biomass to energy with the acceptable efficiencies and their lower costs when compared to the state-of-the-art technologies. In Thailand, the Ministry of Energy has strongly promoted Small Power Producer (SPP) and Very Small Power Producer (VSPP), in particular those who use biomass electricity generation, with high grid buy back prices.

Materials and Experimental Procedures

Methodology

Analysis of power generation systems are of scientific interest and also essential for the efficient utilization of energy resources. The most commonly used method for analysis of the energy conversion process is the first law of thermodynamics. However, there is increasing interest in combined utilization of the first law and second law of thermodynamics, using such concepts as exergy and exergy destructions in order to evaluate the efficiency with which the available energy is consumed. Exergy analysis provides the tool for the clear distinction between energy losses to the

*Corresponding author E-mail : bundit@siit.tu.ac.th

environment and internal irreversibility of the process. Exergy analysis is a methodology for the evaluation of the performance of devices and processes, and involves examining the exergy at different points in a series of energy conversion steps. With this information, efficiencies can be evaluated, and the process steps having the largest losses can be identified. For these reasons, the modern method approach to process analysis uses the exergy analysis, which provides a more realistic view of the process and is a useful tool for engineering evaluation. The objective of the work is to analyze the 1.4 MW rice husk power plant from the energy and exergy perspectives. Sites of primary energy loss and exergy destruction will be determined.

Plant Description

The rice husk power plant has a total installed power capacity of 1,500 kW as shown in Figure 1. The rice mill cogeneration capacity is 576 tons paddy/day. The generated electricity is supplied to the heat processes in the mill and the surplus electricity is exported to the grid. The topping cycle cogeneration with back-pressure turbine was designed for rice husk cogeneration with a boiler capacity to produce the superheated steam to the turbine with the maximum capacity of 18 tons/hour, inlet pressure of 2.5 MPa, and inlet temperature of 400°C. It can generate electricity of 1,432 kW or total electricity of 6,187.9 MWh/year. This case is based on 180 days of working operations and the operating condition of the rice husk plant is shown in Figure 1.

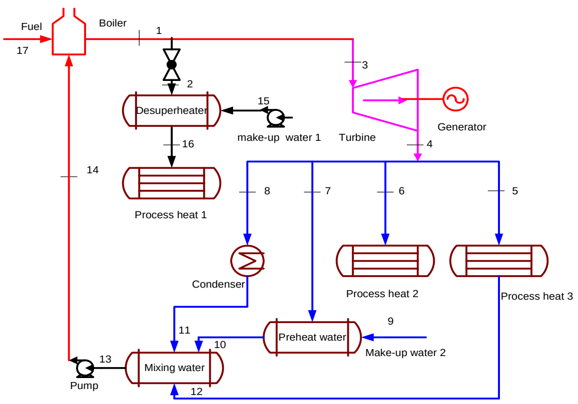

Figure 1. Schematic diagram of rice husk power plant.

Table 1. Operating condition of the rice husk power plant.

Operating condition	Rice husk process data
Mass flow rate of fuel (kg/s)	1.2405
Steam flow rate (kg/s)	4.53
Steam temperature (°C)	400
Steam pressure (MPa)	2.5
Max. Turbine capacity (MW)	1.5 MW
Electrical power output (MW)	1.432 MW
Lower heating value(MJ/kg)	12.340

Source: Data from rice husk cogeneration plant.

Energetic and Exergetic Performance Analyses

Energy performance analysis is based on the first law of thermodynamics; the main performance criteria are commonly power output and thermal efficiency. The parameters are also decisive performance criteria in economic analysis of power plants. Exergy performance analysis is based on the second law of thermodynamics. Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system.(1) Mass, energy, and exergy balance for any control volume at steady state with negligible potential and kinetic energy changes.

Energetic Performance Analysis

The power output of the steam turbine is calculated as follows

$$\sum \dot m_i = \sum \dot m_e \quad (1)$$

$$\dot Q - \dot W = \sum \dot m_e h_e - \sum \dot m_i h_i \quad (2)$$

$$\dot W_T = \dot m_{in}(h_{in}-h_1)+(\dot m_{in}-\dot m_1)(h_1-h_2)+(\dot m_{in}-\dot m_1-\ldots-\dot m_n)(h_n-h_{out}) \quad (3)$$

