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A Closed Model of Production System for Energy Self-Sufficiency Rice Mill

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Abstract

Rice mills consume considerable amount of energy, which is mainly supplied by fossil fuel. It has been approved that such energy is declining, and its negative impacts on the environment has also been significant. A more sustainable energy resource, such as biomass, should be considered to replace fossil energy. This research was aimed to assess energy potential of generated waste and to develop a model of energy self-sufficiency rice mill through by-products utilisation as energy source. The model was based on mass balance principles by assuming that there is a linear relationship of material flows in and out of each process compartment. The simplest model assumed the rice mill as a single compartment, while the complex model used a more detailed step of processes as compartment. The complex model was suitable to represent real process of rice mill. According to this model, head rice yield, rice husk ratio, and bran ratio is 0.572; 0.231, and 0.074 of dried paddy respectively. Energy potential of by-product is about 18,830 MJ/day from processing 20 tons harvested paddy. This energy potential exceeds the need of the rice mill at 28.25% surplus. This research revealed that rice mills can be energy self-sufficient. Therefore, it is possible to propose regulation to limit the use of fossil fuel in rice mill.

Keywords: rice mill, closed production system, energy self-sufficiency

1. Introduction

Rice is the staple food for most people in the world especially for Asians where 90% of the world's rice is grown and consumed (Adjao and Staatz 2014; Singha 2013; Suh 2014). Indonesia is one of the big five rice-producing countries in the world. BPS (2015) stated that Indonesia was predicted to produce about 75 million tons of paddy in 2017. About 90% was consumed by domestic population (Lim *et al.* 2014). This makes rice milling industry is a vital for the nation food security.

Rice mill is one of energy-consuming industries with variation amount of consumption between 734–1,194 MJ/ton paddy inputs (Basappaji and Nagesha 2013; Goyal et al.2012; Kapur et al. 1995). Variations of energy used depend on capacity and complexity of process technology. Regardless the consumption, the energy needs and consume in the industry will continue to increase after the increasing rice demands. Currently, the energy used is dominated by fossil fuels. For the country level, consumed energy is supplied by fossil fuel (48%), coal (19%), natural gas (14%), Liquid Petroleum Gas (5%), electricity (13%) and other resources (1%).

The industrial sector has the largest share of energy consumption as much as 33% of total national energy consumption with an average growth of 4.5% per year (KESDM 2014). Meanwhile, stocks of oil, coal and natural gas are declining and will be limited in the near future. This situation causes serious challenge to all industries, including rice mills, to substitute their energy with a more sustainable sources. Biomass is one of the potential alternative energy with huge potency (Bridgwater 2006; Pimentel *et al*. 1981; Ragauskas 2006).

Biomass-based energy sources is a safer to the environment than those of fossil energy since it has lower content of sulfur and nitrogen (Chungsangunsit et al. 2004; Sarasuk and Boonrod 2011). Gadde et al. (2009) discovered that biomass application as an energy source for rice production can prevent greenhouse gas emission (GHG) in India, Thailand and Philippines for 0.75%, 1.81% and 4.31% respectively based on the national specific GHG. Developed countries also fulfill their energy needs (up to 35%) using biomass energy resource (Basappaji and Nagesha 2013). Biomass as an alternative energy source is a promising choice for sustainable rice mills. Bantacut and Novitasari (2016) proposed agroindustry that process raw material bearing energy (containing fiber, carbohydrate, sugar and oil) should be developed as an energy independent production system that producing net product. Rice husk is a potential biomass for energy resource that produced by rice milling industries since it has high calorific value of 13–15.4 MJ/kg at 14% moisture content (Ahiduzzaman and Islam 2009; Hiloidhari 2014). It is also conveniently converted into energy (UNEP 2007). Rice milling process produces rice husk as much as 20–22% of dried paddy weight (Buggenhout 2013; Lamberts *et al.* 2007; Nugraha *et al.* 2007). Handling of rice husk is a major problem in rice-producing countries where it is not handled properly (Lim *et al.* 2012).

Several researches have been conducted to analyse the potency of rice husk for energy generation. Chungsangunsit *et al*. (2004) assessed the electricity production from rice husk in Thailand, stated that rice mills have a potency to fulfill their energy needs. Majhi et al. (2014) studied utilisation of rice husk for power generation in India and showed that rice husk could cut energy cost. Okeh *et al*. (2014) studied the potency of rice husk for alternative energy resource in Nigeria, and showing that rice milling industry has a potency to fulfill its energy needs. However, those researches were not aimed to estimate the energy independence level of rice mill. Detailed modeling and estimation the extent of energy self-sufficiency was the scope of this research. Energy generation from rice husk can be used to meet total energy needs to develop a closed system of rice mills without any energy input from outside of the system. Based on the environmental engineering rules, closed system means a system which is all input and output flows are known (Davis and Cornwell 2013) to which this research refers and start from mass balance modeling and rice husk potency analysis. A closed system is designed to integrate rice production (processing systems) with rice husk utilisation as energy resource of the rice mill (energy generating systems).

