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ARTICLE

Comparison of Ashes Produced in a Biomass Moving Grate Boiler by Wood Chips and Sewage Sludge

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ABSTRACT

One option to fight global warming is to convert our use of fossil energy into renewables such as biomass energy. However, the forest preservation and the quality of the ambient air are also two major issues. Therefore, the use of biomass waste without any supplementary emissions could represent a part of the solution. In this study, two fuels were considered for a 200 kW moving grate boiler. A multicyclone and a bag filter were fitted on the boiler. The first fuel consisted of classical wood chips whereas the second was a mixture of wood chips with sewage sludge. This second fuel presented a high ashes mass ratio compared to wood chips. The aim was to verify the possibility to burn this kind of fuel without any modification of the installation. The first relevant result is that the conventional pollutants, i.e., CO and NOx, remained under the emissions limits even with the sewage sludge combustion. The Total Suspended Particles emissions at the exhaust were always under 5.4 mg·Nm^{-3} dry based corrected at 6% of O_2, which is low with respect to the standard limitation. The majority of the ashes remained on the combustion room. However, with both fuels, about 5% of ashes mass remained in the heat exchanger. Nevertheless, the heat exchanger was more clogged with the second fuel, which produced five time more ashes. This may lead to a yield loss. Thus, sewage sludge can be used in a wood boiler without any issue if an automatic exchanger sweep is fitted on the installation.

KEYWORDS

Combustion; energy; biomass; ashes; TSP

Nomenclature

NO_x	Nitrogen Oxides (mgEqNO_2.Nm^{-3})
SO_x	Sulphur Oxides (mgEqSO_2.Nm^{-3})
TSP	Total Suspended Particles (mg.Nm^{-3} dry based)

1 Introduction

The necessity to reduce greenhouse emissions and to increase sustainable energy production has led to the promotion of renewable energy, such as biomass energy, which is the first renewable energy in the world: representing 9% of the world total primary energy supply, in 2018 [1]. In France, biomass energy is the main source of renewable energy: it represents more than 55% of final energy production in 2020 and therefore contributes significantly to reduce fossil fuels consumption [2]. Wood combustion energy represents the majority of the biomass energy, with 35.8% (114 TWh) in primary renewable energy production in 2019 in France [3]. Currently, wood combustion is used to produce heat and/or electricity in plants with capacities ranging from a few kWth to more than 500 MWth [4].

In this context, wood combustion represents an important source of energy. Nevertheless, the use of this source of energy needs to be realized in accordance with the forest preservation policy and the quality of the ambient air standards. At the European level, directives 2004/107/EC and 2008/50/EC set sanitary standards which involves the obligation to monitor air quality, to inform the population about air quality and to implement action plans [5,6]. Therefore, expanding the wood resource could be very challenging since not only natural wood is used but also wood waste, coated and treated wood and even wood mixed with other waste will be increasingly used [7], which may induce a degradation of the quality of the ambient air.

It has been proved that natural wood combustion does not seem to cause emissions problems when it is burned alone [8]. Therefore, special attention has been paid to the combustion of wood waste such as wood collected from waste disposal sites, industrial by-products and those emerging from construction and demolition activities [4,9–11]. These types of fuels have a very different composition and could contain high levels of pollutants, which both promotes harmful emissions and leads to the production of combustion waste like: ash and pollutants in the flue gas. During combustion processes, pollutants formation occurs due to two reasons: either the incomplete combustion leading to high emissions of unburnt pollutants such as CO, VOC, soot,… and the fuel constituents such as N, K, Cl,… from which pollutant such as NO_x and particles are formed [12]. Moreno et al. presented a study on the characterization of gaseous emissions and ash from the combustion of waste furniture in comparison with emission from solid wood combustion [11]. The results of this study showed that NO emissions are higher in the combustion of furniture wood waste mixed with 10% of polyurethane foam and in the combustion of furniture wood waste in comparison with emissions from solid wood. This was explained by the higher nitrogen content in the furniture waste used [11].

Testing new biomass combustion and studying its effects and its products comparing with the usual biomass used; namely "wood", will surely help expand biomass resources used in biomass boiler.

In this context, the aim of the present paper is to check the feasibility to burn biomass waste mixtures without any modification of the installation while keeping pollutants emissions at the lowest possible level.

For this purpose, the results of the ashes deposition and gaseous and particulate pollutants emissions of two different biomass fuels combustions will be compared and studied.

2 Materials and Methods

2.1 Boiler

The tests were conducted in an automatic 200 kW boiler (50 kg per hour) with moving grate firing and separate primary and secondary air supply (Fig. 1). The removal of waste gas particles is carried with a multicyclone and a fabric filter. The flue gas composition was measured thanks to two analyzers: TESTO 350XL and HORIBA PG350.

