THE MOISTURE EFFECT ON WOOD COMBUSTION IN AN UPDRAFT GASIFIER

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ABSTRACT

This paper studies the fuel moisture content effect on the wood combustion behaviour in the gasifier. The combustion process is evaluated with the variation of fuel's moisture content, i.e. set at 17%, 31%, and 40% respectively. The ignition front rate decreased with increasing fuel moisture content which resulted in slower gasification process in the chamber. The temperature and oxide of nitrogen (NO) concentration are decreased with the increase of the moisture in the fuel. Furthermore, the concentration of carbon monoxide (CO) increases while the change for carbon dioxide (CO_2) and oxygen (O_2) concentrations are only around 1% with the variation of this operating parameter. At highest gasification efficiency of 92.7%, the moisture content of the fuel is best set at 16-17%; giving outlet operating temperature of 500°C and exhaust gas concentrations with 1500 ppm of CO, 2.8% of CO_2, 30 ppm of NO and 17.6% of O_2 respectively.

***KEYWORDS**: Gasification, moisture content, drying, devolatilisation, ignition front rate.*

1.0 INTRODUCTION

Gasification is a thermal conversion technology where the solid fuel is converted to combustible gases under sub-stoichiometric of air. It capables of converting hydrocarbon-based hazardous materials to nonhazardous byproducts. The first commercial gasifier which built up in 1839 is updraft gasifier type with air-blown gasification (Quaak P. *et.al*. 1999).

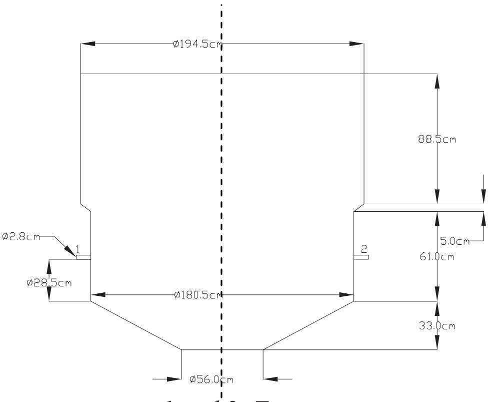
The importance of analyzing the fuel characteristics should be done to meet the gasifier requirement according to some parameters. Desirable moisture content of fuel which is lower than 20% is an advantage to any gasifier. This is due to the lower heat loss for evaporation and this does not affect much on the gasifier's efficiency. However for updraft gasifier, it is suitable to use fuel with moisture content up to 40% but not for using the gases for running engines which normally need clean gases (Goswami, 1986).

2.0 EXPERIMENTAL SET UP

The experimental work comprised of experiment set-up, performance and evaluation of the running test. The experimental works were done at equivalence ratio in the range of 0.19 to 0.43. This range is the equivalence ratio of gasification process (Lucas, 2005) and (Reed, 1981) or the oxygen used is less than 40% of that required for complete combustion (Evan and Milne, 1987) for a typical gasifier. From previous studied the optimum equivalence ratio is 0.3 and 0.26 respectively which run on biomass gasification (Zainal *et.al*., 2002) and (Wu *et.al*., 2003).

2.1 Experimental Equipment

The main equipment in this research is the primary chamber. The combustion of fuel takes place under sub-stoichiometric combustion resulting in the liberation of the combustible gases. Once the combustion starts, the air is supplied from a blower and the combustion would be self sustaining and maintained at temperature about 500 to 800oC. The air is supplied to the primary chamber through the air inlet pipe work having a 5cm in diameter. The liberated gases will then flow through the primary chamber outlet while the left ash and slag left from the primary chamber falls to the bottom of the primary chamber into container and is moved to a storage area. FIGURE 1 shows the schematic view of the primary chamber.



1 and 2: Tuyeres

FIGURE 1 Schematic view of the primary chamber

3.0 RESULTS AND DISCUSSION

3.1 The Effect of Wood Moisture Content

The moisture content of the wood is varied by wetting the wood with water several days before experimental work starts. To get regular moisture content for the whole wood, the wood should be soaked in the water that require a very large bin to soak the large size of wood.

