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Emission Assessment of Rice Husk Combustion for Power Production

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***Abstract*—** Rice husk is one of the alternative fuels for Thailand because of its high potential and environmental benefits. Nonetheless, the environmental profile of the electricity production from rice husk must be assessed to ensure reduced environmental damage. A 10 MW pilot plant using rice husk as feedstock is the study site. The environmental impacts from rice husk power plant are evaluated by using the Life Cycle Assessment (LCA) methodology. Energy, material and carbon balances have been determined for tracing the system flow. Carbon closure has been used for describing of the net amount of CO_2 released from the system in relation to the amount being recycled between the power plant and the CO_2 adsorbed by rice husk. The transportation of rice husk to the power plant has significant on global warming, but not on acidification and photo-oxidant formation. The results showed that the impact potentials from rice husk power plant are lesser than the conventional plants for most of the categories considered; except the photo-oxidant formation potential from CO. The high CO from rice husk power plant may be due to low boiler efficiency and high moisture content in rice husk. The performance of the study site can be enhanced by improving the combustion efficiency.

***Keywords*—**Environmental impact, Fossil fuels, Life Cycle Assessment (LCA), Renewable energy, Rice husk

I. Introduction

THAILAND's energy supply comes mostly from fossil fuels, a large percentage of which are imported from other countries causing concern for energy security. Moreover, fossil fuels combustion is associated with emissions of CO_2, SO_2 and NO_X leading to environmental impacts. The proposed solution for these problems is using renewable energy sources instead of conventional (fossil) energy sources [1, 2]. The Energy Conservation Promotion Fund committee (ENCON Fund) authorized the Energy Policy and Planning Office (EPPO) to subsidize the Small Power Producers (SPP) producing electricity from biomass for selling to the Electricity Generating Authority of Thailand (EGAT) [3]. This paper is focused on rice husk power plant because it is one major energy sources from the agro-industrial sector. Rice husk is considered to be an environmentally friendly fuel because it can mitigate CO_2, SO_X and NO_X emissions when compared with conventional fuel [4]. However, the emissions from rice husk energy production have not been assessed in quantitative way in Thailand. To answer that, Life Cycle Assessment (LCA) has been used to evaluate the environmental profile of rice husk power plant. All the data; resource and material usage, emissions and wastes as well as energy usage in the energy production will be based on 1 MWh of electricity production for comparing the results with conventional power production

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II. Rice Husk Energy Overview

Rice is cultivated in every region of Thailand. Rice husk, which accounts for 20% by weight of rice, comes from rice milling process as by-product. Generally, a large amount of rice husk is dumped as waste which results in waste disposal problem and methane emissions. Moreover, the low density of rice husk can cause it to be air-borne easily resulting in breathing problems, if inhaled. Rice husk can be converted to a useful form of energy to meet the thermal and mechanical energy requirement for the mills themselves. This helps minimize the waste problem in addition to converting rice husk to a renewable energy resource. Smaller mills can sell the husk to power plants set up under the SPP scheme mentioned earlier. However, the cost of rice husk is increasing now due to its usage for other applications such as; cement additive [5], fertilization in fields [6] and chicken incubation [7], etc., which makes the investment in energy production from rice husk higher than before.

III. Power Plant Background

The Northeastern region is particularly important as one of the major rice growing belts of the country [2]. Due to the environmental and economic scenarios, the Thai government has supported renewable energy production from indigenous sources. One project that has been conducted under this support is a 10 MW pilot plant in Roi-Et province, using rice husk as feedstock for water tube boiler type. Approximately 255 tons of rice husk is supplied daily from the nearby rice mill (located 2 km from the power plant) as the main source and others from 7 to 125 km. The water supply (138 tons) is from the Shi river water and 24 MWh of electricity are required for power production in one day. The maximum power production capacity is 10.2 MW and the minimum is 6.5 MW, depending on raw materials availability. The surplus electricity is sold to EGAT for the commitment under the SPP scheme which has been designed for 21 years. Raw water is pretreated by demineralization before feeding to boiler and cooling tower. Water from boiler blow down (flash tank) and cooling tower blow down is sent for treatment, which includes pH balance, coagulation and demineralization. Solid wastes are sludge from waste water treatment, bottom ash and fly ash.