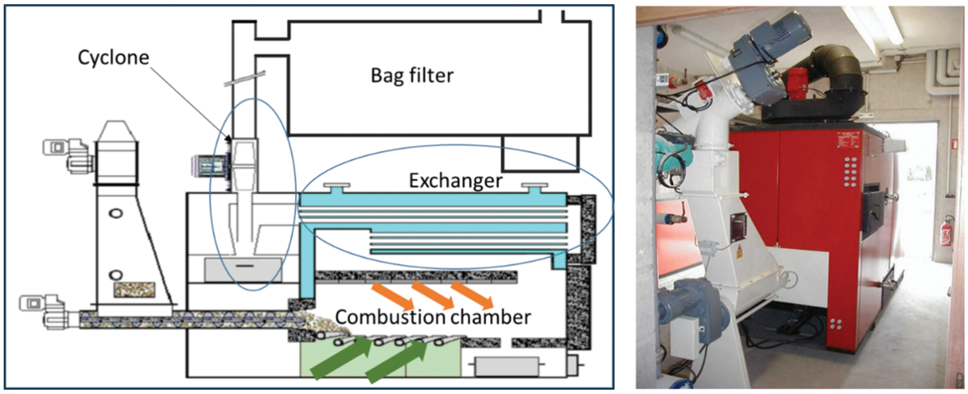

Figure 1: Sectional photo view of the LERMAB pilot boiler (200 kW, 50 kg/h) with primary air inlet (green arrows) and secondary air inlet (orange arrows)

2.2 Fuels

Two different fuels were used in the 200 kW LERMAB pilot boiler. The first test was conducted with natural forest chips as a fuel. The second test was carried out with a mixture of natural forest chips and sewage sludge (Table 1).

Table 1: Amount of the 2 fuels

	Natural forest chips	Natural forest chips + sewage sludge
Mass of burnt dry fuel (kg)	706	619*

Note: *619 kg including 396 kg forest wood chips and 223 kg of sewerage sludge.

The mixture wood chips and sludge was prepared by making alternative layers with each fuel and then mixing it all until it becomes as homogeneous as possible. The Table 2 presents the proximate/ultimate analysis results for both used fuels.

Table 2: Proximate and ultimate analysis of used fuels

	Natural forest chips	Natural forest chips + sewage sludge
Moisture (% r.b.)[1]	27	35
Average ash (% r.b.)[1]	1	6
HHV (high heating value) (kJ/kg)	19650	17694
Net Calorific Value (wet basis) (kJ/kg)	12744	10593
	Mass fractions	
C[2]	0.51	0.47
H[2]	0.06	0.06
O[2]	0.43	0.47
N[2]	0.002	0.004
S[2]	0.0001	0.0006
Cl[2]	<0.00007	0.0003

Note: [1]: calculated on a raw basis.
[2]: calculated on a dry basis.

The Oxygen mass fraction is calculated by subtracting the measured elements to complete the total mass fraction.

2.3 Experimental Parameters

The experiments have been performed with an optimized primary and secondary air supply in a way to maintain the adequate levels of O_2 and CO_2. The air factor was calculated according to the mass of the burnt fuels and those parameters (Table 3).

Table 3: Combustion parameters

	Air excess	Average combustion temperature (°C)	O_2 (% dry)	CO_2 (% dry)
Natural forest chips test	1.9	737	9.4	9.7
Natural forest chips + sewage sludge test	1.9	789	8.3	8.9

3 Sampling and Analysis

After each tests, a complete cleaning of the boiler was carried out and all the ashes obtained were collected for later analysis. The ashes were deposited on different parts of the boiler, which do not have the same aspect and color. This point leads to suppose that these ashes do not have the same composition and/or size distribution. This is why each type of ash were collected apart (Fig. 2).

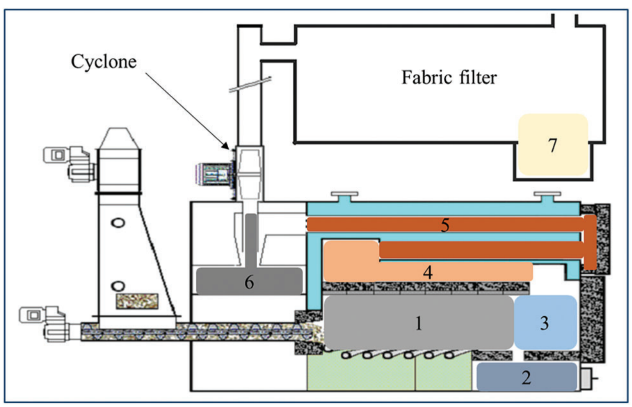

Figure 2: Diagram of the LERMAB pilot boiler and ash sampling points from 1 to 7. 1: ashes from the grate and the inner walls of the combustion chamber, 2: ash pan, 3: combustion chamber door and surrounding walls, 4: before exchanger, 5: exchanger medium, 6: cyclone, 7: bag filter

During these tests. the concentration in O_2, CO, CO_2 and NO_x of the smoke was measured. Elementary analyzes (C, N, Cl, S, metals, i.e., Cr, Cu,…) were carried on the ashes as well particles size distribution.

