A comparative approach in the utilisation of rice husk and empty palm bunch in the biomass boiler

Sivabalan Kaniapan¹, Kartikeyan Patma Nesan², Hamdan Ya¹, Suhaimi Hassan¹, Azizul Buang² and Mohd Safuan Zakaria¹

¹Mechanical Engineering Department, Universiti Teknologi Petronas, Seri Iskandar Perak, Malaysia
²Chemical Engineering Department, Universiti Teknologi Petronas, Seri Iskandar Perak, Malaysia

sivabal_19001036@utp.edu.my, kartik_91@hotmail.com

Abstract. Growing world’s population has immense contribution towards world economy and energy utilisation. The enormous usage of conventional fuel has contributed many environmental problems such as greenhouse gas emission (GHG), world climate change, and deterioration of human health. Recent study focuses on the generated power from EPB compared with methane in a typical biomass boiler. Also, there are very limited studies on the Air to Fuel (ATF) ratios value in boiler operation. In this paper, empty palm bunch (EPB) and rice husk (RH) have been selected as biomass fuel in the biomass boiler. The same recommended parameters of boiler and turbine was chosen for both EPB and RH feedstocks from previous study. Overall, the study proven to produce about 33% and 25% of energy from EPB and RH respectively, with EPB producing 13.31% of higher turbine power than RH. This directly contributes to the technical feasibility and adaptability of environmentally friendly elements by seizing the opportunity of carbon emission of conventional fuel and replacing it with natural resources such as EPB and RH which are part of the biomass fuel replacement regime. However, ATF ratio of RH is significantly minimal of what a CH₄ and EPB utilised to burn 1 kg of fuel. Therefore, EPB and RH would be suitable for future renewable biomass feedstock in comparison with conventional fuel for power generation purposes.

1. Introduction

Energy needs are essential for both social and economic growth of every nation in the world. The development of energy usage is expected to grow simultaneously with the world population index. According to the U.S Energy Information Administration (EIA) statistic [1], both non-OECD countries involving India, Indonesia, China, etc. and OECD countries such as Japan, Germany, U.K, etc. have shown a continuous increase in both energy consumption and population growth from 2010 to 2015 as shown in Figure 1 below. Today’s world population reaches almost 7.7 billion people in 2019 and will continue to expand to 8.5 billion in 2030 [2]. In addition, according to the Department of Statistics Malaysia (DOSM), Malaysia population growth has increased from 28.6 million to approximately 32.4 million [3] in 2010 and 2018, respectively, which also causes an increment of 47.3% [4] from the overall expected power consumption for both domestic use and non-domestic use.
Figure 1. Shows global electricity consumption and global population growth from the year 2000 to 2015.

Moreover, power generation is also inter-related with the economic growth and living standards among individuals in the particular region. Energy is consumed predominantly in terms of electricity for cooking, washing, internet browsing, and others. However, nearly 86% [5] of generated electricity is harnessed from conventional fuel in Malaysia which is expected to extinct in another few decades. Also, the immense usage of fossil fuel for long term could potentially accumulate greenhouse gas emissions (GHG), world climate change, and others. Therefore, switching to biomass elements such as rice mill residues and oil palm residues is likely to be utilised as a power solution and indirectly able to reduce the conventional fuel usage due to the abundant availability of the feedstocks. Moreover, biomass is an exceptional and efficient option to be replaced conventional fuel as it is part of the renewable energy sources and will not extinct sooner. Biomass does not contribute to the release of carbon emission even after combustion as it uses carbon during the growing stage through the process of photosynthesis. Therefore, empty palm bunch (EPB) and rice husk (RH) is chosen as biomass fuels for this study as potential fuel replacement.

2. Rice mill residues
Rice has always been a staple food for many years among individuals worldwide, particularly in Southeast Asia, where nearly 80% of the world’s rice is consumed by Asians [6]. The world rice production in 2019 is nearly 755 million tonnes, with an increase of 8.79% from the year 2010 [6]. In Malaysia, rice production has increased from 2.5 billion tonnes in 2018 to 2.9 billion tonnes in 2019 [6]. In line with rice's spur production rate, the accumulation of rice residues or waste has been a multi-faceted problem faced by the growers. Rice waste comes in a various forms and shapes, such as rice husk (RH) and rice straw (RS). Almost 40 % of RS and 20 % of RH are produced for every kilogram of harvested paddy depending on the cultivation method [7].