IV. METHODOLOGY

LCA is an environmental assessment methodology developed to evaluate the inputs and outputs of systems and to convert them into environmental burdens associated with a product, process or activity over the entire period of its life from the extraction and processing of raw material from which it is made, through the manufacturing, packaging and marketing process, and the use, reuse and maintenance of the product, and on to its eventual recycling or disposal as waste at the end of its useful life. The ISO/EN14040 defines LCA framework in four phases: Goal definition and scoping, Inventory analysis, Impact assessment and Interpretation [8].

A. Goal Definition and Scoping

Goal Definition and Scoping is the first phase of LCA, which is used for defining the objectives of the study and the system boundaries for providing environmental information [8]. The goal for this study is to conduct a comparative LCA between electricity production at a rice husk power plant and conventional power generation in Thailand. Energy and material balances are conducted to evaluate the efficiency and check the data consistency. As rice husk is considered as a waste of rice production, the system boundary includes only energy generation and transportation of rice husk to the plant (Fig. 1). Rice cultivation and production are not included in the system boundary. Power plant construction is also excluded from the system boundary as its life is quite large and hence its contribution to power production will be relatively small. Functional unit, which is the basis of comparison, is 1 MWh of electricity.

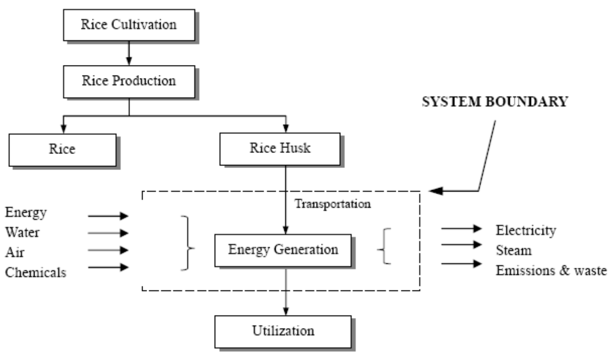

Fig. 1 Scope and system boundary of the study

B. Inventory Analysis

Inventory Analysis is the identification and quantification of materials, resources and energy usages, and environmental releases in power production. This step includes material and energy balances, carbon closure and data analysis. According to the conservation law, matter and energy cannot be created or destroyed [9]. Hence, materials/ energy inputs must be equal to material/ energy outputs. The calculations in this phase have been done for checking the consistency of the data. Material balance deals with material flow, calculation of the balance, C balance and C closure. Energy calculations include energy flow, energy balance, Sankey diagram, overall efficiency, combustion (boiler) efficiency and turbine efficiency.

- *Material flow and Material balance*

The characteristics of rice husk in Table 1 have been determined by CHONS analysis method, moisture content analysis and bomb calorimeter analysis. The emission data in Table 2 was determined based on JIS code method [10]. Material balance can be calculated as presented in Fig. 2 (Eq. 1), carbon balance is Fig. 3 and carbon closure is Fig. 4 (Eq. 2).

$$M_{RH} + M_A + M_{RW} = M_{FA} + M_{BA} + M_{FG} + M_{WE} + M_{WD}, \quad (1)$$

Where; M_{RH} is mass flow rate of rice husk, M_A is mass flow rate of air inlet, M_{FA} is mass flow rate of fly ash, M_{BA} is mass flow rate of bottom ash, M_{RW} is mass flow rate of raw water, M_{WE} is mass flow rate of water evaporation and M_{WD} is mass flow rate of water discharge. The difference in material input and output works out to 3.79 t/h, which is about 4.34 % of the total material input.