Based on the above reasons, this research was aimed to develop a model of a rice mill energy self-sufficiency. To meet this objective, this research steps were as follows: (1) developing rice production mass balance model, (2) calculating energy needs of rice mill, (3) calculating rice husk potency for energy generation, and (4) developing closed rice production system. The input of the mass balance model is harvested paddy and the outputs are head rice and broken rice. The value of input flow was 20 tons paddy/day. This value followed the observed rice mill capacity. The measured parameters of the models were head rice yield, rice husk ratio, and rice bran ratio.

The energy produced from rice husk utilisation then compared to the rice mill energy consumption. This comparison determines the rice mill energy independency level. If the energy generated were greater than energy need, the rice mill can potentially be energy independent. However, if the energy generated is smaller, the system is not independent for its energy.

2. Method

2.1. Data Collection

This research used primary and secondary data. Primary data (actual mass balance of rice mill) was collected from direct observation at a rice mill in Cianjur District of West Java Province Indonesia, while the secondary data (mass flow of production, energy need and by-product generation) were collected from research reports, journal articles, books, thesis and other scientific papers.

2.2. System Boundary

Material Balance Model is useful to analyse and predict energy sufficiency in agricultural product processing industry (Bantacut and Destiara 2016). Rice production is a complex system that involves many inter-connected factors one to another. Factors and constraints of balance model are material, energy need and by-product. A comprehensive approach was used to minimise energy use, optimise production and utilise by-product. Therefore, this research used a system approach to analyse the flow of mass and energy needs including energy potency of by-product. In general, rice milling process consist of five compartments: drying, de-husking, whitening, polishing and grading. The main outputs is head rice and by-products (broken rice, rice husk and rice bran). Broken rice is output of grading, rice husk from de-husking, and rice bran from polishing and whitening.

2.3. Model Description

The model was developed based on mass balance of process flows and compartments to describe the real situation of rice mills. Development of the model was aimed to obtain an applicable model representing real mass balance of the rice mills. The inputs were treated as the independent variables and the outputs as the dependent variables. The modeling used coefficient values in the ratio form (efficiency) of dependent and independent variable based on the linear equation principles. Microsoft Excel matrix operation used to calculate the variables value.

Model development process was based on the real mass flows of rice mill with capacity of 20 tons of paddy per day. This is to make modeling process easier and applicable. Results of the model were then compared with the international standard of rice production data from International Rice Research Institute (IRRI) and actual data of the rice mills. This was used to confirm and validate the accuracy of the model. The model outputs then used to identify and calculate by-products amount and their energy potential to meet energy needs of the production process. The model has a high degree of accuracy and, in accordance with the real production process, forms a basis of analysis to calculate potential energy of by-product to further develop an independent energy rice-production process.

2.4. Mass Balance

Mass balance is a mathematical representation of input and output mass flows in a system. It can be applied for modeling of the production, transportation, and fate of pollutants in environment. It shows every flow in the system and every accounted component in the closed system (Davis and Cornwell 2013).

The first step in creating a mass balance is to identify the compartments. Then, a mass balance is set to link inputs (paddy) and output (head rice and by-products) for all compartments. By-product is assumed to be recyclable. In identifying the efficiency equation (the ratio of variables) secondary data on the mass flows of the rice mill process were used. After the mass balance and efficiency equations identified, the values of the efficiency factor and mass balance can be determined. Mass balance model illustrates rice production process. Matrix operation was used to calculate the value of variables. Input values for the matrix operation are variables of mass balance and efficiency value of each compartment. This research developed two levels of mass balance model based on the complexity of production process to check consistency of the models, they are simplest and complex models.

2.5. Calculation of Rice mill By-product Energy Content

The potential energy was calculated by the equation: Potential energy (MJ) = Mass (ton) x calorific value (MJ/ton). The total biomass was calculated with mass balance model whereas the calorific values were obtained from the literature (13–15.4 MJ/kg of rice husk). This research used lowest calorific value 13 MJ/kg of rice husk for self-sufficient energy analysis.

2.6. Process Flow of Self-sufficiency on Rice Mill

Analysis of self-sufficient energy potency needs actual energy consumption of rice mill for comparison. Actual energy consumption of rice mill is obtained from literatures. The value is varied depends on technology and capacity. Several studies stated that it was about 734 MJ/ton paddies (Basappaji and Nagesha 2013). In addition, it also needs some supporting data to calculate the generated energy from rice husk. Table 1 summarises the properties parameters used in the calculation.