According to Kadam et al. [8], around 1.35 tons of rice waste will remain in the field after producing 1 ton of rice grain. Consequently, this rice waste was not properly discarded which causes environmental-related issues through the emission of greenhouse gases (GHG) from traditional open burning [9], short-cut to eradicate pest problem which eventually causes respiratory-related problem like asthma [10] due to the inhalation of suspended particles from this activity.

These rice residues (RH and RS) can be used in various thermochemical and biochemical processes to produce char, liquid biofuel, or steam for power generation. In 2017, it has been anticipated that around 638.03PJ of energy could be potentially harnessed from almost 0.77 billion tons of RS and 0.15 billion tons of RH [11]. Mohiuddin et al. [12] have estimated that about 70% rice husk is needed to produce 1328 GWh/ year of electricity with a cost of 47.36 cents/kWh in comparison with coal which needs 55.22cents to produce a kWh of power. Nevertheless, in Malaysia rice husk is still not being exploited for optimal utilisation in terms of power generation, S. M. Shafie [13] estimated that about 5652 GWh power could be produce from rice residue which accounted for 5.4% of the overall power demand in Malaysia.
3. Palm mill residues
Palm oil is one of the largest edible oil in the world accounted for nearly 71.48 million tonnes [14] surpassing other oil commodities such as sunflower oil and soybean oil. Palm oil is very distinctive in its own way, as it is edible oil which is also common in biofuel and bio-chemical production. Palm oil production is a very prominent business commodity in Malaysia where nearly 425 palm oil mills in operation throughout the region produces roughly 19.8 million tonnes of oil in 2019, carrying approximately 38.23 billion ringgit business [3], [15]. Apart from being the secondary palm oil producers globally, Malaysia carries a lot of research and development to yield more oil for every ton of fresh fruit bunch.

In line with the huge production of palm oil, Malaysia is producing large quantity of waste where 22-23 million tons of EPB is produced annually [16]. Empty Palm bunch (EPB) is the main source of palm biomass with huge market potential that can be used in enormous ways such as in power production and other waste to value-added processes. Currently, EPB is the least used element in power fuel production due to its high moisture absorption rate, lower bulk density, and lower calorific value in comparison with the conventional fuel properties [17]. However, EPB can be altered in a way that it fits with the current biomass boiler application to produce maximum power output.

Recent study of Nnaemeka Sp et al. [18] has only focused on the power yield from EPB in contrast with methane in biomass boiler. Also, there are very limited studies on the air to fuel ratios computation in biomass boiler operation. Thus, this research paper computes by comparing the usage of RH and EPB in biomass boiler through air to fuel stoichiometric derivations and the turbine output. Both EPB and RH have been focused as an important biomass material in this research article due to the abundant availability, lower emission rate and produces new employment opportunity.

4. Materials and method

![Figure 2. Sample materials of EPB and RH.](image)

The material of EPB and RH for this research article was procured from Palm Oil Mill, Teluk Intan, Perak, Malaysia and Sungai Manik Rice Mill, Perak, Malaysia, respectively. The EPB is received in a fibre form which has been pressed and shredded into small pieces in the palm oil mills, whereas the RH is received as it is from the production mill. Both EPB and RH were then left to dry in the oven under 105°C for about 24 hours to remove any excessive moisture. Both the dehydrated EPB and RH were then sent to the grinding section to produce fine powder and sieved to make even sizing of $0.30 < \text{dp1} < 0.50$ mm. Finally, powdered EPB and RH were kept in the container as shown in Figure 2.