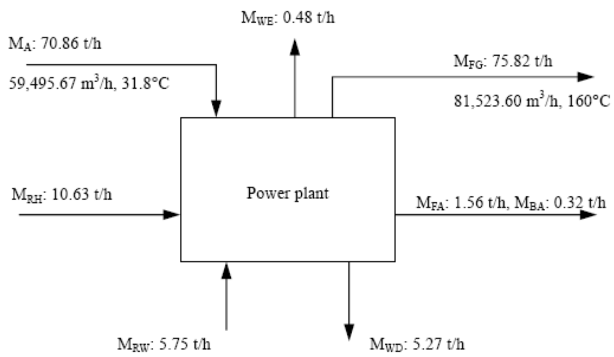

Fig. 2 Material balance

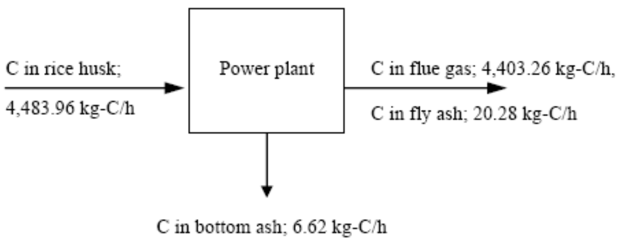

Fig. 3 Carbon balance

The data in Table 1 show that the main elemental components of rice husk are carbon and oxygen, and there is little nitrogen and sulphur content. The main emission is CO_2, while CO, SO_2 and NO_2 are very low (Table 2). Thus only carbon balance has been done for this study. Carbon input to the power plant comes mainly from rice husk where the carbon content is 42.2 %. Total carbon output during the power production consists of 10 % CO_2 and 0.08 % CO in 81,523.6 m^3/h of flue gas, 1.3 % carbon content in 1,560 t/h of fly ash and 2.05 % carbon content in 323 t/h of bottom ash. There is also a small input from the CO_2 in the air which has been adjusted for.

TABLE I
ELEMENT COMPOSITION OF RICE HUSK SAMPLE

Parameter	Result	Std. Dev.	Basis
C	42.2 %	0.99	Dry
H	5 %	0.06	Dry
O	36 %	2.16	Dry
N	0.7 %	0.15	Dry
S	*	-	Dry
Total moisture	11 %	1.11	As received
Heating value	13.78 MJ/kg	0.07	Dry

*: Below detection limit of instrument which is 1 %

TABLE II
STACK EMISSIONS DATA [10]

Parameter	Value, v./ v**.	kg/h	kg/MWh
CO_2	10 %	16,013.56	1,685.64
CO	0.08 %	81.52	8.58
NO_2	153 ppm	12.47	1.31
SO_2	16 ppm	3.72	0.39
TSP	12.7 ppm	1.03	0.11
Fly ash	1,560 kg/h	1,560	164.21
Bottom ash	323 kg/h	323	34

**: @ Volume of flue gas; 81,523.6 m^3/h, 160°C

Carbon closure of the system is illustrated as Fig. 4. The flows that cross the system boundaries indicate carbon inflows and outflows from the system. Overall, the outflows of carbon equal to the inflows of carbon in rice husk and carbon in diesel oil. Carbon content in rice husk is 4,493.96 kg-C/h and in diesel oil is 0.20 kg-C/h. Rice husk is transported from rice mill to the power plant in trucks. The base case transportation distance is 4 km/round trip which consumes 0.50 L of diesel oil. Carbon emission from transportation is 0.20 kg-C/h (base distance) in the form of CO_2, CH_4 and CO. Carbon emissions from the rice husk power plant are 4,367.33 kg-C/h as CO_2, 34.93 kg-C/h as CO, and 26.9 kg-C/h as unburned carbon.

$$\text{Carbon closure} = \{(C_{input} - C_{output})/ C_{input} \} \times 100\ \% \quad (2)$$

$$\text{When; } C_{input} = RH + T \quad (3)$$

$$C_{output} = T + UA + FG_{CO} \quad (4)$$

Where; C_{input} is total carbon content in (kg-C/h), C_{output} is total carbon content in (kg-C/h), RH is carbon content in rice husk (kg-C/h), T is carbon released from the transportation (kg-C/h), UA is carbon released as unburned carbon in total ash (kg-C/h), FG_{CO2} is carbon released with flue gas as CO_2 (kg-C/h) and FG_{CO} is carbon released with flue gas as CO (kg-C/h).

