EMISSIONS FROM DIRECT COMBUSTION OF AGRICULTURAL BIOMASS ON FARM

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ABSTRACT

Rising energy cost pushes toward the development of new sustainable green energy. In that context, biomass combustion of wood, switch grass or willow could be an interesting way to produce green energy (heat or electricity). Emissions from wood combustion are well documented, but it is not the case for agricultural biomasses. Furthermore, the global impact on the environment of biomass combustion is not well known, mainly the aspect of air pollution. The main objective of this study was to measure and compare emissions from the direct combustion of wood and three different biomasses: dried solid fraction of pig manure, switch grass and willow. Experiments were carried out in a biomass pellet stove producing 60,000 BTU/h. The stove was installed in a calorimetric chamber to measure the efficiency. Gas emissions from the stove (CH_4, CO, CO_2, O_2, SO_2, and H_2O) were measured using a FTIR analyser. Physico-chemical characteristics of the biomass and the ashes were analysed in laboratory. Preliminary combustion tests have been carried out to find the optimal combustion conditions. Tests were done measuring gas concentrations in the chimney while varying the airflow of fresh air in the combustion chamber. The optimal combustion conditions were determined by the lowest CO concentration measured and the corresponding airflow. The CO average concentrations measured from different airflows ranged from 52 to 149 for switch grass, 271 ppm to 631 for willow, from 60 ppm to 544 for wood and from 158 ppm to 726 ppm for dried solid pig manure. At the optimal combustion conditions, wood and switch grass produced less CO than the other tested biomasses. In terms of agricultural biomasses, switch grass produced less CO than dried solid pig manure and willow.

Keywords: Agricultural biomass; direct combustion; gas emissions.

1. INTRODUCTION

Rising energy cost and climate change push toward the development of new sustainable green energy. In that context, biomass combustion could be an interesting way to produce heat or electricity. In fact, biomass is a renewable energy source that can contribute to reduce greenhouse gas emissions and replace fossil fuels. With the abundance of woody biomass, the Province of Québec (Canada) has been developing a feedstock supply chain for energy production from woody materials. However, the use of agricultural biomasses as potential solid fuels has just been emerging and studied among last years. Besides energetic and environmental advantages, according to Cantrell et al. (2008), the use of agricultural and livestock waste as bioenergy feedstocks for waste-to-bioenergy conversion processes would allow farmers to take advantage of new markets for traditional waste products. Research involving heat production from combustion of agricultural biomasses includes: (1) organic-based waste from agricultural activities such as cereal straws and cereal seeds; (2) energy crops such as switchgrass, *Miscanthus* and willow; and (3) animal manure such as poultry litter and the solid fraction of pig manure.

Gas emissions from combustion are related to fuel composition and properties, combustion equipment, and the amount of air introduced in the combustion cycle. In a combustion process, all these variables interact together and produce an extensive variety of emission levels and compounds. Nevertheless, unlike emissions from wood combustion that are well documented, it is not the case for agricultural biomasses. Godbout et al. (2010) concluded that emissions from the combustion of agricultural biomasses present a lack of knowledge, thus further research is highly needed. In fact, a wide proportion of the scientific research in biomass combustion focuses on woody fuels while research in agricultural biomasses is less intensive.

The gas-phase emissions from biomass burning are dominated by water vapour (H_2O) and carbon dioxide (CO_2) (Burling et al., 2010). Primary pollutants formed during biomass combustion include particulate matter (PM), carbon monoxide (CO), oxides of sulphur (SO_x, mainly SO_2) and nitrogen oxides (NO_x, mainly NO and NO_2). Biomass feedstock with high chlorate concentration (such as straw) leads to the formation of acid gases including HCl, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF). In addition, these high chlorate concentration feedstocks contribute to accelerate the fouling and the corrosion of the combustion system. Heavy metals in the biomass, i.e. lead, cadmium, selenium, and zinc form aerosols or accumulate on the fly ash particles. Sometimes, the resulting heavy metals concentrations in the ash exceed the hazardous waste thresholds.

The main objective of this study was to measure and compare specific emissions from the direct combustion of wood pellets and three agricultural biomasses. This paper presents the work done to determine the optimal air flow input in the combustion cycle for each biomass and compare the gas emissions of the biomasses at each corresponding optimal air flow CO concentration was used as a combustion efficiency indicator: a low CO concentration ensures better combustion conditions and consequently, less incomplete combustion emissions.

2. MATERIALS AND METHODS

2.1 Biomasses and stove installation

Four biomasses (table 1) were tested: willow, switchgrass, dried solid fraction of pig manure (SFPM), and commercial wood pellets (mixtures of black spruce and gray pine pellets), which was used as reference. The experiments were carried out in a 60,000 BTU/h (17.58 kW) output biomass pellet stove. The stove control board allowed five different burning rates. The input air flow was controlled by a damper which restricted the air flow conducted into the combustion chamber. The damper was adjusted to obtain three different flows. In addition, the burner was installed into a calorimetric room to determinate the heat produced from every biomass in relation to their calorific values.