The ignition front velocity is being affected by changing the fuel moisture content. It is a significant factor that shows the velocity of the devolatilization front movement (Yang *et.al.*, 2006). The global ignition speed is defined as the reaction front speed and can be calculated as the ratio between the time lag of Position 1 and Position 4, and the distance between them as in FIGURE 2. This method assumes that the ignition speed is constant along the chamber. The value of temperature is taken at highest temperature gradient (Katunzi, 2006) at 570^{o}C. The ignition front velocity at moisture content of 17 %, 30.8 % and 40 % are 2.82 cms^{-1}, 2.58 cms^{-1} and 0.33 cms^{-1}. The ignition front rate is then defined by multiplication of the ignition front velocity with the density of the fuel (Yang *et.al.*, 2006). It shows a decreasing response with increasing moisture content as in FIGURE 3. Slower ignition front rate due to increasing of fuel moisture contents results in lower moisture evaporation rate and hence causes slower gasification process.

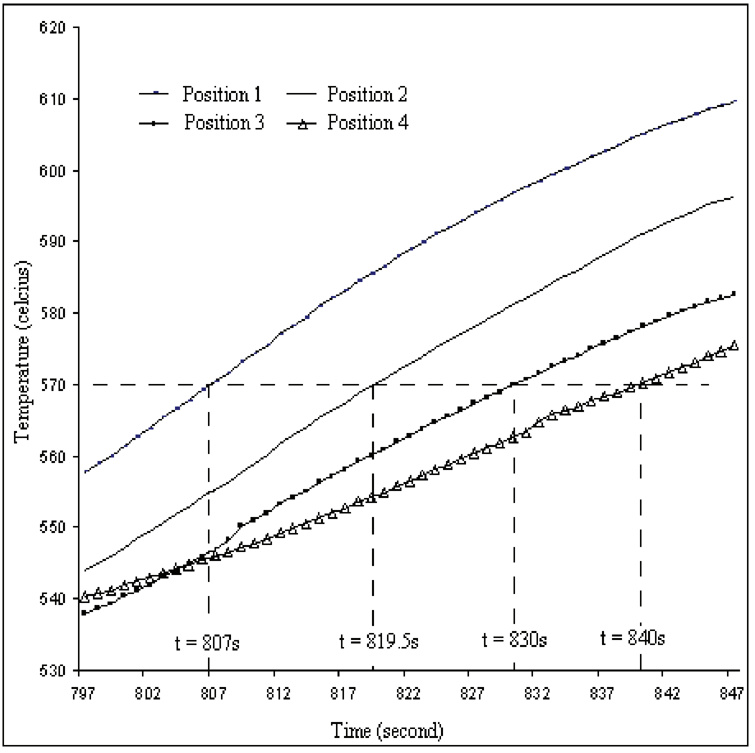


FIGURE 2 The determination of global ignition speed at fuel moisture content of 17°C

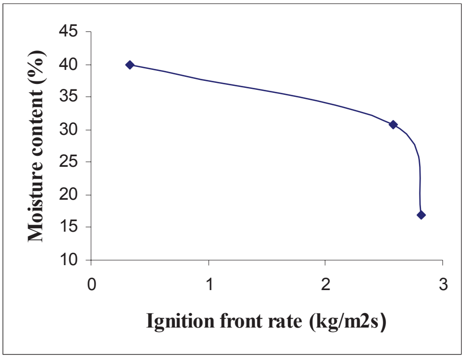


FIGURE 3 Ignition front rate at various moisture contents

The effect of various moisture contents on the gas composition at the chamber's outlet is displayed in FIGURE 4. This figure shows the moisture content in the fuel affected the quantity of the gas generated. There are not much different of CO_2 and O_2 pattern in increasing of moisture content. However, a clear different is observed on both CO and NO pattern. Increment in CO is observed while NO showed a reverse trend with decreasing in value.

A greater yield amount of CO is observed by 20% from 1500 ppm to 1800 ppm with moisture content increment in between 17% to 40.8%. This is due to the favourable of exothermic reaction; water-gas reaction $(C + H_2O \leftrightarrow O \quad + H_2)$ (Sheth and Babu, 2005) and (Lucas *et.al*., 2004). At higher temperature, this reaction tends to shift to the reactants where the compositions of C and H_2O become dominant. Apart from that, the conversion to CO2 and H2 more dominant at lower temperature (Bustamante F., 2004).

Measured CO_2 increased from 2.8% to 4% and decreased to 2.1% at 40.8% moisture content. CO_2 is produced during water gas shift reaction at the expense of CO and H_2 (Bhattacharya and Dutta, 1999) while NO decreased by 33.3% from 30 ppm to 20 ppm.