Where the subscripts of 1, 2, …n represent the number steam extraction in steam turbine. As internal power consumption of the plants. The calculation of pump power can be simply given as follows:

$$\dot W_P = \frac{\dot m(h_{out}-h_{in})}{\eta_P} \quad (4)$$

where η_P is the pump efficiency. Net electrical power output is given by:

$$\dot{W}_{Net} = \sum \dot{W}_T - \sum \dot{W}_P \quad (5)$$

The total required heat energy in the boiler can be determined from:

$$\dot{Q}_B = \frac{[\dot{m}_{sh}(h_{sh,out} - h_{sh,in}) + \dot{m}_{rh}(h_{rh,out} - h_{rh,in})]}{\eta_B} \quad (6)$$

where the subscripts of *sh* and *rh* indicate superheated and reheat conditions, respectively. Also, η_B is the boiler efficiency and boiler inlet enthalpy $h_{sh,in}$ in Eq.(6) is calculated from energy balance at the feed water heater.

$$(\dot{m}_s h_s)_{in} + (\dot{m}_{fw} h_{fw})_{in} = (\dot{m}_s h_s)_{out} + (\dot{m}_{fw} h_{fw})_{out} \quad (7)$$

where *s* and *fw* of the subscripts represent steam and feed water, respectively, and thermal efficiency of the power plant can be calculated as follows:

$$\eta_{th} = \frac{\dot{W}_{Net}}{\dot{m}_{fuel} LHV} \quad (8)$$

where *LHV* is lower heating value of fuel and $\dot{m}_{fuel}$ is the mass flow rate of fuel (kg/s) and is found as:

$$\dot{m}_{fuel} = \frac{\dot{Q}_B}{LHV} \quad (9)$$

Exergetic Performance Analysis

For control volume of plant's components at steady-state conditions, a general equation of exergy destruction rate derived from the exergy balance can be given as:

$$\dot{E}x_D = \sum(\dot{E}x)_{in} - \sum(\dot{E}x)_{out} + [\sum(\dot{Q}(1-\frac{T_o}{T})_{in} - \sum(\dot{Q}(1-\frac{T_o}{T})_{out}] \pm \dot{W} \quad (10)$$

where the first two terms of the right hand side represent exergy of steam entering and leaving the control volume. The third and the fourth terms are the exergy related to heat transfer; T_0 is the environment temperature of the systems surroundings, $\dot{Q}$ represents heat transfer rate across the boundary of the system at a constant temperature *T*. The last term is work transfer to or from the control volume.

The energy transfer by heat ($\dot{X}_{heat}$) at temperature *T* is given by:

$$\dot{X}_{heat} = \sum (1 - T_0/T)\, \dot{Q} \quad (11)$$

And the specific energy is given by heat required

$$\psi = h - h_0 - T_0(s - s_0) \quad (12)$$

Then the exergy rate associated with a fluid stream becomes

$$\dot{E}x = \dot{X} = \dot{m}\psi = \dot{m}(h - h_o - T_o(s - s_o)) \quad (13)$$

where *h* and *s* represent specific enthalpy and entropy, respectively.

Total exergy destruction rate in the plant can be determined as the sum of the exergy rate of components:

$$\dot{E}x_{D,total} = \sum \dot{E}x_{D,i} = \dot{E}x_{D,B} + \dot{E}x_{D,T} + \dot{E}x_{D,C} + \dot{E}x_{D,P} + \dot{E}x_{D,H} \quad (14)$$

For the whole power plant, the exergy efficiency can be given as:

$$\eta_{Ex} = \frac{\dot{W}_{Net}}{\dot{m}_{fuel}\, ex_{fuel}} \quad (15)$$

Results and Discussion

The rice husk cogeneration power plant was analyzed at the environment reference of temperature of 30°C and pressure of 0.101 MPa**.** The mass flow rate of rice husk fuel is 1.2405 kg/s. The thermodynamic properties of water**,** and the results, are shown in Table 2.

Table 2. Exergy analysis of the rice husk cogeneration power plant, when T_o=303.15 K, P_o=101.3 kPa.

Point	*T* (°C)	*P* (MPa)	Flow rate (kg/s)	*h* (kJ/kg)	*s* (kJ/kg °C)	Energy (kW)	Exergy (kW)
0	30	0.101	-	125.9	0.437	-	-
1	400	2.5	4.53	3229	7.015	14102.34	5068.70
2	389	1.1	0.583	3229	7.384	1814.94	587.110
3	400	2.5	3.947	3229	7.015	12287.41	4416.37
4	182.8	0.2	3.947	2836	7.432	10696.77	2326.78
5	182.8	0.2	1.89	2836	7.432	5122.09	1114.17
6	182.8	0.2	1.58	2836	7.432	4281.96	931.42
7	182.8	0.2	0.1388	2836	7.432	376.16	81.820
8	182.8	0.2	0.338	2836	7.432	916.10	199.25
9	30	0.101	0.922	125.9	0.437	0.0000	0.0000
10	105	0.2	1.06	440.2	1.363	333.16	35.530
11	120	0.2	1.58	503.7	1.378	596.924	74.260
12	120	0.2	1.89	503.7	1.528	714.04	88.840
13	116.5	0.2	4.53	488.8	1.49	1643.94	197.61
14	116.5	2.5	4.53	490.5	1.488	1651.64	208.06
15	30	2.2	0.084	127.8	0.4362	0.1600	0.1800
16	184	1.1	0.667	2782	6.554	1771.62	534.71

