Effects of Moisture Content in Simulated Bagasse by Equilibrium Analysis

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Abstract

Bagasse is an alternative fuel which is often used as a primary source to generate steam for sugar milling and electricity generation in sugar factories. It consists of cellulose, hemicellulose, lignin, ash and moisture content. As bagasse moisture content increases, greater combustion is obtained. Thus, the bagasse moisture content is an important parameter to control combustion in boilers. Simulated bagasse was used to monitor the effects of moisture content on gross calorific value (GCV) and net calorific value (NCV), water evaporation load, adiabatic flame temperature (AFT) and equilibrium analysis. In this paper, the moisture content in simulated bagasse is varied from 45 to 70%, which is to be expected in a typical sugar mill boiler. With increased bagasse moisture content, the simulated bagasse compositions, i.e. carbon (C), hydrogen (H) and oxygen (O), are decreased and results in a decrease in GCV, NCV and AFT. However, the water evaporation load increases to about 4% with each 1% increase in simulated bagasse moisture content. From calculating these results, the suggested moisture content in bagasse for a sugar mill boiler should not be more than 56% for stable combustion.

Keywords : Adiabatic flame temperature, Bagasse, Equilibrium analysis, Evaporation, Moisture content.

1. Introduction

As global demand for sugar has increased significantly along with world population, the sugar industry has become particularly important to developing countries such as those in Southeast Asia (including Thailand), Latin America and Africa. For this reason, many of these countries have made efforts to increase sugar productions to meet the increasing demand by improving the performance of production equipment and reducing costs [1]. In the past, bagasse was merely an industrial waste from sugar. Now, sugarcane waste or bagasse is an economically valuable and environmentally friendly biomass which can be used as a renewable petroleum fuel to produce not only electricity but also steam from sugar production process. Bagasse consists of cellulose, hemicellulose, lignin, ash and moisture content. The production process had been operated in the past ongoing until the crisis of energy since 1970. As the crisis continued, the price of petroleum, gas and electricity increased dramatically. Thus bagasse received attention for use as a petroleum replacement fuel with focus on high performance utilization. Many countries enacted policies to promote the production of electricity from biomass fuels in order to decrease climate change (global warming). Many of these countries found that electricity generated from biomass in all forms including bagasse was more efficient than that produced from petroleum. Moreover, bagasse use also produces fewer carbon dioxide emissions than combustion of petroleum fuels. In a previous study [1], 1 kg of crude oil can be replaced with 5.95 kg of bagasse to produce an equal production of steam for a boiler. To improve efficiency of steam boiler fueled with bagasse, the physical and chemical properties of the fuel and boiler working environment were the key factors in boiler design[2]. For these reasons, it was necessary to understand the influence of various parameters which may affect the performance of boiler when used with bagasse fuel. The influence of bagasse moisture content on heating value, grate heat release rate, excess air to boiler evaporation rate ratio, steam to dry fiber ratio and overall boiler efficiency [2], was especially important to study. To calculate the heating value of bagasse, the physical analysis of bagasse composition had been reported as receive or wet basis (wt%) of brix, ash and moisture [3].

In this study, a simulated bagasse is investigated from the dry bagasse in order to study the effect of bagasse moisture content on bagasse composition, calorific value, equilibrium analysis, evaporation of bagasse and adiabatic flame temperature.

2. Methodology

2.1 Dry bagasse

The bagasse simulation is investigated for the influence of moisture content on the composition of simulated bagasse compared to dry bagasse. The elemental analysis of the reference dry bagasse obtained by analytical method [4], is shown in Table.1.

