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ScientEvents

ProScience 1 (2014) 219-224

ProScience

Conference Proceedings

1st International Conference on Atmospheric Dust - DUST2014

Emission factors of gas and particulate matter during the energy recovery of grape marc in a domestic boiler

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Abstract

The demand for renewable energies needs to be diversified in order to avoid deforestation. The combustion of different agricultural by-products has been already compared (Caillat et al. 2012). Regarding environmental issues, the pollutant emissions control is the key factor for the development of biomass combustion. Therefore, the present study focuses on the gas and particulate matter emissions of grape marc combustion. Combustion experiments were carried out in a small scale biomass boiler 40 kW from REKA. Pollutant emission were measured with on-line gas analysers (CO, CO_2, HC, NO, NO_2, SO_2 and O_2) and an Electrical Low Pressure Impactor (ELPI) manufactured by Dekati Ltd. (Tampere, Finland) was used to measure on line concentration numbers of particles ranging from 29 nm to 10 µm into 12 size fractions. Due to the high moisture content, the grape marc has been blended with different co-combustible as pellets, wood chips and miscanthus. The best conditions for the combustion have been found with miscanthus which has been tested with several blending fraction.

Keywords: Grape marc; energy recovery; combustion; emission factors; particles.

1. Introduction

Producing energy through biomass combustion is considered sustainable because of the rarefaction of fossil resources and its low carbon balance impact. The routes leading to sustainability have to pass through a diversification of the biomass used, if there are a local implantation and a social benefit. As integrant part of the Project 'OUI Biomasse' (Interreg IV, project C 30) the focus has been made on the grape marc combustion development for a

*Corresponding Author: gwenaelle.trouve@uha.fr
ISSN: 2283-5954
Selection and peer-review under responsibility of DUST2014 Scientific Committee
DOI:10.14644/dust.2014.036

low environmental impact. The Alsace Region (France) is well-known for wine production leading to large quantities of grape marc. This wine residue has also a great interest for energy recovery in other regions (Celma et al., 2007; Toscano et al., 2013).

Among the different combustion techniques and power capacities, we decided on the one hand to avoid pellets boiler in order to limit the transformation made on the grape marc and on the other hand the use of a medium or large scale boiler which would imply transportation issues in term of global environmental impact. The aim of the present study is to analyze the energy recovery of grape marc in a domestic boiler with focussing on the emission factors of gas and particulate matter.

2. Experiments

2.1 Characterization of biomasses

The sample of wine residue tested in this study was produced in Alsace and collected directly after the pressing step. The grape marc is Gewürztraminer variety. Three different biomasses were used in this study as co-combustible:

- Miscanthus was locally produced at Ammertzwiller (Alsace, France).
- Beech chips were purchased from Agrivalor (Hirsingue, France).
- DIN Certco pellets were purchased from SOFAG (Arc sous Cicon, France).

The different biomasses were characterized following the standard XP CEN/TS for the moisture, ash contents and the low heating value (LHV) (Table 1). The ultimate analyses were performed for C, H, O, N and S (Table 2).

Table 1. Fuel properties.

Biomass sample	LHV ($MJ.kg^{-1}$)	Moisture[a] (%)	Ash[a] (%)
Miscanthus	16.7	10	1.4
Beech chips	19.6	40	0.4
DIN Certco pellets	17.7	8	0.3
Grape marc	4 (18.4 daf)[b]	67	1.8

a: on raw basis; b: daf: dry and ash free

Table 2. Ultimate analysis on dry basis.

Biomass sample	C	H	O	N	S
Miscanthus	48.70	5.89	43.67	< 0.3	0.12
Beech chips	49.50	6.02	43,48[a]	< 0.3	0.06
DIN Certco pellets	47.06	6.10	46.64[a]	< 0.1	< 0.1
Grape marc	50.04	6.42	36.48[a]	2.49	<0.3

a: calculated by difference

2.2 Samples preparation

The adopted methodology for the combustion tests of grape marc, due to the high moisture content, exhibits two steps. Combustion tests began with the co-combustible alone until the boiler temperature stabilization. Then, the grape marc was added with the corresponding co-combustible as pellets, wood chips and miscanthus. Some preliminary tests showed that it was not possible to stabilize the combustion with blended fuels samples. Then grape marc was grinded with miscanthus in order to get more homogeneity in the combustion chamber.

2.3 Combustion experiments

Combustion tests at laboratory scale were performed in a multi-fuels boiler (HKRST/V-FSK) supplied by REKA (Aars, Denmark) and equipped for combustion studies. Performance of the boiler ranges from 30 to 40 kW. The boiler basis is a moving stepped grate. The boiler is equipped with a water-cooled volume of 220 L, a fireproof lining on the sides and the top, blower for primary and secondary preheated air and with semi-automatic ash removal. As the boiler was located on a balance, the mass loss and then the consumption of pellets were recorded. The combustion efficiency was estimated using the NF EN 12809 standard related to boilers with a heating power lower than 50 kW.