Table 1. Reference data for energy potency calculation

Supporting data	Value	Reference
Energy need of rice mill (MJ/ton paddy)	504 (thermal) & 230 (electrical)	Basappaji and Nagesha (2013)
Efficiency of hot air	30%	Basappaji and Nagesha (2013)
Efficiency of boiler	68%	Yadav and Singh (2011)
Steam/rice husk ratio	4.3	Yadav and Singh (2011)
Efficiency of generator	77%	Narvaez *et al.* (2013)

The comparison of energy potency and energy needs will show the independence level of rice mill. If the net energy potency of by-product were greater than or equal to the energy needs, then rice mill can potentially be self-sufficient in its energy. However, if the energy potency is smaller than the energy needs, the rice mill needs energy from outside then the system is not independent in its energy.

3. Mass Balance Model of Rice Mill

Two levels of mass balance models of rice mill were developed; the simplest model assumed the rice mill as a single compartment and the complex model used steps of processes as compartment.

3.1. Simple Mass Balance Model

The simplest model was developed by assuming all steps of the process are taking place in a single compartment (Figure 1). It explains total amount of input and output of the system generally. Thus, it only contains single efficiency values, which is head rice yield (HRY). In general, rice mills in Indonesia produces HRY as much as 45% based on harvested paddy (Rachmat 2012).

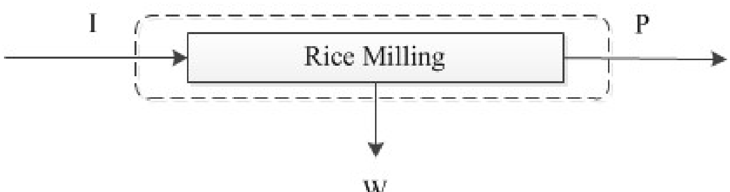

Figure 1. Simple Mass Balance Model ($I = P + W$)
Notes: I = input, P = product, W = waste

3.2. Complex Mass Balance Model

A complex mass balance model is detailing of simple model by making compartments based on the process steps involved in rice production (De Datta 1981; Chung and Lee 2013). The model has efficiency values as much as the number of compartments (13 compartments see Figure 2). It consists of one independent variable (I_1) and 26 dependent variables (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, P_1 and P_2). The independent variable is a consistent variable which has a given changable value (for instance 20 tons of paddy) where the dependent variables have various values depend on the efficiency coefficient values.

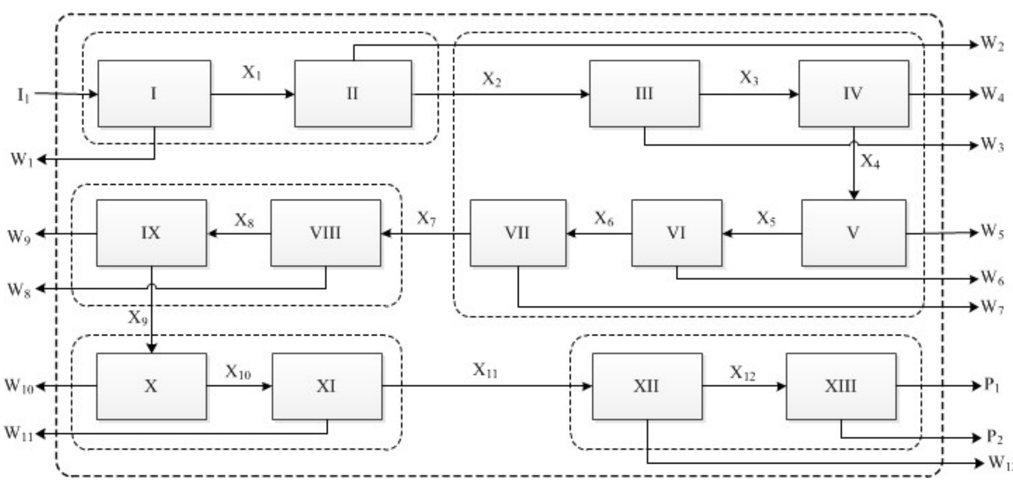

Figure 2. Complex Mass Balance Model (The symbols are described in Table 2 and 3)

Tabel 2. Compartments of complex model

Compartment	Description	Compartment	Description
I	Pre-cleaning	VIII	Brown Rice De-stoning
II	Drying	IX	Whitening
III	De-stoning	X	Rotary shifting
IV	De-husking	XI	Polishing
V	Paddy Separating	XII	Color Sorting
VI	Brown Rice Separating	XIII	Lenght grading
VII	Thickness Grading		

Mass balance equations:

