Emissions of A Small-Scale Combustion Unit Utilizing Wheat Straw Pellets As Fuel

Engr. Donnalyn C. Cabaces
Dept of Mechanical/Petroleum
Batangas State University, Philippines

Abstract- *Emission limit values in Germany is based on 1.BImSchV for CO and NO_x are 1000 mg/Nm^3 and 500 mg/Nm^3, respectively and for dust particle emission limit is 100 mg/Nm^3. The objective of this study is to evaluate concentrations of CO, NO_x and dust particle emissions of a small-scale combustion unit with bulk material filter utilizing wheat straw pellets as fuel and compare it with the limits given by law. This is an experimental study of an air-staged combustion unit. Flue gas was measured by Testo gas analyzer and dust emissions was measured gravimetrically according to VDI 2066 by isokinetic sampling. Emission concentrations were calculated and normalized to 13% oxygen level as prescribed by law in Germany. Results show that CO and NO_x concentrations measured at an excess air below 1.6 and at a post combustion temperature higher than 550℃ were below the limits. Dust measurements show that emissions are below the limits given by law.*

Keywords- air-staged combustion, CO, dust emissions, NOx, wheat straw pellets

I. INTRODUCTION

The development and use of renewable energies is one of the priorities of many countries in world. Renewable energy has an important role to play in reducing carbon dioxide (CO_2) emissions. Increasing the share of renewable energy in the energy balance enhances sustainability. It also helps to improve the security of energy supply by reducing the community's growing dependence on imported energy sources. Renewable energy sources are expected to be economically competitive with conventional energy sources in medium to long term.

The annual accumulation of unused wheat straw in agricultural field led to its utilization as fuel. However the ash content of wheatstraw is high, approximately 10 times than that of wood. It has low ash melting point which causes formation of slag in the combustion chamber. A further problem is the high chlorine content of wheat straw which lead to HCl that cause strong corrosion to the heat exchanger. Considering the emission limit values in Germany based on 1.BImSchV for CO, NO_x and dust particle emission, this study evaluates the performance of a small-scale combustion unit utilizing wheatstraw pellets as fuel.

Objectives ofthe Study

The main thrust of this study is to evaluate the CO, NO_x and dust particle emissions of a small-scale combustion utilizing wheat straw pellets as fuel. Specifically, it aims to:

1. Establish the mass flow rate of wheat straw pellets and air-fuel ratio needed for the air-stage combustion;
2. Determine the factors that influence carbon monoxide (CO) and nitrogen oxides (NO_x) emissions;
3. Determine the emission level of the small-scale combustion unit in terms of:
   3.1. CO emissions
   3.2. NO_x emissions
   3.3. dust particle emissions

II. MATERIALS AND METHODS

Description of the Small-Scale Combustion Unit

The small-scale combustion unit consists of different weighing system of the burning material, combustion chamber,post combustion chamber, heat exchanger, primary and secondary air supply, filter, and induced draft blower.

The heart of the weighing system is a load cell. Strain gage type of load cell is used in this system. Wheat straw pellets are fed into a hopper and delivered to the combustion chamber by a screw conveyor controlled by a Simatic Text Panel for the correct running and break timing.The water-cooled combustion chamber is in a form of ladder/stairs with four steps. The wheat straw pellets in the combustion unit is conveyed from first step to the next by means of slider operated by motors. This combustion chamber is water-cooled to prevent slagging due to low ash melting points of straws by lowering the glow bed temperature. Combustion of the burning material occurs in this chamber. In the first step, drying and gasification of the fuel occurs. Combustion is done with primary air only which starts at the second step and is completed in the third step. Cooling of ash is at the last step then to the ash collector. Combustion with primary air supply only results to high CO and NO_x. In order to minimize these emissions, flue gas passes through the reduction zone and to oxidation zone. In the reduction zone, NO_x, is reduced.

Oxidation of CO to CO_2 occurs in the post combustion chamber. Secondary air is supplied in this region and mixed with the flue gas. Mixing is done through a cyclone. This chamber is designed in such a way that oxidation of CO occurs in an enough period of time. Air staging method of CO and NO_x reduction is used in this small-scale combustion unit. Staged combustion uses low excess air levels in the primary combustion zone with the remaining air added at higher levels in the furnace to complete combustion. [Mahallawy, et.al., (2002)]. A schematic diagram of its principle is presented below.