4.1. Tools and equipment
In this research paper, ultimate analysis (UA), proximate analysis (PA) and high heating value (HHV) of the feedstock are identified by using lab equipment such as CHNS analyser, thermogravimetric analyser, and bomb calorimetric analyser respectively.
4.2. Power generation method
In this research article, steam turbine has been used which involves three stages of conversion such as thermal energy dissipation through combustion of the biomass feedstock in the boiler (converting water into high pressure steam), followed by generation of kinetic energy via ejected steam into turbine (injection of high-pressure steam to rotate steam turbine), and finally converting the mechanical energy of turbine rotation into electrical power. Figure 3 below shows the overall representation of biomass power plant process conversion into electricity.

![Figure 3. Operation of biomass power plant.](image)

5. Results and discussion
Table 1 illustrates the chemical composition of EPB and RH from the experimental analysis of (PA, UA, and HHV).

| Parameter                     | Proximate analysis | Ultimate analysis (dry basis) | Components       | Related properties |
|-------------------------------|--------------------|-------------------------------|------------------|--------------------|
| Material                      | EPB                | RH                            |                  |                    |
| MS, (%wt)                     | 8.15               | 4.92                          |                  |                    |
| VM, (%wt)                     | 74.20              | 63.20                         |                  |                    |
| AC, (%wt)                     | 12.76              | 12.35                         |                  |                    |
| FC, (%wt)                     | 4.89               | 18.19                         |                  |                    |
| C, (%wt)                      | 46.00              | 42.50                         |                  |                    |
| H, (%wt)                      | 6.45               | 5.42                          |                  |                    |
| N, (%wt)                      | 0.48               | 0.43                          |                  |                    |
| O, (%wt) \(^{a}\)           | 31.80              | 34.61                         |                  |                    |
| S, (%wt)                      | 0.10               | 0.01                          |                  |                    |
| Cellulose, (%wt) \(^{b}\)    | 37.82±0.57         | 32.67                         |                  |                    |
| Hemicellulose, (%wt) \(^{b}\)| 21.85±0.54         | 31.68                         |                  |                    |
| Lignin, (%wt) \(^{b}\)       | 12.16±0.17         | 18.81                         |                  |                    |
| HHV, (MJ/kg)                  | 16.96              | 14.70                         |                  |                    |
| Bulk Density, (kg/m\(^3\)) \(^{b}\) | 150               | 121                           |                  |                    |

\(^{a}\)Calculated by difference
\(^{b}\)[19],[20]
5.1. Chemical formula derivation

Presumption has been made for both EPB and RH molecular formula as \( C_a H_b O_c N_d S_e \) which consist of carbon, hydrogen, oxygen, nitrogen, and sulphur derived from the experimental result ( ultimate analysis) from Table 1. Thus, the molecular formula derived for 100g of the provided sample (EPB and RH) is as shown in Table 2.

Table 2. Molecular formula derivation of EPB and RH.

| Properties | EPB  | RH       |
|------------|------|----------|
| C          | \( a = 0.460 / 12; \ a = 0.03730 \) | \( a = 0.425/12; a = 0.03542 \) |
| H          | \( b = 0.0645 / 1; b = 0.06450 \) | \( b = 0.0542 / 1; b = 0.05420 \) |
| O          | \( c = 0.318 / 16; c = 0.01990 \) | \( c = 0.3461 / 16; c = 0.02163 \) |
| N          | \( d = 0.0048 / 14; d = 0.00034 \) | \( d = 0.0001 / 32; d = 0.000003 \) |
| S          | \( e = 0.0010 / 32; e = 0.000003 \) | \( e = 0.0001 / 32; e = 0.000003 \) |

Hence, the molecular formula of EPB is \( C_{0.0373} H_{0.0645} O_{0.0199} N_{0.00034} S_{0.00003} \) and RH is \( C_{0.03542} H_{0.0542} O_{0.02163} N_{0.00031} S_{0.000003} \) which is a dry molecular formula eliminating both ash and moisture presence in the molecular structure of both feedstocks. Also, the molecular weight (MW) of EPB and RH is 0.83622 and 0.82976 respectively.