Table 1. Properties of the biomasses

	Willow	**Switchgrass**	**SFPM**	**Wood**
Ash content	3.7%	3.8%	9.1%	0.6%
Calorific value (MJ/kg)	19.6	18.6	15.0	20.5
Humidity (% w.b)	12.7	14.1	10.5	6.6
Bulk density (kg/m^3)	590	509	769	686

2.2 Procedure

Tests were carried out to measure flue gas concentrations for three burn rates at three air flow inputs. Burning rates and combustion methodology were based on E2779–10 ASTM standard (ASTM, 2010). The biomass was burned during two hours at each burning rate for each air intake setting including one hour to get the optimal burning conditions. The biomasses were burned randomly and only one repetition was done for this preliminary experiment. CO concentrations in the flue gas were analysed in order to determinate the ideal input air flow. In fact, CO is an incomplete combustion gas. A lower CO concentration means that the combustion is almost complete indicating that the air intake is well adjusted.

2.3 Combustion gases measurement

Monitored gases included CO, CO_2, CH_4, SO_2, O_2 and H_2O. The Fourier transform infrared spectrometer (FTIR) was used to measure their concentrations in the flue gas (figures 1 and 2). A probe installed into the chimney and connected to the FTIR spectrometer cell allowed gas concentration measurements. The cell was purged every five minutes.

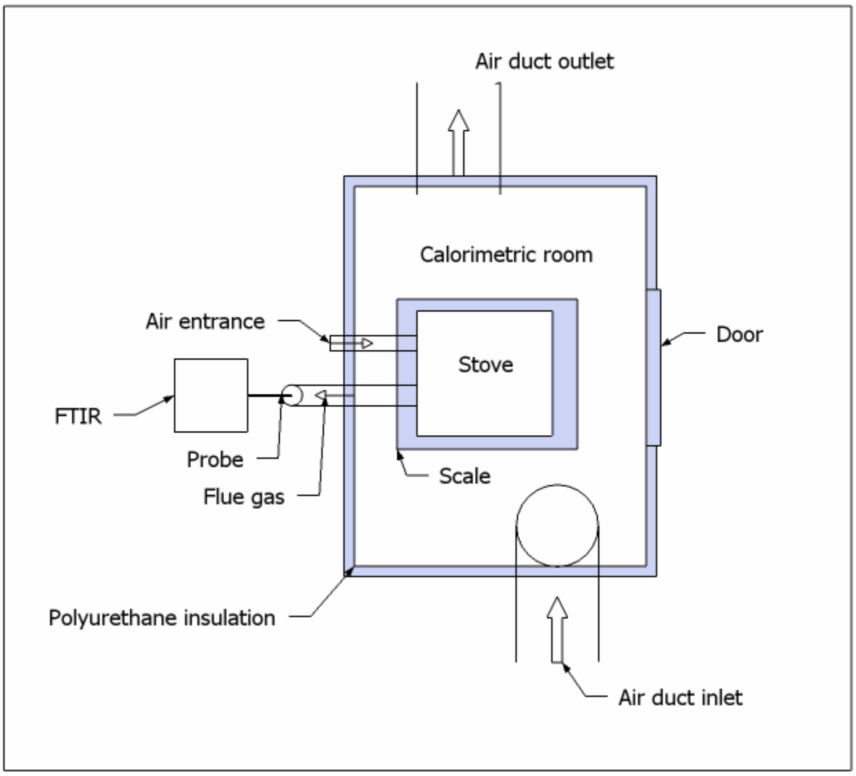

Fig. 1. Diagram of test setup, top view

2.4 Heat balance

The calorimetric room (1.96 m x 1.52 m x 1.91 m) (figure 2) was isolated with polyurethane in order to minimize heat losses. Sampling was conducted when a constant temperature inside the calorimetric room was achieved. A fan continuously forced cold air stream to circulate through the chamber and to evacuate heated air. A second fan was installed at the air intake in order to keep a neutral differential pressure inside and outside the calorimetric room. Additionally, thermocouples were installed on the inside and outside portions of the walls in order to measure conductive heat losses. Measurements were collected every 10 minutes by a data logger.

Fig. 2. Biomass combustion test setup, front view (left) and rear view (right).

2.5 Ashes and burning rate

The pellet stove was installed on a scale (± 0.05 kg precision) which collected weight at regular intervals during the combustion process. Combustion rate was determined by the change of the stove’s weight at the beginning and the end of the trial, divided by the length of the burning test. After each test, the bottom ashes in the stove and the fly ashes in the chimney were collected and weighed in order to determine the ash content of the evaluated biomass.