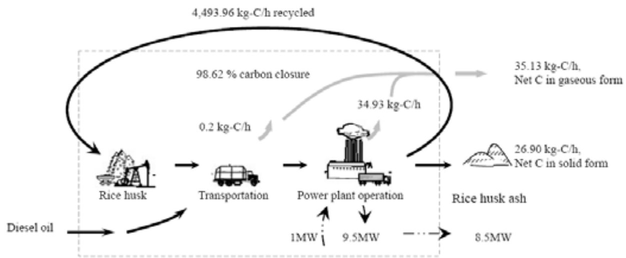

Fig. 4 Carbon Closure

The amount of carbon recycled by rice husk energy production is 98.62 % of total carbon input. About 1.38 % of total carbon input, which are carbon emissions from transportation of rice husk to power plant and CO from incomplete combustion of rice husk, are released to the atmosphere and contribute to global warming.

- *Energy flow and Energy balance*

A useful way of charting energy flow is to use a Sankey diagram. Sankey diagram of rice husk energy production can be used for describing the losses at every sub process of rice husk energy production. The equation of Sankey diagram calculation is Eq.5.

$$\text{Energy input} = \text{Electricity} + \text{Waste heat} + \text{Total loss} \quad (5)$$

TABLE III
STACK DATA OF CONVENTIONAL [15]

Plant Types	Electricity Production (MWh)	CO_2		CO		SO_2		NO_2		TSP	
		tons	kg/MWh	tons	kg/MWh	tons	kg/MWh	tons	kg/MWh	tons	0.037
Coal	17,338,580	22,011,748	1,269.52	3,421	0.197	48,005	2.77	101,212	5.84	633	0.927
Oil	12,947.2	10,521	812.61	3.52	0.27	16.6	1.28	37	2.86	12	0.036
Gas	56,247,083	31,997,720	568.88	11,070	0.197	19	0.0003	76,634	1.36	2,042	0.036
Combined*	73,598,610	54,019,989	733.98	14,495	0.197	48,041	0.65	177,883	2.42	2,686	0.036

* Weighted average of coal, oil and gas-fired power plant

Fig. 5 describes the Sankey diagram. Energy input is only from rice husk which is defined as 100%. Electricity produced accounts for 23.14% of the total energy input. Waste heat is the heat rejected at condenser (61.07%). Total loss consists of energy losses at boiler, losses at steam turbine and losses from distribution which are accounted as 13.15 %. The recycled energy is the energy content in air inlet and feed water, which are heated by the flue gas before releasing to the stack. Loss at boiler includes heat loss in flue gas, fly ash, bottom ash, radiation loss, water blow down discharge loss. At the steam turbine, there is loss during conversion of thermal energy to mechanical energy and mechanical energy to electricity along with the waste heat during condensation.

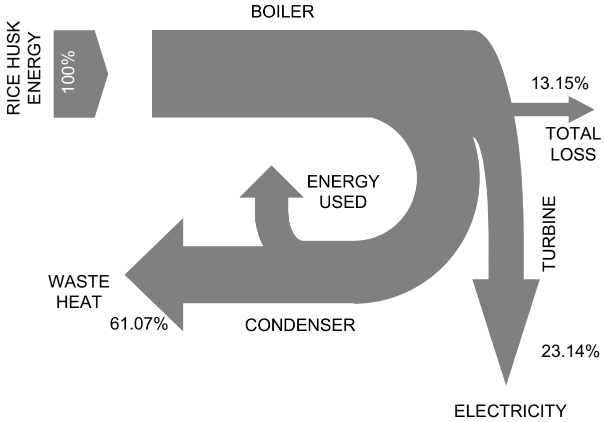

Fig. 5 Sankey diagram

Energy balance in Fig. 6 is also a part for checking the consistency of process flows. The calculation of overall energy balance is based on the law of conservation of energy. The calculation of energy balance is Eq.6.

$$E_{RH} = E_{FA} + E_{BA} + E_{FG} + E_{WE} + E_{WD} + E_{R\&Ub} + E_{ST} + E_{Elec} \quad (6)$$

Where; E_{RH} is energy in rice husk (GJ/h), E_{FA} is energy in fly ash (GJ/h), E_{BA} is energy in bottom ash (GJ/h), E_{FG} is energy in flue gas (GJ/h), E_{WE} is energy in water evaporation (GJ/h), E_{WD} is energy in water discharge (GJ/h), $E_{R\&Ub}$ is radiation and unaccounted loss at boiler (GJ/h), E_{ST} is heat rejection (GJ/h) and E_{Ele} is electricity (GJ/h). The difference in input and output energy from energy balance calculations, in terms of percentage is 2.64 %.