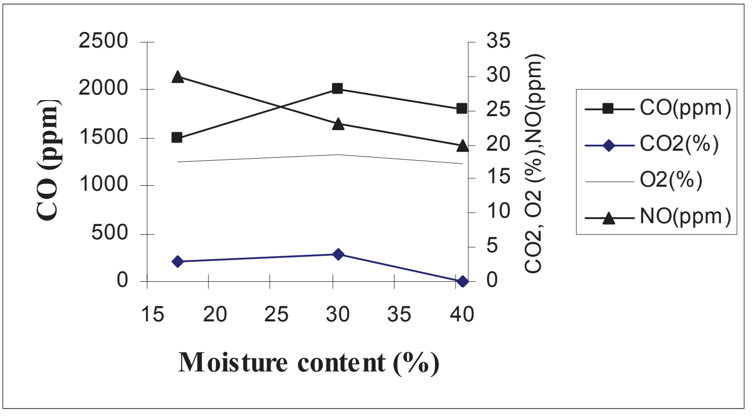


FIGURE 4 Gas compositions at various moisture contents

The effect of fuel moisture content on some heat losses during the experimental works can be shown as in FIGURE 5. These heat losses are referred to heat losses due to dry gas, heat losses due to the moisture in the fuel, heat losses due to CO formation and water formation.

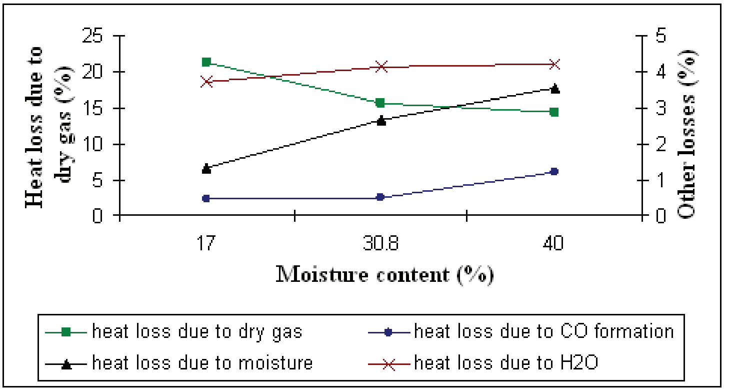


FIGURE 5 Heat losses due to the moisture content (%) in the fuel

The highest loss is indicated by heat loss due to dry gas which accounted in between 15% to 23%. This loss is more affected by the temperature difference between the flue gases and the air inlet. Higher temperature difference in a drier fuel leads to higher loss in dry gas. In this study, the dry gas loss cannot be avoided and however will be recovered in thermal reactor which needs higher operation up to 1200°C. This higher heat will help in reducing the fuel sources in thermal reactor. Hence, this loss is not included in the total loss of the system.

Besides, the combustion of hydrogen content in the fuel caused a heat loss due to the water formation or heat loss due to H_2O. This loss accounted for only 1% of the total heat loss from the system. Heat loss due to H_2O increased for higher moisture content as in Figure 5.9 due to higher content of hydrogen in the wetter fuel.

Furthermore, more heat is used to evaporate the moisture in the fuel. This occurred when the water goes phase changes form water to vapour and it absorbs energy. This condition leads to heat loss due to moisture in the fuel. FIGURE 5 shows that this heat loss increases for fuel with higher moisture content. Meanwhile, the heat loss due to CO formation increases with higher moisture content. The oxidation of carbon will generate the CO and then CO_2. Insufficient of O_2 causes the reaction to stop at CO formation and some energy is lost.

Moreover, the NO behaviour seems to decrease with the increase of moisture content. NO is very much dependent on the temperature. The higher moisture content causes decreasing in temperature and this affect the NO as illustrated in FIGURE 6 and 7.