5.2. Stoichiometric balance combustion equation of EFB and RH

The biomass calorific values, ash content, bulk density and moisture content play a vital role in determining the combustion efficiency in the boiler. Theoretically, in complete combustion system by-products such as carbon dioxide (CO\(_2\)), water vapour (H\(_2\)O), sulphur oxides (SO\(_x\)), nitrogen oxides (NO\(_x\)) and other by-products will be produced depending on the number of moles presence in each constituent in biomass feedstock and the reaction capabilities of the feedstock with the provided air supply and heat. In this study, further presumption has been made where both RH and EPB reacted with air in the boiler with the ratio of (79% nitrogen:21% oxygen) and the produced by-products is only composed of (CO\(_2\)), (H\(_2\)O), sulphur dioxide (SO\(_2\)) and nitrogen (N\(_2\)). Therefore, the remaining stoichiometric equation of complete combustion process for both EPB and RH can be derived with respect to equation (1) and (2) depicted from Nnaemeka Sp et al. [18]:

a) (EPB)

\[
C_{0.0373}H_{0.0645}O_{0.0199}N_{0.00034}S_{0.00003} + \gamma (O_2+3.76N_2) \rightarrow \beta CO_2 + \alpha H_2O + \delta SO_2 + \rho N_2
\]  

C: \( \beta = 0.0373 \)

H: \( \alpha = 0.0645 / 2, \ a = 0.03225 \)

S: \( \delta = 0.00003 \)

O: \( 0.0199 + 2\gamma = 2\beta + \alpha + 2\delta, \gamma = 0.043505 \)

N: \( 0.00034 + 2(\gamma) (3.76) = 2\rho, \rho = 0.1638 \)

Thus, the overall stoichiometric equation of EPB combustion would be as follows:

\[
C_{0.0373}H_{0.0645}O_{0.0199}N_{0.00034}S_{0.00003} + 0.043505 (O_2+3.79N_2) \rightarrow 0.0373CO_2 + 0.03225H_2O + 0.00003SO_2 + 0.1638N_2
\]

b) (RH)

\[
C_{0.03542}H_{0.0542}O_{0.02163}N_{0.00031}S_{0.000003} + \gamma (O_2+3.79N_2) \rightarrow \beta CO_2 + \alpha H_2O + \delta SO_2 + \rho N_2
\]  

C: \( \beta = 0.03542 \)

H: \( \alpha = 0.0542 / 2, \ a = 0.0271 \)

S: \( \delta = 0.000003 \)

O: \( 0.02163 + 2\gamma = 2\beta + \alpha + 2\delta, \gamma = 0.037258 \)

N: \( 0.00031 + 2(\gamma) (3.76) = 2\rho, \rho = 0.1403 \)

Thus, the overall stoichiometric equation of RH combustion would be as follows:
Therefore, the stoichiometric of air to fuel ratios to burn one kg of EPB and RH would be as follows:

a) EPB

Mass of Air / Mass of fuel = (0.043505) (MW_{\text{air}} / MW_{\text{EPB}})

= [0.043505 ((16 x 2) + (3.76 x 14 x 2))] / 0.83622

= 7.14 kg

b) RH

Mass of Air / Mass of fuel = (0.037258) (MW_{\text{air}} / MW_{\text{EPB}})

= [0.037258 ((16 x 2) + (3.76 x 14 x 2))] / 0.829756

= 6.16 kg

5.3. Boiler feeding and heat dissipation of RH and EPB

Specific size and consistency of biomass materials should be achieved through size measurement protocols where larger size of EPB is shredded into smaller pieces to improve bulk density and further enhances the fuel thermo-chemical characteristic and vice-versa for smaller biomass feedstock like RH. Table 3 shows the calculated combustion rate and heat released for both EPB and RH.

Table 3. Combustion rate and heat released of EPB and RH.

| Components | EPB | RH |
|------------|-----|----|
| Combustion rate, C_R (kg/hr) | 900 | 900 |
| Heat released, Q (GJ) = (calorific value x combustion rate) | 15.20 | 13.17 |

5.4. Turbine output power

Rajput et al. [21] have identified equation (3) through the combustion of 10.35 tonnes of EPB.