Table.1 Bagasse contents (% dry fuel)

Ultimate analysis	Sugar cane bagasse (% dry fuel)
Carbon	48.64
Hydrogen	5.87
Oxygen (diff.)	42.82
Nitrogen	0.16
Sulfur	0.04
Chlorine	0.03
Ash	2.44
Total	100

2.2 Calorific value

The calorific value of fuel is the heat released per unit mass of fuel at 25°C with completed combustion. Generally, there are two calorific values: a gross calorific value (GCV) and a net calorific value (NCV). The GCV is the total energy released during the combustion process and can be accurately measured by using a bomb calorimeter. The NCV is the GCV without the latent heat of the water formed by the combustion process [5]. However, both calorific values are also obtained by calculation derived from experiment and method of calculation laid down in ISO1928 [6]. Calculation of the fiber content results in an equation for the GCV and NCV of bagasse as a function of the moisture (M), brix (B) and ash (A) shown in eqs. (1)-(2).

$$GCV=19{,}605-196.05\times M-31.14\times B-196.05\times A \quad \frac{kJ}{kg} \qquad (1)$$

$$NCV=18{,}260-207.15\times M-31.14\times B-182.60\times A \quad \frac{kJ}{kg} \qquad (2)$$

2.3 Evaporation load of bagasse combustion

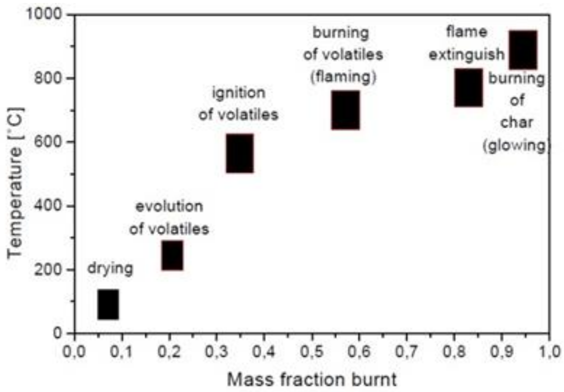

Fig. 1 Bagasse combustion mechanism [7].

The bagasse combustion mechanism (Fig.1) starts with bagasse drying and a portion of the bagasse combustion entered previously to use latent heat for water evaporation. Bagasse was then experienced as an evolution of volatiles, ignition of volatiles, burning of volatiles and turned off as the flame was extinguished, followed by the burning of solid carbon residue as burning of char. As this mechanism proceeded, the higher the moisture content, the greater latent heat was required to evaporate water in bagasse as evaporation load. The evaporation load shown in eq. (3), is the ratio between the mass of moisture or latent heat of water contained in 1 kg of bagasse and the mass of the ash free fiber.

$$\text{Evaporation load of bagasse} = \frac{\text{Moisture (\%)}}{\text{Ash free fiber (\%)}} \qquad (3)$$

2.4 Equilibrium analysis

In this study, we focus on chemical equilibrium analyzed by the single step irreversible completed combustion with the proposed empirical formula of bagasse as shown in eq. (4).

$$C_wH_xO_y+(1+EA)K(O_2+3.76N_2)$$

$$\longrightarrow wCO_2+LH_2O+(EA)O_2+(1+EA)(3.76)KN_2 \qquad (4)$$

2.5 Adiabatic flame temperature

Generally, the reaction temperatures are controlled either by the addition or removal of heat. This is due to conflicting demands from kinetic and thermodynamic considerations. When a temperature control is provided, the reaction becomes non-adiabatic. Oxidation reactions are practically irreversible, hence they can be carried out without the control of temperature. When the fuel is burned, the adiabatic reaction temperature is called the adiabatic flame temperature because it represents flame temperature [8]. In this case, it is possible to develop an empirical relation for the heat of reaction at T K using the empirical equation for heat capacity as eqs. (5)-(6) [8].

$$\Delta H_1 = \int_{T_0}^{T_1} \Big(\sum n_i . C^0_{mpi}\Big)_{Reactants} dT \qquad (5)$$

$$\Delta H_2 = \int_{T_0}^{T_2} \Big(\sum n_i . C^0_{mpi}\Big)_{Products} dT \qquad (6)$$