2.4 Gaseous emissions

Emissions were measured in the chimney according to EN-304 standard during experiments at laboratory scale on the REKA boiler. Flue gas temperatures were continuously recorded. O_2, CO, CO_2 and NO_x were analyzed by specific Infra-red analyzers ROSEMOUNT. According to EN 303-5 standard, concentrations expressed in mg. Nm^{-3} were referred to 10% of O_2 in the exhaust to insure comparison for both experiments.

2.5 Particle number concentrations

An Electrical Low Pressure Impactor (ELPI) manufactured by DEKATI Ltd. (Tampere, Finland) was used to collect particles from 7 nm to 10 µm into 12 size fractions. Within the ELPI, the particles are first electrically charged according to their Stokes diameter, and then impacted on different stages according to their inertia related to their aerodynamic diameter. Before entering the impactor stages, the particles are charged in a positive unipolar particle charger (corona charger). After being charged, the particles are introduced in the cascade impactor in order to be separated on the basis of their inertia and their aerodynamic diameter. A multistage electrometer counts the charged aerosol particles. The current induced is then simultaneously measured for the twelve impactor stages and it is directly converted by the electrometer in particles number and concentrations using mathematical algorithms (Marjamäki et al., 2000). The number of particles depends both on the induced current measured at each stage, and on the density of the particles in the exhaust gas, which has to be provided by the user. Particle number and concentrations calculated accounts for this particularity using 1 g. cm^{-3} of density value (Marjamäki et al., 2000).

The total mass fraction of Total Suspended Particles (TSP) has been measured by gravimetry according to DIN Certco certification rules (DIN Certco, 2008).

3. Results and discussion

3.1 Combustion process

3.1.1 Combustion and boiler efficiency

Due to the high humidity of grape marc sample, drying step in the combustion chamber tends to slow or to inhibit the combustion process. Moreover, as already mentioned in section 2.2, it was not possible to get a stabilized combustion when the co-combustible was simply blended with the grape marc. Consequently, blending and grinding grape marc with miscanthus were necessary to both homogenize and reduce humidity in the combustion chamber.

The values presented in Table 3 are average values on 30 minutes of steady state for experiments repeated at least three times. The boiler efficiency corresponds to the useful power compared to the input power. The useful power is not the theoretical maximal one for the biomass boiler due to the heat exchanger used here which limits the performance of the installation.

Table 3. Average values of combustion parameters during steady state.

Biomass sample	**Humidity (%)**	**Residual carbon (%)**	**Useful power (kW)**	**Input power (kW)**	**T_{fumes} (°C)**	**Boiler efficiency**
Miscanthus	10	8	20	29	126	69%
Miscanthus_Grape marc 66/33	32	4	24	35	126	69%
Miscanthus_Grape marc 50/50	36	7	23	30	122	76%

3.1.2 Gaseous emissions

Table 4 shows the average values of gas concentrations in the flue gas obtained at steady state of combustion for the different biomass samples. The mixture grape marc/miscanthus (50/50 by weight) leads to a humidity of 36%. CO emission increased up to 1691 mg/Nm^3 at 10% of oxygen. This value is below the regulation level (EN 303-5) of 3000 mg/Nm^3 at 10% of oxygen. Even if the manufacturer recommends the burning of biomass containing a maximal humidity of 30%, we found that this co-combustible 50/50 with the highest wine residue proportion could be burnt in small scale biomass boilers.

Table 4. Average values of gas concentrations in the flue gas during steady state.

Biomass sample	**CO_2 (%)**	**O_2 (%)**	**CO at 10% O_2 (mg/Nm^3)**	**NO_x at 10%O_2 (mg/Nm^3)**
Miscanthus	8.7	11.7	89	233
Miscanthus_Grape marc 66/33	8.7	12.1	277	151
Miscanthus_Grape marc 50/50	7.4	12.6	1691	281

The level of NOx yielding do not show particular issues compare to others biomass(Caillat et al. 2012). According to the literature, NOx emissions are mainly related to the nitrogen content in fuels (Eskilsson et al., 2004; Johansson et al., 2004; Brassard et al., 2014; Díaz-Ramírez et al., 2014). Other factors could reduce NOx emissions as air staging or the level of temperature which should be higher than 1200 °C (Williams et al., 2012). These two factors may not apply in our study and no specific correlation was found with the other gas concentrations and NOx emissions are of the same order of magnitude for the three samples.

3.2 Particulate matter

The total number of particles (p/cm^3) measured in the fumes with the ELPI is 1.87x10^7, 2.00x10^7 and 1.47x10^7 p/cm^3 respectively for the miscanthus, the mixture 66/33 and 50/50 of miscanthus and grape marc. There is no significant difference in term of number.