Compartment 1 : $I_1 - W_1 - X_1 = 0$ .... (1)
Compartment 2 : $X_1 - X_2 - W_2 = 0$ .... (2)
Compartment 3 : $X_2 - X_3 - W_3 = 0$ .... (3)
Compartment 4 : $X_3 - X_4 - W_4 = 0$ .... (4)
Compartment 5 : $X_4 - X_5 - W_5 = 0$ .... (5)
Compartment 6 : $X_5 - X_6 - W_6 = 0$ .... (6)
Compartment 7 : $X_6 - X_7 - W_7 = 0$ .... (7)
Compartment 8 : $X_7 - X_8 - W_8 = 0$ .... (8)
Compartment 9 : $X_8 - X_9 - W_9 = 0$ .... (9)
Compartment 10 : $X_9 - X_{10} - W_{10} = 0$ .... (10)
Compartment 11 : $X_{10} - X_{11} - W_{11} = 0$ .... (11)
Compartment 12 : $X_{11} - X_{12} - W_{12} = 0$ .... (12)
Compartment 13 : $X_{12} - P_1 - P_2 = 0$ .... (13)

Table 3. Description of symbols of Complex Mass Balance Model

Input		Output	
I_1	= paddy	P_1	= clean head white rice
		P_2	= broken white rice
Waste		**Internal flows**	
W_1	= leaves and stems	X_1	= clean wet paddy
W_2	= vapor	X_2	= clean dried paddy
W_3	= stone	X_3	= clean (no stone) dried paddy
W_4	= rice husk	X_4	= husked rice
W_5	= unhusked grain	X_5	= raw brown rice
W_6	= raw brown rice	X_6	= whole brown rice
W_7	= immature grain	X_7	= mature brown rice
W_8	= stone	X_8	= clean brown rice
W_9	= rice bran	X_9	= white rice
W_{10}	= broken rice	X_{10}	= whole rice
W_{11}	= rice bran	X_{11}	= polished white rice
W_{12}	= colored rice	X_{12}	= clean polished white rice

***Efficiency values*:**

Pre-cleaning efficiency (a_1)

$$a_1 = \frac{\text{clean wet paddy}}{\text{rough wet paddy}} = \frac{X_1}{I_1} \quad \text{....................(14)}$$

Pre-cleaning process separates impurities such as weed, seed, leaves and stalks (De Datta 1981). It applies oscillating sieve mechanism. Impurities separated as much as 0.25% by weight of rough wet paddy (Chung and Lee 2003; Rachmat 2012). Thus efficiency value of pre-cleaning (a_1) is 99.75%.

Drying efficiency (a_2)

$$a_2 = \frac{\text{dried paddy}}{\text{clean wet paddy}} = \frac{X_2}{X_1} \quad \text{.......(15)}$$

Drying process is basically the transfer of heat to the grain to convert water in grain into vapor and emitting it to the atmosphere (De Datta 1981). In tropical countries, the moisture content of harvested paddy is about 25% (Jittanit *et a*l. 2010). It needs to be decreased to 14% (Rahmat 2012; Steffe *et al.* 1980). Based on the mass balance equation, 12.8% of water from the paddy needs to be evaporated to get 14% moisture content. Thus the efficiency value of drying process (a1) is 87.2%.

Destoning efficiency (a_3)

$$a_3 = \frac{\text{clean dried paddy}}{\text{dried paddy}} = \frac{X_3}{X_2} \quad \text{.......(16)}$$

De-stoning process removes stone from paddy (Chung and Lee 2003). This process takes advantage of gravitation force to separate stone from paddy. It generates various value depends on harvesting process (IRRI 2015). In an estimation, stone and such material separated is about 0.25% by weight of clean dried paddy (Chung and Lee 2003). Thus efficiency value of de-stoning (a_3) is 99.75%.

De-husking efficiency (a_4)

$$a_4 = \frac{\text{husked rice}}{\text{clean dried paddy}} = \frac{X_4}{X_3} \quad \text{.......(17)}$$

De-husking process applies frictional force between two rollers with different speed and direction to crack rice husk (Araullo *et al.* 1976). This process generates various amount of husk, and an average number is 20% by weight of clean dried paddy (Lambrets *et al.* 2007; Dhankhar *et al.* 2014). Thus the efficiency value of rice husk removal (a_4) is 80%.

Screen sorting efficiency (a_5)

$$a_5 = \frac{\text{raw brown rice}}{\text{husked rice}} = \frac{X_5}{X_4} \quad \text{.......(18)}$$

Screen sorting is a recycling process to bring back the unhusked rice to de-husking process using separator (Chung and Lee 2003; Lambrets *et al.* 2007). It is assumed the value of screen sorting (a_5) is 98%.

Brown rice separating efficiency (a_6)

$$a_6 = \frac{\text{whole brown rice}}{\text{raw brown rice}} = \frac{X_6}{X_5} \quad \text{.......(19)}$$

Brown rice separating is a secondary recycle of uncompleted brown rice based on paddy size by using a tray separator. It also applies oscillating mechanism so that the whole brown rice can be separated (Chung and Lee 2003; Lambrets *et al.* 2007). It is assumed that the value of brown rice separating (a_6) is 98%.

