Energy Template

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EFB is a byproduct of the palm oil production process and has recently been used as a power plant fuel. In general, the water content of un-dried EFB is very high, 60-70%, for use as fuel for power plants. The use of high water content EFB as a fuel for the plant reduces the efficiency of the boiler and therefore the drying process is essential. Drying increases the heating value and boiler efficiency, but it is a trade-off relationship that consumes both cost and energy. It is therefore important to dry properly. The purpose of this study is to model an EFB 10 MW power plant that integrates economic feasibility studies to find optimal drying conditions. A hot air dryer was used to utilize steam from the power plant. The water content of the dried EFB could be the same under different conditions. (Optimum drying condition is more suitable for describing trade-off relationship than optimal term.) Optimum drying condition was when steam reuse ratio was 25%, drying time was 22 minutes and water content was 9.79% at optimum point . The cost was reduced by 5.75% compared to non drying.

 **1. Introduction**

Using biomass as fuel for power plants is well accepted by many countries due to fossil fuel depletion and global warming. Indonesia, one of them, plans to reduce the proportion of fossil fuel power plants by 2025 and increase the proportion of biomass power plants. **[References]** As a fuel for power plants, various types of biomass such as wood, grain, and MSW(Municipal Solid Wastes) will be used. EFB(Empty Fruit Bunch), a kind of biomass, which occurs in palm oil production in Indonesia, seems to be the most suitable fuel. Because Indonesia is the largest producer of palm oil, it produces a large amount of EFB. Therefore, fuel prices are lower than other biomass, and it is easy to supply and secure fuel continuously. However, not all the EFB is suitable as fuel for power plants except when properly dried. Moisture content of biomass like EFB is typically 60%-70%. **[Reference]** this highly moisture content causes many problem such as lowering combustion temperature and stability of burning, higher CO and VOC emissions, difficulty of boiler operation. In addition the boiler efficiency is reduced by increasing the heat loss of the boiler such as flue gas loss, chemical unburned carbon loss, and mechanical unburned carbon loss. **[Reference]**

Having multiple disadvantages using raw-biomass as fuel for power plant can be solved by removing moisture from biomass. Drying method is broadly divided into mechanical drying and thermal drying. Mechanical drying methods can reduce moisture by up to 50 wt% through shredding, grinding, pressing and filtering. Thermal drying with direct or indirect dryer is used to lower the moisture to less than 50 wt%. Thermal drying requires large energy and cost because moisture have high specific heat. Recently drying processes have been integrated with power plants to increase energy efficiency and reduce costs. To dry the feedstock directly or indirectly, the waste heat and steam discarded from the plant are used appropriately.

The lower the moisture content of the biomass, the higher heating value and the boiler efficiency, but the energy and cost required for drying also increase. So it is important that determination of optimum drying level by trade-off among higher heating value of biomass, boiler efficiency, energy input and dryer cost. In many literature, the optimum moisture content of biomass is 10-20%. **[References]** Gebreegziabher et al. Studied the trade-off between drying level, dryer cost, energy consumption and boiler efficiency, When the heating value is limited to 15 MJ / kG (moisture content 17%), the operating conditions are mainly focused on drying temperature and particle size. Few discussions on how to obtain the optimum moisture content in a true sense. In this study, we have modeled a 10-MW EFB power plant incorporating economic evaluation. Through the process model, optimal drying conditions and optimal moisture content were determined by considering operating conditions such as drying temperature, drying time, and steam recirculation ratio. Even if the moisture content of the dried EFB was the same, the efficiencies could be different if they were reached under different drying conditions.

**2 Process flow diagram description**

A 10-MW small-scale biomass power plant under construction in Indonesia was simulated. The overall process consists of a shredding process, a drying process, a boiler, and a steam cycle (Figure 1). The amount of dried EFB to generate 10-MW will be less than raw-EFB, since the dried EFB increase the heating value and boiler efficiency. In other words, simulation was designed to vary the amount of EFB to 10-MW power generation. The process flow proceeds as follows.