The energy balance of rice husk cogeneration and exergy destruction are shown in Table 3 and in Table 4, respectively, and exergy losses are shown in Figure 2. It can be concluded that the process heat consumes most of the energy in the rice husk cogeneration**.** This means that the cogeneration needs much heat in the processes. The exergy balance also revealed that the boiler has the highest component loss in rice husk cogeneration (boiler losses of 77.90%, condenser losses of 0.86% and the loss by turbine is 3.42%). This indicates that tremendous opportunities are available for improvement in the boiler for higher overall plant efficiency. It was found that the exergy destruction rate of the boiler is dominant over all other irreversibilities in the cycle, it counts alone for 77.90%. The real loss is primarily back to the boiler where entropy was produced. The calculated exergy efficiency of power cycle is 26.38 %, which is relatively low and has tremendous opportunities for improvement.

Table 3. Energy balance of the rice husk cogeneration.

Components	Heat loss (kW)	Percent ratio
Boiler	2,857.19	18.67
Net power output	1,432.40	9.360
Heat process 1	1,771.62	11.58
Heat process 2	4,281.96	27.97
Heat process 3	4,408.04	28.80
Condenser	319.090	2.090
Desuperheater	43.481	0.280
Preheat water	43.000	0.280
Pump (make up water 1)	0.1600	0.001
Pump (water feed up)	7.7000	0.050
Turbine	141.90	0.930
Total	15,306.54	100.00

Table 4. Exergy destruction (kW) and exergy efficiency of the rice husk cogeneration.

Components	Exergy destruction (kW)	Exergy destruction (%)	Exergy efficiency (%)
Boiler	11,366.95	77.90	29.95
Heat process 1	534.71	3.67	-
Heat process 2	931.42	6.38	-
Heat process 3	1,025.33	7.03	-
Condenser	124.99	0.86	27.97
Desuperheater	52.4	0.36	91.07
Preheat water	46.29	0.32	43.43
Pump(make up water1)	0.175	0.001	70.62
Pump(water feed up)	10.447	0.072	97.97
Turbine	498.95	3.42	76.21
Total / exergy efficiency	14,591.66	100.00	26.38

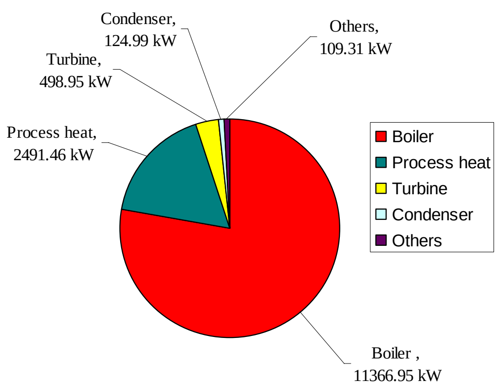

Figure 2. Exergy diagram of the rice husk cogeneration power plant.

Economic Evaluation

The rice husk cogeneration power plant economic evaluation considers the economic costs and the revenues from electricity sold to the grid (see Table 5). It is based on 180-day plant operation. It shows that the rice husk cogeneration has electricity capacity production of 1,432.4 kW, has total revenues of around 10.6 million Baht/year, and has a payback period of 3.7 years.

Table 5. Summary of economic evaluation of the rice husk cogeneration.

Items	Economic of the rice husk power plant
Plant capacity	1,432.4 kW
Capital investment cost	39.317 Million Baht
Variable cost	
Rice husk	1.980 Million Baht
Maintenance cost	1.966 Million Baht
Man power	0.540 Million Baht
Water cost and other	0.365 Million Baht
Total cost (A)	4.851 Million Baht
Electricity sold	14.857 Million Baht
Revenue from selling ash	0.579 Million Baht
Total revenue (B)	15.436 Million Baht
Net Present value (B-A)	10.585 Million Baht
Pay back period	3.7 years
% IRR	26.72%

(Exchange rate in 2009: 1 US$ = 35 Baht)

Conclusions

In this study, an energy and exergy analysis of an actual rice husk cogeneration has been presented. In the considered power plant, neglecting the heat process, the maximum exergy loss was found in the boiler; on the other hand, exergy analysis of the rice husk cogeneration power plant shows that the exergy destruction occurs in boiler 77.90% and the exergy loss in turbine is 3.42%. It can be concluded that the boiler is the major source of irreversibility in the rice husk cogeneration power plant.