Turbine shaft power = \( \frac{m \times C_v \times \eta_{\text{circle}} \times \eta_{\text{turbine}} \times \eta_{\text{heat}} \times \eta_{\text{combustion}}}{3600} \) (3)

The same equation used by Nnaemeka Sp et al. [18] to find the turbine power with the following recommended parameters except feedstock mass, calorific values, and cycle efficiency as shown in Table 4 below.

Table 4. Turbine parameter with EPB and RH.

| Turbine parameters | Current feedstocks | Nnaemeka Sp et al. [20] |
|--------------------|-------------------|------------------------|
|                    | EPB | RH | EPB | CH_4 |
| Cycle efficiency, \( \eta_{\text{circle}} \) (%) | 30 | 30 | 45 | 45 |
| Turbine efficiency, \( \eta_{\text{turbine}} \) (%) | 90 | 90 | 90 | 90 |
| Heat transfer efficiency of boiler, \( \eta_{\text{boiler}} \) (%) | 85 | 85 | 85 | 85 |
| Combustion efficiency, \( \eta_{\text{combustion}} \) (%) | 95 | 95 | 95 | 95 |
| Calorific value, \( C_v \) (kg/kJ) | 16960.0 | 14700.0 | 19500.0 | 55178.2 |
| Mass of feedstock, \( m \) (kg) | 900 | 900 | 896 | 896 |

In this study, the same equation is utilised to calculate the power produced from the turbine for both EPB and RH with a little alteration of feeding mass value to 900 kg/hr.
a) EPB
Turbine shaft power = 0.924 MW

b) RH
Turbine shaft power = 0.801 MW

Overall, the result obtained from this study shows a significant variance in the turbine output for both EPB and RH in comparison with the previous study’s result. It is proven that the turbine output power was basically inter-related with the HHV of the biomass feedstock, existing studies have used EPB with the HHV of 19500 kg/kJ [18] which is approximately 13.03% and 24.62% higher than the current HHV values of both EPB and RH used in this research paper. In addition, EPB exhibits more turbine power of 13.31% than the RH with the constant parameters as depicted in Table 4. Figure 4 and Table 5 illustrate the comparison of turbine power with the current fuel of EPB and RH referring to Nnaemeka Sp et al. [18] output for different feeding rate. The study has revealed that EPB and RH produce almost one-third and one-fourth power of what a CH$_4$ gas could produce from previous study with the same amount of fuel feeding. On the contrary, the air to fuel ratios of RH is significantly lesser than the EPB or CH$_4$ needed for full combustion to take place. In RH combustion, only 6.16kg air is needed to burn 1 kg of fuel as due to the higher oxygen in the fuel molecular structure which contributed in the completion of the burning process.

Table 5. Power generated based on the feeding rate EPB, RH and CH4.

| Feeding rate, (kg/hr) | Power generator, kW |
|----------------------|---------------------|
|                      | Current Feedstock   | Nnaemeka Sp et al. [18] |
|                      | EPB (1)  | RH         | EPB (2)  | CH$_4$   |
| 100                  | 154.07  | 133.54     | 187.57   | 511.51   |
| 200                  | 308.14  | 267.08     | 375.13   | 1023.02  |
| 300                  | 462.21  | 400.62     | 562.70   | 1514.52  |
| 400                  | 616.28  | 534.16     | 750.26   | 2046.03  |
| 500                  | 770.36  | 667.70     | 937.83   | 2557.54  |
| 600                  | 924.43  | 801.24     | 1125.40  | 3069.05  |
| 700                  | 1078.50 | 934.78     | 1312.90  | 3580.60  |
| 800                  | 1232.57 | 1068.32    | 1500.52  | 4092.06  |
| 900                  | 1386.64 | 1201.86    | 1688.10  | 4603.60  |
6. Conclusions
The research study has reached its objective. The usage of EPB and RH has been an ideal and sustainable replacement as biofuel in a biomass boiler. Overall, the study has proven to produce about 33% and 25% of energy from EPB and RH of what a methane (CH\textsubscript{4}) can produce from the same amount of feeding rate, respectively, with EPB producing 13.31% of higher turbine power than RH. This directly contributes to the technical feasibility and adaptability of environmentally friendly elements by seizing the opportunity of carbon emission of conventional fuel and replacing it with natural resources such as EPB and RH which are part of the biomass fuel replacement regime. EPB and RH have abundant availability, lower emission rate and produces new employment opportunity in the bioenergy field. Malaysia has abundant natural resources such as palm oil waste, rice mill waste, coffee waste and others which can be utilised in many ways to produce valuable energy for electricity generation. Most of these biomass materials were left unattended on the mills or even on the production land which cause a lot of environmental defects in the form of landfill gaseous which are twenty times more dangerous than the conventional fuel emission. However, biomass fuels are always abandoned due to several reasons behind its inefficiency of being a boiler feedstock such as low bulk density, higher water absorption, low heating value and high transportation cost. Technically, these above-mentioned issues can be catered through several pre-processing methods such as pyrolysis, hydrothermal carbonization, torrefaction, and densification.