Thickness grading efficiency (a_7)

$$a_7 = \frac{\text{mature brown rice}}{\text{whole brown rice}} = \frac{X_7}{X_6} \quad \text{.......(20)}$$

Thickness grading is to separate immature grain based on the thickness (De Datta 1981; Chung and Lee 2003). It has various values based on the harvesting time (IRRI 2015). This process separates immature grain as much as 0.455% of the weight of dried paddy (Chung and Lee 2003). It is equal to 0.782% of the weight of whole brown rice. Thus, the efficiency value of thickness grading (a_7) is 99.218%.

Brown rice destoning efficiency (a_8)

$$a_8 = \frac{\text{clean brown rice}}{\text{mature brown rice}} = \frac{X_8}{X_7} \quad \text{.......(21)}$$

Stone separation takes an advantage of gravitation force to separate stone from paddy (Chung and Lee 2003). It is a secondary stone removal. The separated stone is as much as 0.13% of the weight of paddy (Chung and Lee 2003). It is equal to 0.023% of the weight of mature brown rice. Thus, the efficiency value of brown rice de-stoning (a_8) is 99.977%.

Whitening efficiency (a_9)

$$a_9 = \frac{\text{white rice}}{\text{clean brown rice}} = \frac{X_9}{X_8} \quad (22)$$

Whitening removes rice bran from grain surface to get white rice (Araullo *et al.* 1976; De Datta 1981). Rice bran separated is as much as 4.58% by weight of paddy (Gurjar and Sengupta 2015; Hansen *et al.* 2012). It is equal to 7.95% by weight of clean brown rice. Thus the efficiency value of whitening (a_9) is 92.05%.

Rotary shifting efficiency (a_{10})

$$a_{10} = \frac{\text{whole white rice}}{\text{white rice}} = \frac{X_{10}}{X_9} \quad (23)$$

Rotary shifting process is to separate whole white rice grain with those of broken one (De Datta 1981). Broken rice is grain which has less than 50% whole kernel length (Rachmat 2012). The produced broken rice is as much as 2.68% of the weight of paddy (Arora *et al.* 2007; Chung and Lee 2003). It is equal to 5.054% of the weight of white rice. Thus, the efficiency value of rotary shifting (a_{10}) is 94.946%.

Polishing efficiency (a_{11})

$$a_{11} = \frac{\text{polished white rice}}{\text{whole white rice}} = \frac{X_{11}}{X_{10}} \quad (24)$$

Polishing is removal of existing fine rice bran on the kernel to smooth its surface (De Datta 1981). This process applies abrasive polisher. Polished rice produced is about 98% by weight of whole white rice (Chung and Lee 2003; Prakash *et al.*2013). Thus the efficiency value of polishing (a_{11}) is 98%.

Color sorting (a_{12})

$$a_{12} = \frac{\text{Premium polished white rice}}{\text{polished white rice}} = \frac{X_{12}}{X_{11}} \quad (25)$$

Color sorting separates the colored rice from the polished rice by using color identifier (Chung and Lee 2003). The separated colored rice is about 1.2% of the weight of paddy (Chung and Lee 2003). It is equal to 2.438% of the weight of the polished white rice. Thus, the efficiency value of color sorting (a_{12}) is 97.562%.

Length grading (a_{13})

$$a_{13} = \frac{\text{Cleaned head white rice}}{\text{Premium polished white rice}} = \frac{P_1}{X_{12}} \quad (26)$$

Length grading is a removal of broken rice from clean polished rice to produce head rice based on kernel length (Houston 1972). Head rice has 75%–80% of whole kernel length. Head rice produced about 90% by weight of clean polished white rice (Cnossen *et al.* 2003; Damarjati 1990; USDA 2005). Thus the efficiency value of length grading (a_{13}) is 90%.

Table 4 summarises the efficiency values used in the Complex Mass Balance Model.

4. Result and Discussion

4.1. Mass Balance Model

Head Rice Yield (HRY) calculated with Simple Model is lower than the complex model (Table 5). This because the simple model considered the waste in aggregate (not detailed by process). However, the results show that rice production generates by-product together with main product.

The Complex Mass Balance Model showed greater HRY because there are two recycling flows (W5 and W6) that bring back unhusked grain to the de-husking process. Thus, it increases head rice yield (Chung and Lee 2003; IRRI 2013). This model also revealed impurities such as weeds, seed, leaves, stalks and stones. Stone and straw were as much as 0.002 and 0.003 of the weight of paddy. So, this model is clear enough to illustrate real situation of the rice mill (Figure 3).

The model also showed rice husk ratio which is 0.231 of the weight of dried paddy. This is relatively similar to IRRI standards of maximum 0.23. Recycle process brings back the un-processed rice to de-husking stage then increased the input and output of this process. This improvement causes higher number of the rice husk production. Thus, the recycle process improved HRY and increased rice husk produced.