1. EFB of 60% moisture content is finely crushed by shredder to 5mm size, Moisture content is lowered to 48%. EFB at 48% moisture content enters the hot air rotary dryer.

2. The air entering the rotary dryer rises the temperature by heat exchange with part of the steam coming out of the turbine. The heated air comes into direct contact with the EFB and the inside of the dryer, and moisture is evaporated through the material and heat exchange, reducing the moisture content of the EFB to 20%. Air and EFB are supposed to ideally mix well. The steam(191 ° C, 12atm) used for drying is fully condensed (188 ° C, 12atm) after preheating the air and the condensed water enters the Boiled Feed Water Tank (BFWT) to preheat the water.

3. The dried EFB enters the boiler and burns and the flue gas is discharged at 200 degrees Celsius. The heat generated by the burning of the EFB results in a steam of 433 degrees Celsius 60 atm.

4. The high-temperature and high-pressure steam is discharged at 0.107 atm after turning the turbine and produces 10 MW of electricity. A portion of the steam coming out of the turbine extraction valve is used for drying. The VLP discharged at 0.107atm recirculates the steam cycle when it is fully condensed by the condenser.

2.1 properties of EFB

As the results of industrial and elemental analyzes are required to model the biomass combustion reaction in Aspen Plus, industrial and elemental analyzes were conducted on EFB. (Fig. 2) If we know the water content of EFB and the high calorific value at that time, The high calorific value according to the water content can be estimated by AspenPlus (Figure 3) Estimation of the high calorific value according to the remaining water content using AspenPlus is very similar to the experimental value. Also, when the constant water content is exceeded, black out area where EFB does not burn occurs. [Consider the quotation]

3. **Process model**

The drying process consists of a direct dryer and an air heater. The material and energy balance for the following units are given below.

3.1.1 Dryer model

The dryer can be classified into co-current and counter-current types depending on the direction in which the solid and air flow. A counter-current dryer can achieve a solid with a lower moisture content. However, when the dryer operates at high temperatures, the driest solids contact the hottest air, which can cause a fire if the solids are flammable. So, co-current dryer was selected in this study because biomass generally has a risk of fire. In the dryer, the solid and hot air are in direct contact with each other, and the water of the solid moves to the air due to the transfer phenomenon. The evaporation process requires a large amount of energy because moisture has a high specific heat. The material and energy balance were calculated assuming that the dryer was in a steady state. Eq. (4) represents the material balance of water with respect to the solid, and Eq. (5) represents the material balance for air. Eq. (4) and Eq. (5) gives a material balance equation for moisture. [Reference] Eqs. (6) to (9) show the energy balance. By integrating the following Eqs (1) ~ (12), the moisture content and temperature can be calculated as the air and solids leave the dryer. If there is a difference from the conventional equation, we have to arbitrarily specify the difference between the outlet temperature of the solid and the air to calculate the material and energy balance. However, if you know Q and the drying rate, the equation below calculates the solid and air outlet temperatures, energy and material balance by Aspen Plus. [Picture presentation]

3.2 Drying kinetics

By modeling the drying curve, the limiting moisture content, the equilibrium moisture content and the heat and mass transfer coefficient for EFB in the drying kinetics, Q and the drying rate can be known and the energy consumption required for EFB drying can be predicted.

3.2.1 Drying curve

The drying process goes through several stages of drying. First, the solid is heated by a heat source like hot air. Then the moisture on the surface of the solid is evaporated, which is called the constant rate drying period. The drying rate is also the same regardless of the material if the drying conditions are the same because the moisture on the surface of the material evaporates. When the moisture on the surface of the material is removed, the moisture inside the solid is evaporated. This period is called the falling rate drying period, and the point at which the rate changes from the constant rate drying period to the falling rate drying period is called the critical moisture content. When drying continues, the moisture of the dry air equilibrates with the moisture of the solid and no more moisture evaporates. This point is called the equilibrium moisture content. Since the particle structure inside the material affects the drying rate during the falling rate drying period, the material has different drying curves in the falling rate drying period. In order to more accurately predict the evaporative behavior of EFB, we reflected a falling rate drying curve for the EFB on Aspen Plus.