The calculations of overall efficiency [11], combustion efficiency [12, 13] and turbine efficiency [14] can be used for calculating the production efficiency.

$$\%\eta_O = (E_g - E_u) \times 100/ (LHV \times M_{RH}) \quad (7)$$

Where; η_O is overall efficiency (%), E_g is energy generated (MJ/h), E_u is energy utilized in power plant (MJ/h), LHV is Low Heating Value of rice husk (MJ/kg) and M_{RH} is mass flow rate of rice husk (kg/h).

$$\%\eta_{CD} = E_{Out} \times 100/(E_{RH} + E_{FW} + E_A) \quad (8)$$

Where; η_{CD} is combustion efficiency-Direct method (%), E_{Out} is energy output from boiler (GJ/h), E_{RH} is energy in rice husk (GJ/h), E_{FW} is energy in feed water to boiler (GJ/h) and E_A is energy in air inlet to boiler (GJ/h).

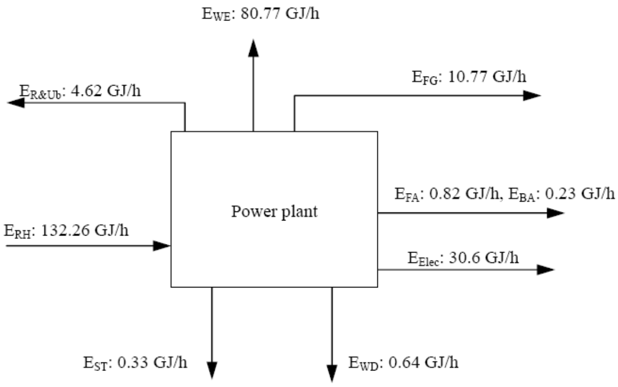

Fig. 6 Energy balance.

$$\%\eta_{CI} = 100 - \left[\frac{(i + ii + iii + iv + v + vi + vii)}{\text{Total energy input}} \times 100\ \%\right] \quad (9)$$

Where; η_{CI} is combustion efficiency-Indirect method (%), 'i' is heat loss due to flue gas (%), 'ii' is heat loss due to moisture in fuel (%), 'iii' is heat loss due to hydrogen in fuel (%), 'iv' is Heat loss due to moisture in air (%), 'v' is heat loss due to incomplete combustion (%), 'vi' is heat loss due to unburned C in ash (%) and 'vii' is radiation loss (%).

$$\%\eta_{STi} = \frac{W_T}{W_s} \quad (10)$$

Where; η_{STi} is steam turbine/isentropic efficiency (%), W_T is work turbine (kJ/h), W_S is work isentropic (kJ/h).

The rice husk power plant produces 9.5 MWh electric power from 10,625.5 kg of rice husk. The Low Heating Value of rice husk is 12,447.27 kJ/kg. Thus, the overall conversion system efficiency can be defined as 23.13 %. The combustion efficiency or boiler efficiency by input-output method is 87.59 % (Eq. 8) and heat loss method is 84.34 % (Eq. 9). The difference between the two methods may be due to unaccounted losses. The range of boiler efficiency generally obtained is 85 to 90 % [14]. Thus, the combustion efficiency is in the range of reference. The range of steam turbine efficiency is generally between 35 to 55 % [14]. The result of turbine efficiency calculation is 54.15 % (Eq. 10), which is in the upper part of the range.