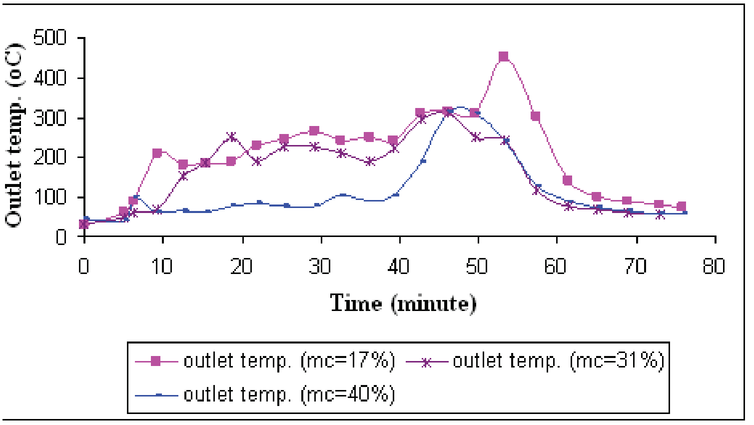


FIGURE 6 Variation of outlet temperature (°C) due to moisture content (%)

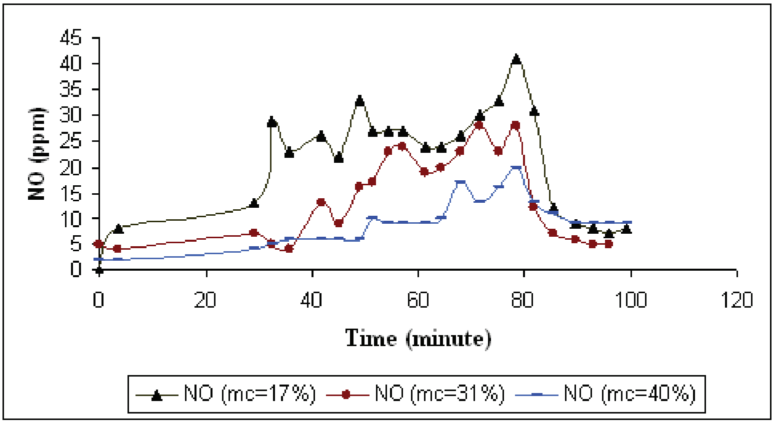


FIGURE 7 Variation of NO (ppm) due to moisture content (%)

5.5 Gasification Efficiency

One of the important factors on a gasifier is the gasification efficiency. The gasification determines the actual technical operation of a gasifier. It also shows how the fuel energy is converted into useful energy effectively in the furnace, boiler or any gasifier. This efficiency should be carefully defined in this study because this efficiency depends on the objective of the gasifier.

In this experiment, this gasifier is used to combust the feedstock rather than to use the producer gas for engine application. The value of gasification system efficiency (mechanical) can be in the range of 60 to 75% whilst the gasification system efficiency (thermal) can be as high as 93% (FAO, 1986).

In this study, the gasification efficiency or thermal efficiency is calculated by considering the heat loss due to some properties below (TSI Inc., 2004).

a) Heat loss due to moisture from burning hydrogen
b) Heat loss due to moisture in fuel
c) Heat loss from the formation of CO

The combustion efficiency is then defined as in equation 5.1.

$$Gasification\ efficiency,\% = 100 - \frac{flue\ heat\ loss\ /\ kg\ \ fuel}{fuel\ heating\ value\ /\ kg\ \ fuel}\ x\,100 \qquad (5.1)$$

The combustion efficiency without considering the heat loss due to the dry gas can be illustrated as in FIGURE 8. The combustion efficiency (%) tends to be decreased with increasing of the moisture content in the fuel. This is due to the decreasing net temperature difference between the outlet temperature and the air inlet temperature for higher moisture content. In addition, some of the heat is used to drive off the water content in the fuel and thus this energy is not available for reduction reactions that require heat. The moisture acts as a heat sink lowered the gasification efficiency.

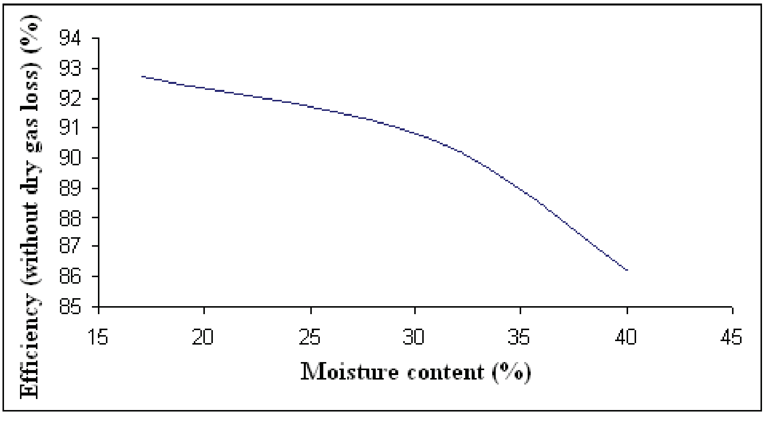


FIGURE 8 Variation of combustion efficiency (%) due to moisture content (%)

Through several experimental works that have been done, some outputs can be observed with changing in the moisture content. The variation in some parameters can be illustrated in table form as in TABLE 1.