3. Results and Discussion

3.1 Effect of moisture content on bagasse composition

Table. 1 shows the composition of dry bagasse as C=48.64%, H=5.87%, O=42.82%, N=0.16%, S=0.04%, Cl=0.03% and Ash=2.44%. When moisture is added into the dry bagasse, the bagasse compositions are changed. For this reason, the obtained simulated bagasse is a method for bagasse composition prediction which is composed of elements including ash. The composition of simulated bagasse at varying moisture contents is shown in Fig. 2. The results show that each 1% increase in moisture content results in a decrease of C and O in bagasse of 0.43% and 0.49%, respectively while N, S and Cl are very slightly changed. For comparison, the composition of actual bagasse with moisture contents of 53.0%, 53.8% and 52.0% are also plotted. This indicates a similar composition of C, H, O, N and ash to the simulated bagasse (Fig. 3). Consequently, the simulated bagasse can be used to represent the actual bagasse to predict calorific values with high accuracy.

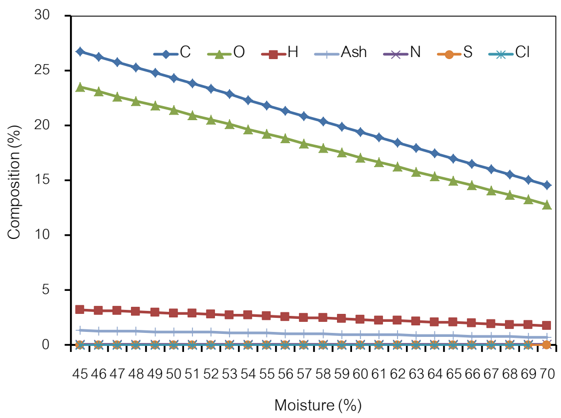

Fig. 2 Effect of bagasse moisture content on composition.

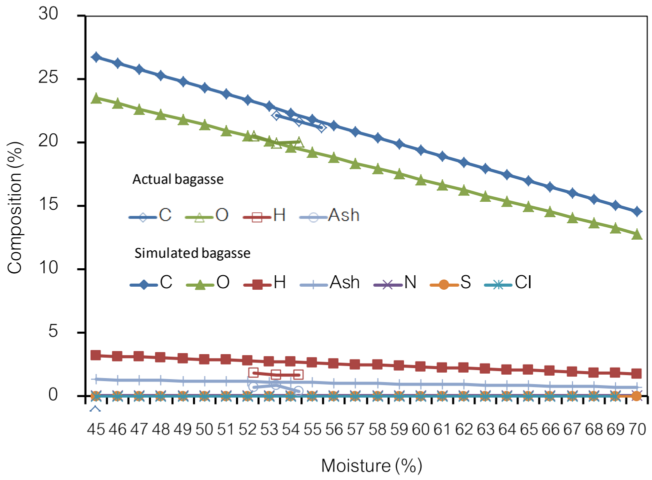

Fig. 3 Comparison between simulated bagasse and actual bagasse composition.

3.2 Effect of bagasse moisture content on calorific value

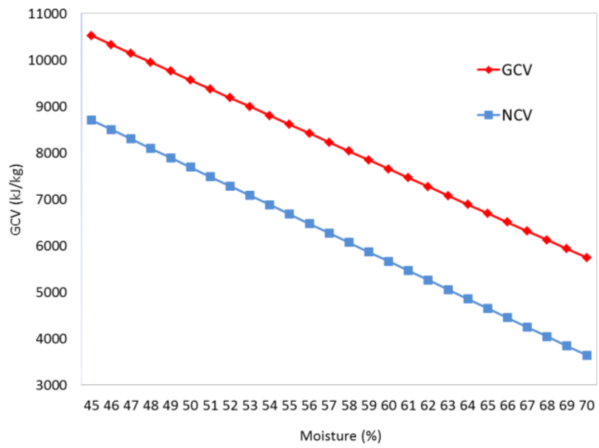

Fig. 4 Effect of bagasse moisture content on GCV and NCV.