C. Impact Assessment

The total emissions to air are from two sources viz., electricity production and transportation. These can be calculated as;

$$E_{P,T} = E_P + E_T \quad (11)$$

Where; $$E_T = \frac{D \times FE \times EF}{E_g} \quad (12)$$

The environmental impact potentials are calculated by Eq. (13) [8]:

$$EP(j)_i = \sum_i Q_i \times EP(j)_i \quad (13)$$

Where $EP(j)_i$ is the emission's potential contribution to the environmental impact category (j), Q_i is the magnitude of emission of substance (i) and EF(j) is the substance's equivalency factor for the environmental impact category (j).

TABLE IV
IMPACT POTENTIAL OF TOTAL AIR EMISSIONS

GLOBAL WARMING POTENTIAL		
Distance, km/round	Total amount (kg CO_2-eq/ MWh)	From transportation (kg CO_2-eq/ MWh)
4	34.40	17.24 (50.12%*)
10	34.52	1736 (50.29%*)
50	35.32	18.16 (51.41%*)
125	36.82	19.66 (53.39%*)
250	39.32	22.15 (56.35%*)
ACIDIFICATION POTENTIAL		
Distance, km/round	Total amount (kg SO_2-eq/ MWh)	From transportation (kg SO_2-eq/ MWh)
4	1.06	0.0003 (0.03%*)
10	1.06	0.001 (0.07%*)
50	1.06	0.004 (0.35%*)
125	1.06	0.087 (0.86%*)
250	1.07	0.17 (1.71%*)
PHOTO-OXIDANT POTENTIAL		
Distance, km/round	Total amount (kg C_2H_2-eq/ MWh)	From transportation (kg C_2H_2-eq/ MWh)
4	0.34	1.68E-05 (0.01%*)
10	0.34	4.21E-05 (0.01%*)
50	0.34	2.10E-04 (0.06%*)
125	0.34	5.26E-04 (0.15%*)
250	0.34	1.05E-03 (0.31%*)

* percent of total impact

Table 4 presents the selected impact potentials of total air emissions from both sources. Transportation has significant investment cost since rice husk has very low density. The rice husk requirement of the factory is met by 13 trucks/day. Usually the rice husk is transported to the power plant from a rice mill 2 km away. However, at times when the rice husk has also to be purchased from sources about 125 km from the power plant. The long distance of rice husk transportation to the plant site can contribute global warming potential up to 56 % of the life cycle amount for a round trip distance of 250 km, but its contribution to acidification and photo-oxidant formation is not significant (1.7% and 0.3% respectively at 250 km/round trip). It is therefore interesting to calculate the transportation distance at which the global warming potential from rice husk power plant will equal that of conventional power plant. This distance works out to about 35,925 km/round. Obviously, this is an unreasonably high distance which will never occur in practice. Hence, we can safely conclude that the performance of rice husk power plant is better than conventional power plant for global warming.

Table 5 shows the results of environmental impact potentials comparison between rice husk power plant and the average value of conventional power plants in Thailand. The data required for calculation for rice husk power plant is presented in Table 2 [10] and Table 3 [15] is for average value of conventional power plants. The environmental impact potentials have been calculated by the characterization equation, Eq.(13).

TABLE V
ENVIRONMENTAL IMPACT POTENTIALS COMPARISON [10, 15]

Impact category	Rice husk	Coal	Oil	Natural gas	Combined*
Global warming (kg CO_2-eq/MWh)	17.16	1,269.91	813.15	569.27	734.37
Acidification (kg SO_2-eq/MWh)	1.06	6.86	3.28	0.95	2.34
Photo-oxidant formation (kg C_2H_4-eq/MWh)	0.34	0.008	0.011	0.008	0.08
Nutrient enrichment (kg N-eq/MWh)	0.39	1.75	0.86	0.41	0.73
Solid waste (kg ash/MWh)	9.81	n.a.	n.a.	n.a.	n.a.

* Combined value of 76.42 % natural gas, 23.56 % coal and 0.02% oil.
n.a. Not available.

D.Interpretation

The results from inventory analysis indicate that material and energy balances are consistent. The small difference of material balance may be due to loss in pipes and tubes, and unsteady state of the production. The difference of carbon balance is 1.42 % which is very small and may be due to minor variations in rice husk characteristics and averaging of measurements. Carbon closure is 98.62 % of total carbon input. Thus, about 1.38 % of total carbon inputs contribute to global warming.