However Fig. 1 and 2 show that the relative distribution changes with the addition of grape marc. Indeed, the amount of the smallest particles $PM_{0.1}$ decreases while the $PM_{0.1\text{-}1}$ increases symmetrically. The increment of the $PM_{1\text{-}2.5}$ keeps the same trend.

Furthermore, TSP concentration was measured three times for the DIN Certco pellets used as a reference, the miscanthus and the miscanthus/grape marc 66/33 sample. The results are respectively 20, 40 and 62 mg/Nm^3 at 10% of O_2**.** These values are below the standard limit EN 303-5 which is 150 mg/Nm^3. When the grape marc is added into the biomass boiler, the TSP increased as well as the ratio $PM_{0.1\text{-}1}$ /$PM_{0.1}$.

The obtained results show a good accordance with the literature. It is reported that the particles size are mainly below 2.5 µm and the emission factor is higher with agricultural by-products (Johansson et al. 2003; Garcia-Maraver et al. 2014).

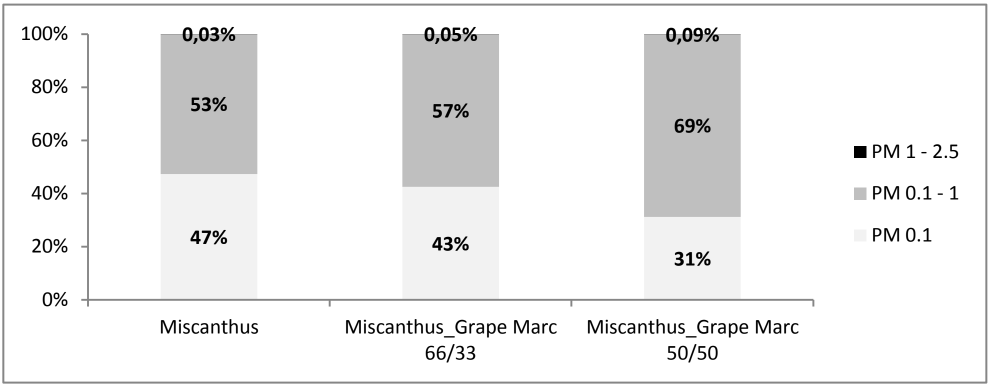

Fig. 1. PM relative distribution of the particles in the exhaust.

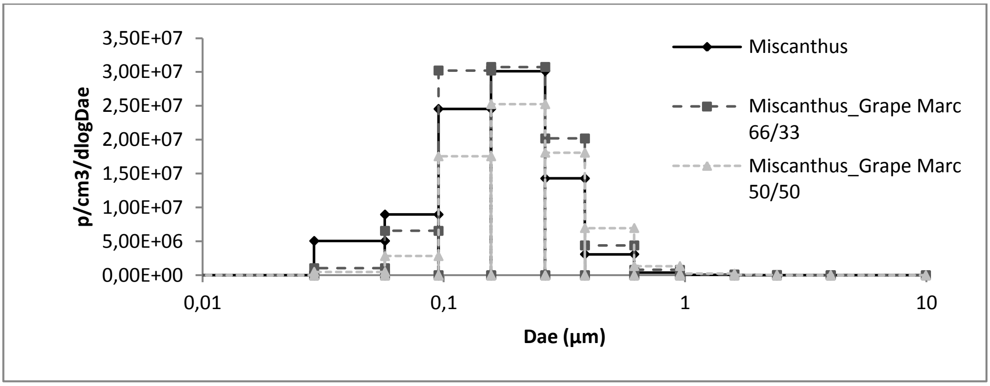

Fig. 2. Number size distribution of particles in the exhaust.

4. Conclusions

The grape marc combustion was studied in this work with a dried co-combustible because of the high moisture content of the wine residue. The energy recovery of grape marc in a domestic boiler shows good results with comparable efficiency between miscanthus and the different mixture of miscanthus and grape marc. The co-combustible proportion of wine residue seems to be limited at 50% in order to get CO emissions below the EN 303-5 emission standard. Dust and NOx emissions factor are not significant issues in term of level compared to other biomass.

As biomass energy recovery is taking an important part on the dust global emission for urban atmosphere, the focus on the emission factors of particulate matter was made in order to evaluate the environmental impact. The particulate matter size in the fumes is below 1µm. The grape marc addition increased the particles relative distribution size from 53% to 69% of $PM_{0.1-1}$, the other part corresponds to the $PM_{0.1}$.

5. Acknowledgements

This work was performed in the framework of the project 'OUI Biomasse' (Innovations for sustainable biomass utilization in the Upper Rhine Region) of the INTERREG IV Program. The authors thank the European Community (ERDF) and the Science Offensive of the Trinational Metropolitan Upper Rhine Region for their financial support.

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