Table 4. Efficiency values of Mass Balance Model Level 3

Efficiency	Rounded off Value	Reference
a_1	0.99	Chung and Lee (2003); Rachmat (2012)
a_2	0.87	Jittanit *et al.* (2010); Nugraha *et al.* (2007)
a_3	0.99	Chung and Lee (2003)
a_4	0.80	Lambrets *et al.* (2007); Dhankhar *et al.* (2014)
a_5	0.98	Chung and Lee (2003); Lambrets *et al.*(2007)
a_6	0.98	Chung and Lee (2003); Lambrets *et al.* (2007)
a_7	0.99	Chung and Lee (2003)
a_8	0.99	Chung and Lee (2003)
a_9	0.92	Gurjar and Sengupta (2015); Hansen *et al.* (2012)
a_{10}	0.95	Arora *et al.*(2007); Chung and Lee (2003)
a_{11}	0.98	Chung and Lee (2003); Prakash *et al.* (2013)
a_{12}	0.98	Chung and Lee (2003)
a_{13}	0.90	Cnossen *et al.* (2003); Damarjati (1990); USDA (2005)

Table 5. Comparison of models and IRRI standards by dried paddy

Parameter	Simple Model	Complex Model	IRRI (2013)
Head rice yield	0.516	0.572	0.5–0.6
Rice husk ratio	-	0.231	0.2–0.23
Rice bran ratio	-	0.074	0.08–0.1

The results of the model are compared to the real data from factory for verification (Table 6). The difference of HRY is about 10% which is acceptable. This means that the model can be used to predict and calculate mass flow of rice mills.

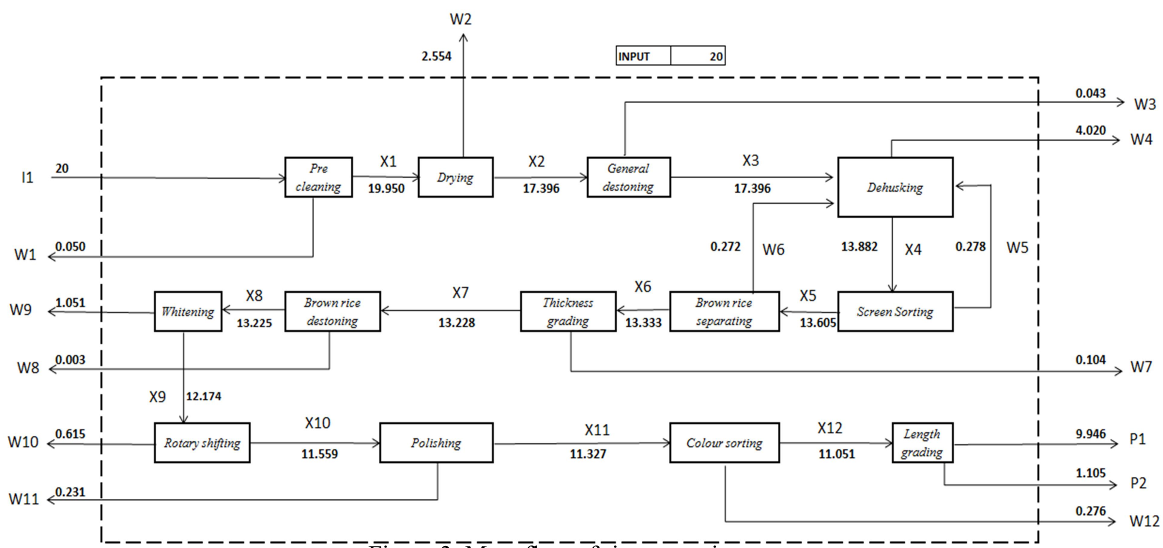

Figure 3. Mass flow of rice prouction process

Rice bran ratio variation caused by differences of technology applied. The model includes recycle process (screen sorting and brown rice separating) which was not exist in the factory. These processes bring back unhusked rice to the de-husking process, thus the number of rice husk produced increased. The higher rice bran ratio of the actual data is caused by addition of fine rice husk to mixture of rice bran.

The results of the model are relatively the same with actual data, meet and no significant difference to the IRRI standards for HRY parameter. So, the model is accepted and can be used for further analysis.Technically, HRY of the factory can be increased up to 10% by improving technology to operate an optimal process. Recycling process is necessary to be applied to produce better quality of rice.

Table 6. Comparison of Model results with actual data (dried paddy basis)

Variables	Complex Model	Actual data	Difference
Head rice yield	0.572	0.517	0.053
Rice husk ratio	0.231	0.229	0.002
Rice bran ratio	0.074	0.125	0.051
Broken rice ratio	0.063	0.063	0

4.2. Energy Self-sufficiency in Rice Mills

Rice husk utilisation is potential for energy generation to fulfill thermal and electrical energy needs of rice mill. The thermal energy is used for the drying process while the electrical energy for the milling process. Variation in the energy consumption is depending on the capacity, process and technology applied. There are several methods to use rice husk for energy generation. Generally, they are divided into two paths, thermochemistry and biochemistry. Thermochemistry path includes combustion, gasification and pyrolysis while biochemistry path are fermentation and esterification (Soltani 2015). Thermochemistry is chosen because it is easier to be applied as biochemistry paths are difficult to be installed due to the high content of lignin and silica (Pode *et al.* 2015).