The plant's exergy efficiency cogeneration is 26.38 % which is acceptable but relatively low because this rice husk cogeneration plant does not only generate electricity but also requires so much energy in its thermal processes. The calculation of output exergy efficiency is based on both electricity and processed heat output, and the exergy destruction in the boiler, and it gives the guideline for engineers on improvement of the process. It also means that its power to heating ratio is too low.

Finally, considering rice husk cogeneration based on economical evaluation, it can be concluded that the rice husk cogeneration power plant capacity is 1,432.4 kW or it can generate electricity of 6,187,968 kWh/year and it has NPV of 10.6 million Baht/year, PBP of 3.7 years and IRR of 26.72 %.

Acknowledgements

The authors are grateful to the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi (KMUTT) for financial support on the study and the Sirindhorn International Institute of Technology (SIIT), Thammasat University for supporting the facilities and utilities.

References

1. Kotas,T. J. 1985. *The exergy method of thermal plant analysis*. London: Butterworth.

2. Kamate, S.C. and Gangavati, P.B. 2009. Exergy analysis of cogeneration power plant in sugar industries. *Appl. Therm. Eng.* **29(5-6)** : 1187 – 1194.

3. Ram, J. R. and Banerjee, R. 2003. Energy and cogeneration targeting for sugar factory. *Appl. Therm. Eng.* **23(12)** : 1567-1575.

4. Kanoglu, M. and Dincer, I. 2009. Performance assessment of cogeneration plants. *Energy Coversion Manage*. **50(1)** : 76-81.

5. Alonso-Pippo, W., Luengo, C.A., Koehlinger, J., Garzone, P. And Cornacchia, G. 2008. Sugarcane energy use: The Cuban case. *Energy policy*. **36(6)** : 2163-2181.

6. Lobo, P.C., Jaguaribe, E.F., Rodrigues, J. and da Rocha, F.A.A. 2007. Economics of alternative sugar cane milling option. *Appl. Therm. Eng*. **27** : 1405-1413.

7. Purohit, P. and Michaelowa, A. 2007. CDM potential of bagasse cogeneration in India. *Energy Policy*. **35(10)** : 4779-4798.

8. Bhattacharyya, S.C. and Quoc, T., Dang, N. 2004. Economic buy-back rates for electricity from cogeneration: Case of sugar industry in Vietnam. *Energy*. **29** : 1039-1051.

9. Alonso-Pippo, W., Garzone, P. and Cornacchia, G. 2007. Agro-industry sugarcane residues disposal: The trends of their conversion into energy carriers in Cuba. *Waste Manage*. **27** : 869-885.

10. Kuprianov, V.I., Janvijitsakul, K. and Permchart, W. 2006. Co- firing of sugar bagasse with rice husk in a conical fluidized-bed combustor. *Fuel*. **85** : 434-442.

11. Sathitruangsak, P., Madhiyanon, T. and Soponronnarit, S. 2009. Rice husk co-firing with coal in a short combustion-chamber fluidized-bed comustor (SFBC). *Fuel*. **88(8) :** 1394-1402.

12. Srivatsav, A. K. 1996. Selection of steam parameters for cogeneration. In: *Proceeding of cogeneration in India 96.* New Delhi, TERI : 158–162.

13. Nation Energy Policy Office. 2000. Thailand biomass-based power generation and cogeneration with in small industries. In: *Final report on research conducted by Black & Veatch.* Bangkok: Nation Energy Policy Office.

14. Natarajan, E, Nordin, A. and Roa, A.N. 1998. Overview of combustion and gasification of rice husk in fluidized-bed reactors. *Biomass Bioenerg*. **14** : 533-546.

15. Nussbaumer, T. 2003. Combustion and co-combustion of biomass: fundamental, technologies, and primary measure for emission reduction. *Energy Fuel*. **17** : 1510-1521.

16. Athasart, S. 2002. *Cogeneration potential of parboiled rice mill in Thailand.* Master Thesis. Bangkok : Department of Energy Management Technology, School of Energy and Materials, King Mongkut's University of Technology.