The critical moisture content depends not only on the material and shape but also on velocity and temperature of the drying air. Since many factors affect the critical moisture content, we used the mean value of the critical moisture content shown in Table. The equilibrium moisture content is influenced by relative humidity and temperature of surrounding air. The equilibrium moisture content is usually close to zero at high temperatures and relative humidity.

3.2.2 Convective heat and mass transfer coefficient

Heat and mass transfer coefficient is calculated by using Eqs. (14) and (15).

to calculate Lewis, Schmidt and Reynolds number are obtained through stream analysis of Aspen Plus. The diameter L in the original mass transfer coefficient and Reynolds number equation was replaced by the sauter mean diameter and the median particle diameter of EFB, respectively. As shown in Eqs. (14) ~ (21), it can be seen that the heat, mass transfer coefficient and evaporation are better at higher drying temperature, velocity and smaller particle size. The air velocity in the dryer was typically 0.5 m / s to 1.5 m / s, and the mean value was used to calculate the Reynolds number.

3.6 Net power generation

Net power generation is to subtract work consumed by pump, blower from work produced by turbine.

3.7 Integration of economic evaluation

Since the equipment cost is influenced by various factors such as usage, capacity, and materials, it is necessary to roughly estimate the equipment cost using equation. Total capital investment in the power plant neglected labor costs, installation costs, transportation costs, and pipeline installation costs except for some equipment costs. The equipment cost only considers devices such as Dryer, Shredder, and Furnace that are affected by the amount of EFB. Turbines are not considered because they are the same at 10 MW power generation, and detailed things like a pump blowers are ignored. The year in which the equipment cost estimate for dryers and shredders was developed was 2003 and the furnace was developed in 2002. Eqs 28 ~ 30 reflect the cost index in 2017.

3.7.1 Dryer cost

The cost of the dryer is affected by the area. Knowing the mass flow rate and drying time of the EFB, before estimating the dryer area, can estimate the volume of the dryer. It is assumed that the volume occupied by the EFB in the dryer is 20% and the density of the EFB is 500 kg / m3. If the EFB does not shrink during the drying process, the volume occupied by the EFB in the dryer is Eq. 24.

When the dryer operates at a load of 20%, the volume of the dryer is calculated by Eq. 25. The L / D ratio of the dryer should be known to determine the area of the dryer. Typical rotary dryers have an L / D ratio of 4-10. The L / D ratio was selected as the average value of 7. The diameter of the dryer can be expressed in equation of volume like Eq. (26), and then the area is calculated by Eq. (27) [dryer cost]

3.7.2 Shredder cost

The shredder which can be crushed by 5mm size is hammer mill. The hammer mill is related to the mass flow rate of the EFB and the equipment cost is estimated Eq. 28

3.7.3 Furnace cost

Ignoring detailed cost such as piping, steam drum, soot blower, fan, deaerator, and pump included in the boiler, only combustion was considered. The furnace cost is varied by the heat transfer rate and can be estimated by Eq. (30).

In this study, we only considered the fuel cost of EFB including the transportation cost of EFB as the operating cost except maintenance, labor, drug, and reprocessing costs necessary to operate the remaining power plants. EFB fuel cost is $ 14.08 / ton.

**4. Objective function**

Considering depreciation as 20 years of life for a typical power plant, annual equipment cost is estimated as Eq. (31). Annual operating costs are calculated by Eq. (32) that multiplies the EFB fuel cost by the annual usage. The objective function was to minimize the annual total cost (AC) that annual equipment costs plus annual operating costs.

Depreciation cost =

Annual working expenditure = 14.08$/ton\*(annual usage)

AC = Depreciation cost + Annual working expenditure

**5. Results**

A case study was conducted by changing the steam recirculation ratio and drying time to find the optimum point. In all cases, EFB of 60% moisture content was applied by shredder to the condition that the particle size was 5mm and moisture content was 48%. When the EFB from the shredder is not dried, the base case is set to produce 10 MW of power.