Sankey diagram and energy balance indicate that the overall efficiency of this plant is about 23 %. This information can be used for improvement of the power plant efficiency by identifying the source and amount of losses. The maximum heat loss occurs during water condensation. To improve the power plant efficiency one way suggested is to install heat exchanger for trapping waste heat from cooling tower for using in other processes, such as for drying rice husk before use as feed stock. The difference of energy balance is 2.64 % which may be due to loss in pipes and tubes.

Transportation of rice husk to power plant has significant effect on global warming potential. However, it will reach global warming potential of conventional power plants only at very long transportation distances which will never occur in practice because the cost of transportation will be too high.

The impact assessment results show that the impact of global warming potential of rice husk energy (17.16 kg CO_2-eq/MWh) is far less than the combined value of fossil fuels plants (734.37 kg CO_2-eq/MWh) because CO_2 from biomass is considered as greenhouse gas neutral. Sulphur and nitrogen contents in rice husk are low when compared with coal and oil. In addition, the combustion temperature of rice husk is lower than 900˚C, preventing the formation of thermal NO_X. Hence, acidification and nutrification potentials of rice husk plant (1.06 kg SO_2-eq/MWh and 0.39 N-eq/MWh) are lesser than combined value of fossil fuels plants (2.34 kg SO_2-eq/MWh and 0.73 N-eq/MWh) even though fossil fuels plants have NO_X and SO_X removal equipment installed. Only in case of natural gas, the acidification potential is lesser than the rice husk power plant because very less SO_X is produced from natural gas plant (0.0003 kg/MWh). NO_X produced from natural gas plant (1.36 kg/MWh) is slightly higher than rice husk power plant (1.31 kg/MWh). Photochemical oxidant formation is from CO emissions of rice husk plant (0.34 kg C_2H_2-eg/MWh) and is higher than the combined value of fossil fuels plants (0.08 kg C_2H_2-eg/MWh). This may be due to the low combustion efficiency of the rice husk power plant resulting in part from the high moisture content in rice husk. For solid waste potential (disposal amount) only the data from rice husk power plant is available as 9.81 kg ash/MWh. Hence, the comparison can not be made. Nevertheless, it must be mentioned that both bottom and fly ash are utilized and hence, not going to the landfill. Also, credits must be provided for the material they displace. This has not been included in this study. The results present that most environmental impacts potentials from rice husk power plant are lesser than the fossil fuels plants.

V. Conclusion

Material balance, energy balance and carbon balance help to confirm the process flow data and understanding the production process. The consistency calculations indicate that the emissions data are reliable. Losses from the balance calculations may be caused from the unsteady plant operation and averaging of data. Carbon balance and carbon closure can be used for guidance to reduce the amount of carbon emissions emitted to the atmosphere which contribute to global warming. The carbon dioxide emissions produced from rice husk power plant will be re-absorbed by the biomass carbon cycle. Thus global warming potential comes only from fossil fuel consumed for fuel transportation and CO from incomplete combustion of rice husk. The amount of carbon emission contributing to global warming is about 1.38 % of total carbon input.

Energy losses are indicated by the conversion efficiency and the efficiency of the equipment. Waste heat loss at condenser is very high at about 61 % of total energy input. To increase the overall efficiency as well as reduce wastage of energy, waste heat at condenser may be utilized for drying rice husk before combustion. Boiler efficiency and turbine efficiency are in the standard range of reference. However, if the efficiencies can be improved the production efficiency will increase and CO emission will reduce also. Transportation has no significant contribution to acidification and photochemical oxidant formation.

When considering the whole system including the electricity production and transportation of rice husk to the power plant, transportation has significant effect on global warming and transportation cost. When considering only the electricity production and comparing the impact potential categories results with the conventional fuels, it is seen that rice husk is an environmentally friendly fuel for global warming, acidification and nutrient enrichment. Only photo-oxidant formation is more than conventional fuel which occurs due to the low combustion efficiency of the rice husk power plant and moisture content in rice husk.

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