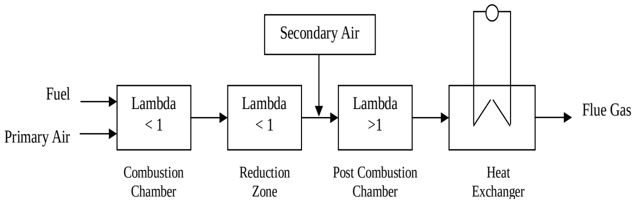

Figure 1: Principles of Air Staging(Nussbaumer, 1989)

Fuel and primary air are supplied in the combustion chamber with excess air factor less than 1 in the first stage. Flue gas then pass through the reduction zone and secondary air is supplied and mixing occurs in the post combustion chamber with lambda higher than 1 to ensure complete combustion.

A fire tube heat exchanger is installed after the oxidation chamber. It is a double stage with 10 tubes per stage. An automatic cleaning device is installed in the heat exchanger to remove the condensed salts and deposited fly ash. Heat carried by the flue gas is absorbed by the circulating water in this equipment.

Flue gas enters at the opening point located at the middle part, passes through the bulk material which filter dust particles and goes out at the exit point at the top as shown. Quartz pebbles of 5.6-8 mm size were used in the preliminary testing and 2-5 mm basalt pebbles were used in the final testing. Vibrating mechanism is installed in this filter which creates movement in the bulk material causing the dust particles to fall down to the collecting box at the lower part of the filter.

Induced draft fan ensures a constant lower pressure in the combustion chamber which results to a high degree of operational safety and constant burning condition.

Fuel Properties

Chemical composition and heating values wheat strawthat were used in the combustion calculationswere provided by the Thüringische Landesanstalt für Landwirtschaft (TLL) as presented in Table 1.

Table 1. Elemental Analysis and Heating Values of Fuels

Carbon	45.500
Hydrogen	5.370
Nitrogen	0.570
Sulfur	0.080
Oxygen	40.651
Ash	7.829
Moisture	8.600
Lower Heating Value (MJ/kg)	17.39

Method of Determining the Mass Flow Rate

The required mass flow of the burning material is determined from the relation of the output of the system, lower heating value of the burning material and its mass flow. This equation is used.

$$m(kg/hr) = \frac{\text{output of the system, kW}}{\text{lower heating value of the burning material, kJ/kg}} * 3600\,\frac{sec}{hr}$$

Output of the system is taken as 50 kW. The lower heating value of the burning material is calculated in the dry basis.

Method of Determining Air-Fuel Ratio

These are the step by step procedures in combustion calculations:

- Establish the combustion equations for the fuel constituents using thegravimetric analysis of wheat straw:
- Determine the amount of oxygen required in the combustion.
- Determine the amount of air needed for combustion
- Express the amount of air needed in Nm^3/kg fuel

Method of Determining Emissions and Their Concentrations

Measurements in ppmv (parts per million volume) is converted to mg/Nm^3 using this relation:

$$1\ ppmv = \frac{\text{Molecular weight}}{22.41\ L}\ [mg/Nm^3]$$

Emission concentrations are then calculated using this equation:

$$Concentration\ of\ X = \frac{21-13\%}{21-O_{2\ measured}} * X\ \ [mg/Nm^3]$$

where X is a constituent of the products of combustion : CO, CO_2, NO, NO_2, SO_2.

All emission concentrations are based on 13% O_2 as prescribed by law.

Method of Dust Measurement and Determining Its Concentration

Dust particle emissions in the flue gas was collected by isokinetic sampling and analyzed gravimetrically using a glass fiber paper filter and dust measuring device. Glass fiber paper filters were dried, weighed and placed in a container with silica gel to avoid moisture absorption. Sampling was done when the temperature of the flue gas is higher than 90°C. Below this temperature, condensation of flue gas on the filter occurs. Pressure difference and the static pressure at the flue gas were determined using a Prandtl tube. Oxygen and water content of the flue gas were taken from the Testo gas analyzer.Filters were again dried and weighed as before. The difference in their weights is the amount of dust collected in the filter. Dust concentration was determined based on 13% O_2 as required by law for combustion units up to 50 kW.