Direct combustion for electricity generation using steam power has been applied using wood biomass. It is also applicable to straw and husk biomass (Matsumura 2005). Fluidised bed combustion is proper technology for low density biomass conversion into energy since it has good mass and heat transfer characteristics (Loha *et al.* 2013), but the high content of silica causes high ash residues (Bazargan *et al.* 2015).

Rice husk combustion is used to produce hot air to supply the drying energy needs. Hot air production uses fluidised bed dryer (FBD) which has an efficiency of 30% (Basappaji and Nagesha 2013). FBD is an effective method for drying the high moisture grain. The main advantages are fast drying rate, moisture content similarity and high drying capacity due to a complete mixing between drying air and paddy (Aghbaslo *et al.* 2013; Atthajariyakul and Leephakpreeda 2006; Golmohammadi *et al.* 2015).The schematic diagram of drying process through FBD is shown in Figure 4.

The efficiency value of electricity production using steam turbine generator is about 77% at 120 °C. Steam production uses boiler heated by fluidized bed furnace. Efficiency of steam production of the boiler is 68% (Yadav and Singh 2011). The energy independency of rice husk utilisation is shown in Table 8.

According to Table 8, there is rice husk surplus that potentially be used to generate steam which uses a boiler at 4.3 kg of steam per kg of rice husk (Yadav and Singh 2011). This husk may produce electricity with surplus of 4,147 MJ, equal to 28.25% of the total production energy needs. The complete information is shown in Appendix 1.

The calculation above showed that self-sufficient energy in rice mill is achievable then applying closed production system is possible. This energy surplus can be used for energy reserve or another purpose to potentially replace fossil fuel that now used in rice production. If the energy need of rice mill is assumed to be fulfilled by the public grid, it can cut the coal consumption. Coal energy is about 2,655 kWh per ton of coal (Sulistyono 2012). If the rice mill consumed 204 kWh per ton of paddy that equal to 76.8 kg coal per ton of paddy. In comparison, rice mill needs 162 kg rice husk to process 1 ton of paddy. Thus, the use of one ton of rice husk will cut coal as much as 474 kg.

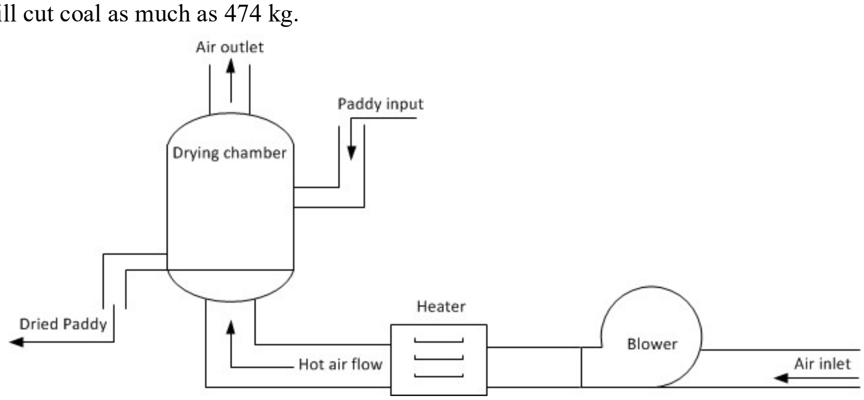

Figure 3 Schematic diagram of fluidized bed drying
(Simplified from Atthajariyakul and Leephakpreeda 2006; Chungcharoen *et al.* 2015)

Table 8. Rice husk potency for energy generation

Parameter	Amount
Energy needs	
Drying energy (MJ)	4,600
Milling energy (MJ)	10,080
Total (MJ)	**14,680**
Energy generation potency	
Rice husk produced (ton)	4.020
Rice husk need for heating (ton)	2.585
Rice husk surplus (ton)	1.436
Steam produced (ton)	4.198
Electricity produced (MJ)	**18,827**
Energy surplus (MJ)	**4,147**

Similarly, rice husk also possible to cut the use of diesel oil of 128.8 liters and 31.2 liters of kerosyne (UCFCCC 2007) that equal to about 50 liter of fossil fuel per ton of rice husk (3.24 rice husk used per day). Moreover, carbon generation of burning rice husk is lower than those of fossil fuel. Rice husk has carbon emission as much as 1.445 kg CO_2/kg of rice husk (Capareda 2014), 2.673 kg CO_2/liter of diesel and 2.538 kg CO_2/liter of kerosene. Thus, the use of rice husk will prevent CO_2 emission as much as 105.339 kg CO_2 per ton of rice husk.