TABLE 1 The different operating conditions on some output parameters for Case D, E and F

Case	D	E	F
Wood mass (kg)	50	50	50
Fuel rate (kg/min)	1.25	1.25	1.25
Air supply (l/m)	1300	1300	1300
Moisture content (%)	16.1-17.0	30.8	40.1
Max. axial (flame) temp. (^{o}C)	545	516	384
Outlet temp. (^{o}C)	500	489	321
CO (ppm)	1500	2000	1800
CO_2 (% vol)	2.8	4.0	2.1
O_2 (% vol)	17.6	17.0	18.5
NO (ppm)	30	23	20
Ash (%)	4.8	4.1	2.9
Efficiency (%) without dry gas loss	92.7	90.6	86.2

5.6 Comparison With Other Relevant Works

A comparison of several measured output is done with other relevant work as shown in TABLE 2 for Case A. A far different of gasification efficiency between this study and other relevant works are because some the gasification efficiencies are based on mechanical efficiency where the gasifier is used to produce high quality of energy for further application rather than for direct heating as in this research.

TABLE 2 Comparison of the measured value (through experimental) with other previous works

Fuel rate (kg/min)	2.94	*n.a*
Air supply (l/m)	1300	*n.a*
Moisture content (%)	16.1-17.0	*25* [3]
Equivalence ratio	0.3	*n.a*
Max. axial (flame) temp.(^{o}C)	840	*n.a*
Outlet temp. (^{o}C)	550	601.4 [1]
CO (ppm) (% vol)	1213	223 [1] 34.4 [2], 10-12 [3]
CO_2 (% vol)	6.0	15.4 [1], 48.9 [2], 10-12 [3]
O_2 (% vol)	14.0	4.8 [1],
NO (ppm)	66	58 [4]
CH_4 (% vol)	*n.m*	6% [2],
Ash (%)	2.28	*n.a*
Gasification Efficiency (%) for direct heating (without dry gas loss)	95.53	*n.a*
Gasification Efficiency (%)	*n.a*	76.7 [1], 60 [2], 56-79 [3]

n.m: not measured, n.a: not available

[1] Surjosatyo, 2000; [2] Lee *et.al.*, 2006, [3] Saravanakumar *et.al.*, 2007,

[4] White and Pasket, 1981.

9.0 CONCLUSIONS

This study has several conclusions which are the biomass gasification required air flow rate at 1.3 kg/m3 which corresponded to equivalence ratio of 0.316 and the gasification consumed wood at a rate of 1.67 kg/hr provided maximum gasification of 95.53%. The ignition front rate decreased with increasing fuel moisture content. This resulted in slower gasification process in the chamber. The increasing in fuel moisture content caused the higher heat loss due to moisture (for moisture evaporation), heat loss due to CO and water formation except that there was decrement in heat loss due to dry gas which accounted in between 15% to 23%.

The final conclusion is the effect of fuel quality by changing the moisture content of the wood fuel was found to affect substantially some output of combustion parameters. This included the effect on peak flame temperature, the gas concentration and the gasification efficiency. The increase in moisture content resulted in deterioration in outlet temperature and NO distribution from 500oC to 321oC and from 30 ppm to 20 ppm respectively. Meanwhile, this response accompanied to the increasing of CO concentration from 1500 ppm to 1800 ppm and diminished the overall gasification efficiency for direct heating in between 92.7% to 86.2%. The behaviour of NO was not fully understand which shows lower response in lower outlet temperature since this thermal NOx is insignificant at lower temperature below 1800K.

10.0 ACKNOWLEDGEMENT

I would like to thank both my supervisor and co-supervisor, Prof. Ir. Dr. Azhar Abdul Aziz and Dr. Normah Mohd Ghazali for their very valuable guidance and supporting views.

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