3. RESULTS AND DISCUSSION

The CO average concentrations measured from the different airflows and combustion rates ranged from 60 (± 15) ppm to 1,140 (± 316) ppm for wood, 170 (± 46) ppm to 509 (± 122) ppm for dried solid pig manure (SFPM), 56 (± 12) ppm to 189 (± 69) ppm for switchgrass, and 284 (± 87) ppm to 627 (± 92) ppm for willow. The average combustion rates tested were 1, 1.7, and 3.1 $kg_{biomass}/h$ concerning respectively to minimal, intermediate and maximal output capacity of the appliance. The flue gas flows ranged from 34 to102 m^3/h in function of input air restriction and combustion rate.

The conditions where each biomass got the lowest CO concentrations were selected in order to compare the emissions. The resulting emissions ($g_{gas}/kg_{biomass}$) are shown in table 2. As expected, most emitted substances were CO_2 and H_2O vapour. Wood produced more greenhouse gases (CH_4 and CO_2) emissions than agricultural biomasses.

Table 2. Gas emissions from combustion of different biomasses

Biomass	CH_4 g/kg	CO g/kg	CO_2 g/kg	SO_2 g/kg	H_2O g/kg	O_2 %
Wood	0.13	7.35	1,152	0.19	1,180	16,8
SFPM	0.06	13.21	649	ND	ND	16,3
Switchgrass	0.09	4.62	958	0.85	1,297	17,7
Willow	0.09	13.07	783	0.45	992	16,4

ND: No data in SO_2 and H_2O emissions from SFPM combustion cells.

Even though wood and switchgrass produced less CO than the other tested agricultural biomasses, the CO emissions measured during this experiment were relatively higher as compared to those published in the literature. In fact, according to the emission data collected from the literature by Godbout et al., (2010), CO emissions from wood range from 0.4 to 4.16 g/kg, and from 0.51 to 6.8 g/kg for other biomasses. In terms of agricultural biomasses, switchgrass produced less CO than dried solid pig manure and willow.

Biomass ash content in residual ash after combustion resulted to 0.63% for wood; 9.11% for SFPM, 3.77% for switchgrass and 3.73% for willow. By far SFPM has the highest ash content value, resulting in higher PM emissions.

Further research will consist of establishing a mass balance from the elemental composition analysis of biomasses to make a relationship between the biomass chemical properties and emissions. In addition, the energy balance from the calorimetric room setup will allow comparison on the energy provided by each biomass. On the other hand, in order to study the critical impacts of agricultural biomass combustion, nitrogen oxide gases and substances formed by the release of Cl, such as HCl and PCDD/F, should be included in further research.

4. CONCLUSION

Combustion tests of wood and three agricultural biomasses were done in order to compare gas emissions. The comparison was made under the optimal combustion conditions for each biomass. The optimal combustion conditions were determined by the lowest CO concentration measured at the corresponding fresh air input. At the optimal combustion conditions, agricultural biomasses produced less GHG emissions (CH_4 and CO_2) than wood. However, before recommending the use of agricultural biomasses for combustion, more research has to be done to avoid any negative environmental and human health issues due to their specific chemical and physical properties. For example, higher ash content in dried solid fraction of pig manure than wood may lead to the formation and emission of larger quantities of PM. Further research is needed for a better understanding of biomass combustion and atmospheric emissions.

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6. REFERENCES

[1] ASTM. *E2779 – 10, Standard Test Method for Determining Particulate Matter Emissions from Pellet Heaters*. 2010.

[2] Brown, R. C., *Thermochemical Processing of Biomass. Conversion to Fuels, Chemicals and Power*. Editor: R.C. Brown. John Wiley & Sons, UK. 2011

[3] Burling, I. R., R. J. Yokelson, D. W. T. Griffith, T. J. Johnson, P. Veres, J. M. Roberts, C. Warneke, S. P. Urbanski, J. Reardon, D. R. Weise, W. M. Hao, and J. de Gouw, *Laboratory measurements of trace gas emissions from biomass burning of fuel types from the southeastern and southwestern United States*, Atmos. Chem. Phys., 10, 11115–11130, 2010.

[4] Cantrell B. K., T. Ducey, K. S. Ro, P. G. Hunt, *Livestock waste-to-energy generation opportunities*, Bioresource Technology 99, 7941-7953, 2008.

[5] Godbout, S., J.H. Palacios, F. Pelletier and J-P. Larouche. *Combustion de la biomasse agricole : caractérisation des effluents gazeux et particulaires, revue de normes et élaboration d'un protocole de mesure*. Final report. Research and Development Institute for the Agri-Environment (IRDA). Québec, Canada, 2010.