When bagasse moisture content increases, the calorific values decrease. This is because the calorific values depend on moisture, brix, and ash as shown in eqs. (1)-(2), thus the calorific values GCV and NCV decrease, due to the increased moisture content (Fig. 4).

3.3 Effect of bagasse moisture content on combustion

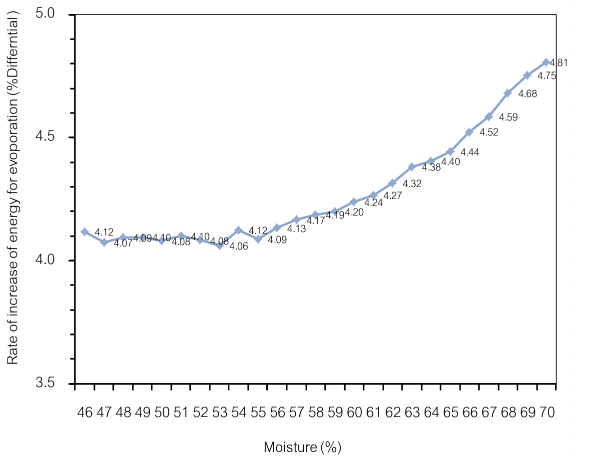

Fig. 5 Effect of bagasse moisture content on energy for evaporation (% Differential).

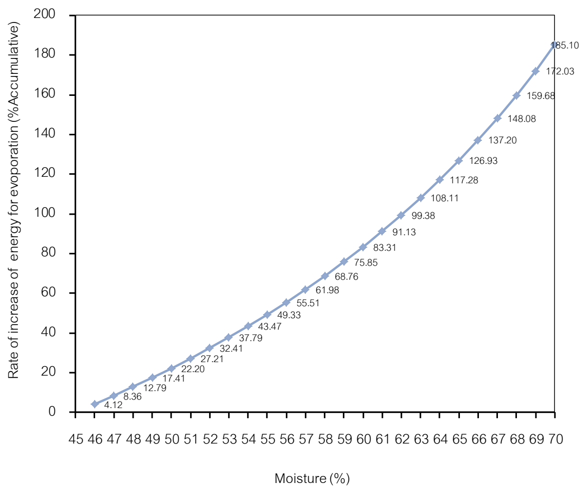

Fig. 6 Effect of bagasse moisture content on energy for evaporation (% Accumulative).

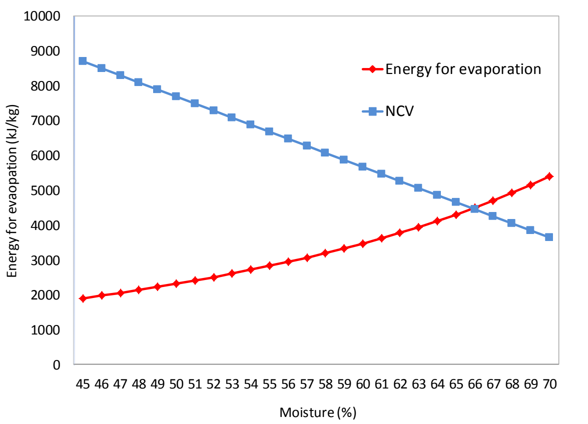

Fig. 7 Effect of bagasse moisture content on NCV and energy for evaporation.

Figs. 5-6 show the influence of moisture between 45% and 70% on the evaporation rate for simulated bagasse as differential and accumulative variation, respectively. The results show that every 1% increase in moisture results in approximately 4.1% constant rate increase in, energy used for evaporation. Consistent with the research of of N.Magasiner [9], the rising rate of evaporation is obvious when the moisture content exceeds 56%. Magasiner has studied the effects of moisture content in bagasse varying from 0 to 56% on the performance of boilers and has suggested that they should not be operated at higher moisture content due to unstable combustion with severe temperature fluctuation above the grate. This is caused by a decrease of sensible heat to dry the fiber owing to increasing moisture content. Fig. 7 shows the effect of bagasse moisture content on NCV and energy for evaporation. When bagasse moisture content increases, NCV gradually decreases but the latent heat of evaporation increases until and they become equal to each other at 66%. This means that the total amount of heat available from bagasse is used only for evaporation taking place at 66% of bagasse moisture content.