4.3. Closed System Production of Rice Mill

By-product of rice production is an energy resource and value adding product. Broken rice can be processed into rice flour. The rice flour yield production is 90% to 95% of broken rice. Rice bran is sold for animal feed or processed into bran oil (Bagchi *et al.* 2015; Rachmat 2012). The closed production system model is shown in Figure 6 (a more detail flow in Appendix 2).

5. Conclusion and Recommendation

5.1. Conclusion

Complex mass balance model is suitable to illustrate real rice mill. Head rice yields, rice husk ratio and rice bran ratio generated as much as 0.572; 0.231 and 0.074 of the weight of dried paddy, respectively. Rice mill can be self-sufficient in energy fulfillment by applying closed production system based on the rice husk use. Rice mill consumes energy as much as 14,680 MJ for 20 tons of raw paddy. It was estimated that energy fulfillment achieved was 128.25% of the total production energy needs. In addition, rice bran for animal feeds or bran oil. Broken rice is processed into rice flour.

Based on this research, every ton of rice husk used as an energy resource will cut 474 kg of coal or 50 liter of fuel (diesel and kerosene). This will cut CO_2 generation as much as 105.339 kg CO_2 per ton of rice husk.

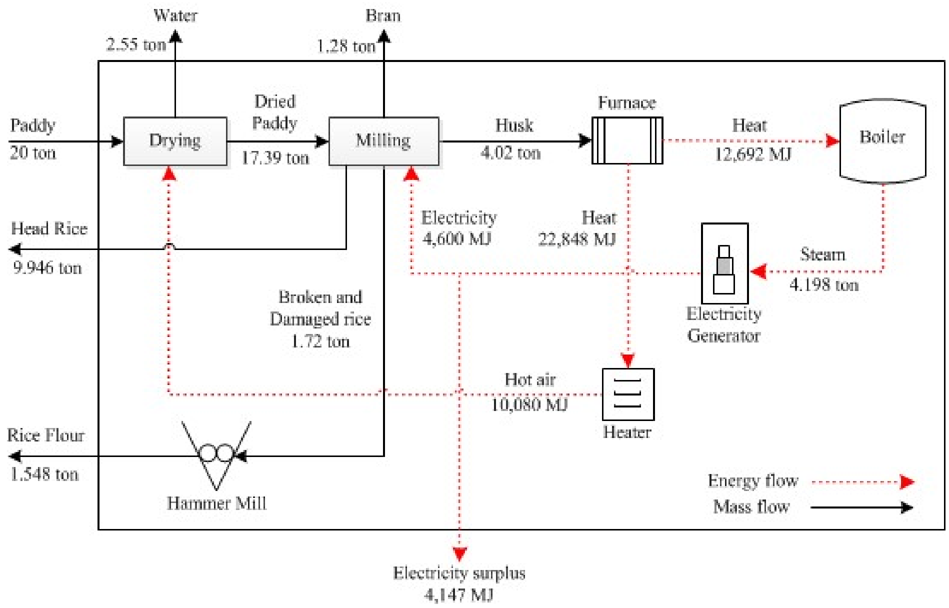

Figure 4. Self-sufficient energy closed production system

5.2. Recommendation

Further study is needed to calculate more detailed mass balance with reference to big scale rice mill, since this research was based on 20 tons of paddy per day of rice mill capacity. The result of this research can be a consideration to integrate rice processing and energy generation as a new process flow of rice mill. This will cut the fossil fuel used and increase HRY in rice milling industries.

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Appendix 1. Completed information of energy generation potency of rice mill

Component	Result	Unit	Refference/ note
Mass balance			
Dried paddy input	20	ton	Model Level 3
Rice husk (RH) produced	4.02	ton	Model Level 3
Supporting data			
Calorific value of RH	13	MJ/kg RH	Ahiduzzaman and Islam 2009; Hiloidhori 2013
Efficiency value of Boiler for hot air	30	%	Basappaji and Nagesha 2013
Efficiency value of Boiler for steam	68	%	Yadav 2011
Steam-rice husk ratio	4.3		Yadav 2011
Efficiency value of electricity from steam	77	%	Narvaez 2013
Energy requirements			
Drying energy requirement (hot air)	504	MJ/ ton paddy	Basappaji and Nagesha 2013
Milling energy requirement (electricity)	230	MJ/ ton paddy	Basappaji and Nagesha 2013
Total drying energy requirement	10,080	MJ	for 20 ton paddy
Total milling energy requirement	4,600	MJ	for 20 ton paddy
Calculation			
Total rice husk needed for drying	2.585	ton	
Rice husk surplus	1.436	ton	
Steam produced from RH surplus	4.198	ton	
Electricity produced from steam	8,747	MJ	
Surplus electricity	4,147	MJ	
Ratio			
Total energy produced	18,827	MJ	
Total energy required	14,680	MJ	
Total energy surplus	4,147	MJ	
Energy fulfillment ratio	128.25	%	

Appendix 2. Complete closed system of rice mill production model