7. References
[1] Ari Kahan. Global electricity consumption continues to rise faster than population - Today in Energy - U.S. Energy Information Administration(EIA) [updated 2020 June 15; cited 2021 Aug 15]. Available from: https://www.eia.gov.todayinenergy/detail.php?id=44095
[2] Department of Economic and Social Affairs Population Division World Population Prospects 2019: Highlights(ST/ESA/SER./423)2019 [updated 2019; cited 2021 Aug 15]. Available from: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf.
[3] Department of Statistics Malaysia Official Portal 2020 [updated 2020 July 15; cited 2021 Aug 15]. Available from: https://www.dosm.gov.my/v1/index.php?r=columeByCat&cat=155&bul_id=OVByWig5YkQ3MWFZRTN5bDjiaEvhZz09&menu_id=L0pheU43NWJwRWVnSklWdzQ4ThUtt09
[4] Statistics - Malaysia Energy Information Hub [updated 2021; cited 2021 Aug 15]. Available from: https://meih.st.gov.my/statistics?p_auth=bLMkSA0&p_p_id=Eng_Statistic_WAR_ST OASPublicPortlet&p_p_lifecycle=1&p_p_state=maximized&p_p_mode=view&p_p_col_id =column-.
Putrajaya, Malaysia, 2018 [updated 2018; cited 2021 Aug 15]. Available from: https://www.st.gov.my

[6] FAOSTAT: Production/Yield quantities of Rice, paddy in World + (Total) Food and Agriculture Organization of the United Nations [updated 2019; cited 2021 Aug 15]. Available from: http://www.fao.org/faostat/en/#data/QC/visualize.

[7] Lim J S, Abdul Manan Z, Wan Alwi S R, Hashim H 2012 A review on utilisation of biomass from rice industry as a source of renewable energy Renew. Sustain. Energy Rev. 16 3084–3094

[8] Kadam K L, Forrest L H, Jacobson W A 2000 Rice straw as a lignocellulosic resource: Collection, processing, transportation, and environmental aspects Biomass and Bioenergy 18 369–389

[9] Junpen A, Pansuk J, Cheewaphongphan P, Garivait S 2018 Emission of air pollutants from rice residue open burning in Thailand, 2018 Atmosphere. 9 449

[10] Kadam K L, Forrest L H, Jacobson W A 2000 Rice straw as a lignocellulosic resource: Collection, processing, transportation, and environmental aspects Biomass and Bioenergy 18 369–389

[11] Mahlia S M 2015 Paddy residue based power generation in Malaysia: Environmental assessment using LCA approach ARPN J. Eng. Appl. Sci. 10 1–6.

[12] Rajput R K 2010 Thermal Engineering (8th Edition) (S.Chand & Company Limited, 7361, Ram Nagar, New Delhi) chapter 19 pp 802–890

Acknowledgments
The authors would like to thank Universiti Teknologi Petronas (UTP) for the academic advice and space given for this study.