5.1 Case study result except economic evaluation

Case study, without consideration of capital cost and operating cost, only compared fuel consumption for the same 10MW power generation. The results for the case study are shown in Table. 3. Figure 4 shows a three-dimensional graph of fuel consumption for the same power generation of 10 MW when the steam recirculation ratio is varied from 0 to 0.9 and the drying time is varied from 1 to 60 minutes. In the base case, the hot air mass flow rate is zero. This is because the steam recirculation ratio used for drying is zero. And to produce 10MW electric power, EFB of 60% moisture content was demanded 19,851kg / hr. The amount of EFB from the shredder was 15,270 kg / hr. Even without the energy used in the drying process, the amount of work required to operate the steam cycle was 95 kW. In case 1, 2 and 3, the change of the parameter value according to the steam recirculation ratio was compared at the same drying time, and in case 4, 5 and 6, the parameter values according to the drying time change were compared at the same ratio. Table. 3, the relative efficiency is the difference between the fuel consumption of the base and the other case. In cases 1, 2 and 3, the efficiency increases gradually as the ratio increases. In case 2, the efficiency becomes maximum at 8.15%. After Case 2, the efficiency decreases gradually and becomes -0.63% lower than Case 3 without drying. In other words, Case 3 uses too much steam for drying. Comparing Case 4, 5, and 6, it can be seen that efficiency increases as the drying time becomes longer. Because it can evaporate moisture from the EFB without additional energy consumption until the relative humidity of the air reaches 99%. Therefore, in the three-dimensional graph of figure 4, the point with the lowest fuel consumption was at the point where the drying time was 60 minutes and the steam recirculation ratio was 0.26. However, since the increase in drying time is much greater than the amount of EFB fuel reduction after a certain point, the cost of the dryer will increase as a result. The other change is that the longer the drying time, the smaller the difference between the EFB and the outlet temperature of the air.

5.2 Case study result including economic evaluation

We have conducted a case study to reflect the equipment and operation costs and compared it with the drying process which power plant currently being constructed in Indonesia. This drying process reduce moisture content of EFB from 48% to 20%. figure. 5 is the objective function graph for ratio and time. The point at which the objective function represents the smallest value is the optimal point. In the optimal point, the steam recirculation ratio, drying time, and moisture content of the dried EFB were 0.25, 22 min, and 9.79%, respectively. Although there were a little differences according to the drying time, most of the cases with steam recirculation ratio above 0.38 were not feasible to dry. The yellow dot in figure 5 shows the points where the moisture content of the dried EFB is 20%. Among them, the red and green dots represent the worst and the best conditions, respectively, which can reach a moisture content of 20%. The black dot represents the best condition among the conditions that can reach the moisture content of 15, 25, 30, and 35%, and the blue dot is the minimum value of objective function. Table 4 shows the data for each point. The moisture content of Case 1,6 was almost the same moisture content under different conditions, but showed a large difference in the cost savings. It does not matter how much moisture is dried, and it is important to know how to dry it. Cases 1, 2, 3, 4, and 5 select the best drying conditions at each moisture content. In terms of water efficiency, 9.79% EFB is the most cost-effective, but it does not show any significant difference in cost savings even when using EFB, which is 10-20%, as fuel for the power plant. From 20% or more, it can be seen that the difference in the cost saving rate becomes so large that it can not be ignored.

**6. Conclusion**

The EFB 10MW power plant process model created by Aspen Plus was used to optimize drying process operation. The model also considers the drying kinetics and material balance and energy balance of the dryer depending on the material properties of EFB. The model balanced the balance between steam, drying time, capital investment and operating costs used for drying. The optimal drying conditions were found to be 25, 22min, and 9.79%, respectively. Also the objective function graph shows that the same moisture content can be obtained, it can be seen that the cost savings can be different if the drying condition are different. This indicates that how to dry it is more important than how much to dry it. Another observation is that it was an optimal point when the water content was 9.79%, but there is no big difference between drying and 15 ~ 20%. so