Dust concentration is determined as:

$$\frac{(weight\ after - weight\ before\ measurement)\ mg}{Nm^3\ \ flue\ gas}$$

The Nm^3 flue gas is measured by the volume counter of the dust measuring device.The dust concentration based on 13% O_2 is also calculated using this equation:

$$Dust\ Concentration = \frac{21-13\%}{21-O_{2\ measured}} * Dust\ \ [mg/Nm^3]$$

III. RESULTS AND DISCUSSIONS

This section presents the results of the performance evaluation of a small-scale combustion unit using wheat straw pellets. Results of the preliminary testing, modifications of the system and the final gathering of data are presented.

Mass Flow Rate

The required mass flow ratewas calculated from the 50 kW system output and its heating value resulted to 11.48 kg/hr.

Air-Fuel Ratio

Air fuel ratio for the primary air supply is less than 1.0 and for the secondary air supply is less than 1.6 to obtain the lowest emission concentrations of carbon monoxide and nitrogen oxides. Primary air supply was measured in the combustion chamber and the secondary air supply was taken from the post combustion chamber.

Influence of Post-Combustion Chamber Temperature to CO and NOx Emissions

As a result of the analysis of data, it was found out that post combustion temperature is one of the factors that influence emissions. The data were taken at λ_2<1.6. Emission limit values based on 1.BImSchV for CO and NO_x which are 1000 mg/Nm^3 and 500 mg/Nm^3 respectively. The target emission values of this study are 200 mg/Nm^3 for CO and 500 mg/Nm^3 for NO_x. CO emission concentration goes down as the temperature at the post combustion chamber goes up. When the temperature is above 500°C, CO concentration is below the target limits.. It is because high temperatures and O_2 concentrations and large residence times are required for the CO oxidation during the combustion process (Combustion, n.d.). NOx, on the other hand, is almost of constant values and below the limits. Unlike CO emission values, NO_x concentration was not affected much by the post combustion chamber at this temperature range. The results are presented in the figure below.

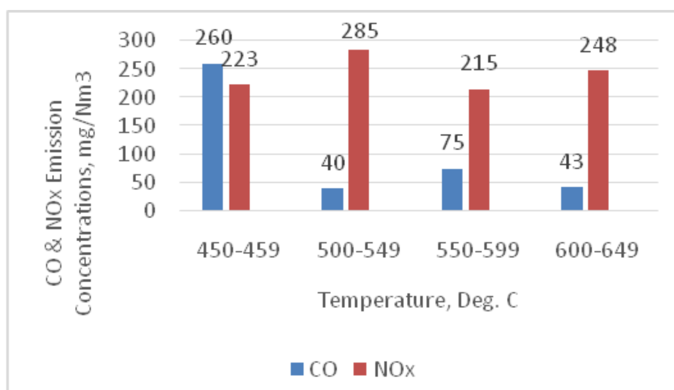

Figure2. CO and NO_x Emission Concentration vs Post Combustion Temperature

Dust Particle Emissions

During testing, dust particle emissions were measured after the bulk material filter with10 centimeter thick

Quartz pebbles and compared to 10 centimeter thick Basalt pebbles. Three sets of reinforced glass fiber paper filters were used. Dust particle emission limits by law for combustion unit up to 50 kW is 100 mg/Nm^3. The results shows that emissions are below this limit.

Table 2: Average Dust Concentration Values

Average Dust Concentration Using Quartz Pebbles	Average Dust Concentration Using Basalt Pebbles
mg/Nm^3	mg/Nm^3
14	20

IV. SUMMARY AND CONCLUSIONS

1. Emission concentrations are below the limits given by law. Carbon monoxide emission concentrations are greatly influenced by post combustion chamber temperature and excess air factor. Nitrogen oxides, on the other hand, are almost of constant values and are not influenced much by these two factors.
2. The lowest emission values were obtained at λ_1<1.0 and λ_2<1.6 and post combustion temperature higher than 550°C.
3. Using 10 cm quartz or basalt pebbles as bulk materials in the filter, wheat straw dust particle emission concentrations are below the limits given by law. Average dust concentrations using quartz pebbles is 14 mg/Nm^3while using basalt pebbles is 20 mg/Nm^3.

VI. RECOMMENDATIONS

For further development of the small-scale combustion unit the following recommendations are presented:

1. In order to determine the efficiency of the small-scale combustion unit, longer time of operation/testing should be done. System losses must be considered.
2. Since only wheat straw has dust particle emissions below the limits and with filter efficiency less than 50%, thickness of the bulk material higher than 10 cm should be evaluated.
3. To compare efficiency of the filter using different bulk materials and to compare bulk material filter with existing devices for controlling particulate matters, dust particle size should be considered.

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