3.4 Effect of bagasse moisture content on equilibrium analysis

Chemical equilibrium is analyzed by a single step irreversible completed combustion with empirical formula of the simulated bagasse. The exhaust gas compositions are changed by varying the bagasse moisture content. Fig. 8 shows the composition of exhaust gas for completed combustion at 30% excess air (EA).

When bagasse moisture content is higher, the composition of H_2O is higher and CO_2, O_2 and N_2 are lower due to a decrease of bagasse fiber ratio.

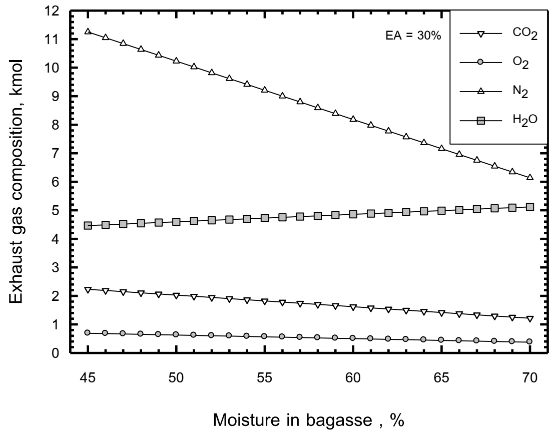

Fig. 8 Effect of bagasse moisture content on exhaust gas compositions. (Completed combustion at 30% of excess air)

3.5 Effect of bagasse moisture content on adiabatic flame temperature (AFT)

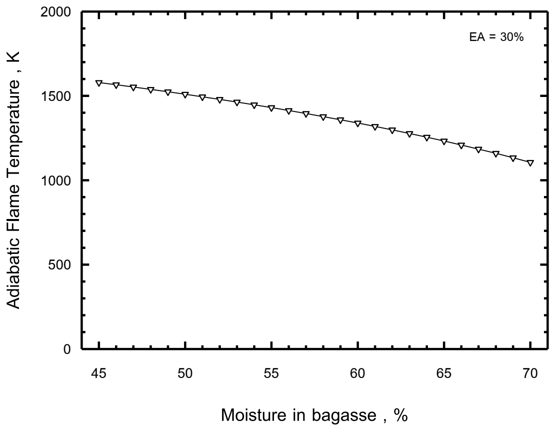

Fig. 9 Effect of bagasse moisture content on adiabatic flame temperature. (30% excess air)

There is an empirical relation for the heat of reaction at AFT using the empirical equation for heat capacity. The composition of simulated bagasse is calculated to examine AFT as illustrated in Fig. 9. This result shows the adiabatic flame temperature gradually decreases when bagasse moisture content increases because most of the heat from combustion is used for evaporation.

4. Conclusions

The results of this study lead to the following conclusions:

4.1 An increase of bagasse moisture content results in the decrease of composition of C and O while N, S and Cl are negligibly changed.

4.2 When bagasse moisture content increases, the calorific values (NCV, GCV) decrease due to the change of bagasse composition.

4.3 With each 1% increase of bagasse moisture content, energy used for evaporation increases at a constant rate of about 4.1%. The rising rate of evaporation is obvious at bagasse moisture contents exceeding 56%. Boilers should not be operated at bagasse moisture content exceeding 56% due to severe unstable combustion.

4.4 When bagasse moisture content is higher, the composition of H_2O is higher and CO_2, O_2 and N_2 are lower due to decreased bagasse fiber ratio.

4.5 The adiabatic flame temperature gradually decreases when bagasse moisture content increases because most of the heat from bagasse combustion is used for evaporation.

5. References

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