4 Results and Discussion

4.1 Ashes Deposition

After collecting the deposited ashes from the different parts of the boiler after each combustion test, the results show that the majority of the ashes remain on the combustion room (sampling points 1, 2 and 3 on the Fig. 2). After the combustion of the mixture of wood chips and sewage, most of the ashes were collected at the combustion chamber, on the grate and the surrounding walls and in the ash pan. Whereas, after the combustion test of wood chips, in addition to the combustion chamber, the grate and the ash pan, there is a quiet a lot of ash collected in the cyclone. Ashes from different sampling point are collected separately and weighted.

Table 4 presents ashes weight (per kg) collected from each sampling point as well as the mass ratios.

The second fuel containing the sewage sludge led to five times more ash than natural chips wood. Results show that the majority of the ash remain in the combustion chamber; 95% of ashes were collected from the combustion chamber (sampling point numbers 1, 2 and 3) during the second fuel test while with the natural forest chips, 73% of ash were collected from these same 3 points. This can be explained by the high ash content of the second fuel comparing to the first one.

Table 4: Comparison between weight of the ashes collected after each test

Sampling point	Natural forest chips test		Natural forest chips + sewage sludge test	
	Ash mass (kg)	Mass ratio (%)	Ash mass (kg)	Mass ratio (%)
1	1.04	12.81	16.81	41.49
2	1.76	21.55	3.51	8.76
3	3.10	38.18	17.98	44.86
4	0.17	2.09	1.10	2.74
5	0.23	2.83	0.32	0.80
6	1.38	17.00	0.22	0.55
7	0.45	5.54	0.14	0.35
Total	8.13	100	40.08	100

With both fuels, about 4% to 5% mass of the ashes are trapped in the heat exchanger (sampling point numbers 4 and 5). Nevertheless, as the second fuel produced 5 time more ashes, the heat exchanger is more clogged, which induce a yield loss. Whereas for ashes collected from the last two sampling points (sampling point numbers 7 and 8 referring to cyclone and bag filter, respectively), 23% of total collected ashes is measured after the first fuel test, while only 1% is measured after the second fuel test. This result show that the combustion of natural wood chips leads to a higher level of fly ashes than the combustion of the mix woodchips/sewage sludge.

4.2 Pollutants Emissions

In order to limit emissions of pollutants into the air from combustion plants, the European standard limits the emissions levels of CO, NO_x, SO_x and Total Suspended Particles (TSP), which are particular for each type of plants depending on their power output (capacity). For those with a capacity of less than 5 MWth. the emissions limits were [13]:

- 250 mg.Nm^{-3} for CO corrected at 6% of O_2;
- 200 $mgSO_2.Nm^{-3}$ for SO_x corrected at 6% of O_2;
- 500 $mgNO_2.Nm^{-3}$ for NO_x corrected at 6% of O_2;
- 50 mg.Nm^{-3} of TSP corrected at 6% of O_2.

Table 5 presents combustion emissions results measured during both tests. For both fuels, the levels of emitted pollutants were below the standards limitation. NO_x emissions were lower during the combustion of natural forest chips than forest chips with sludge and was about 280 and 399 $mgNO_2.Nm^{-3}$, respectively. The same observation was concluded for SO_x emissions with only 1.2 $mgSO_2.Nm^{-3}$ emitted during the first test against 97.1 $mgSO_2.Nm^{-3}$ measured during the second test. However, the CO emissions were lower with the second fuel (164 mg.Nm^{-3}) then the first one (255 mg.Nm^{-3}) which slightly overshot the allowed limit. Similar results were reported in bibliography, while the combustion of virgin wood, wood pellet and beech induced only low NO_x emissions, other biomass fuels such as MDF, particle board and plywood caused higher emissions when burned in the same combustion systems (fluidized sand bed reactor and automatic waste combustor of 50 kW) [7].

Table 5: Combustion emissions results for both test

Pollutants (emissions corrected @6% of O_2)	First test: Natural forest chips	Second test: Natural forest chips + sewage sludge test
O_2 (%)	9.4	8.0
CO (mg.Nm^{-3})	255	164
NO_x (mgEqNO_2. Nm^{-3})	280	399
SO_x (mgEqSO_2.Nm^{-3})	1.2	97.1
TSP (mg.Nm^{-3} dry based)	5.4	5.5

Concerning the TSP, both tests emissions remain under the standard limitation; 5.4 mg.Nm^{-3} during the first test and 5.5 mg.Nm^{-3} during the second.

All the emission values presented in Table 5 were corrected at 6% of O_2 in order to be compared with the standard.

Values for both fuels are similar in the same order of magnitude excepted for SO_2. Emissions of SO_2 are very high for the waste biomass fuel. If it contains six times more sulfur than natural wood chips, values of SO_2 in the exhaust is close to be 100 higher than for natural chips woods. The combustion of the mixture natural forest chips and sewage sludge seems to have good emissions results since all pollutants present low emission regarding to the standard limitations.

5 Conclusions

The new renewable energy target of the European Commission is an increase of 27% of its use and a reduction of 40% in greenhouse gas emissions by 2030, compared to 1990 [14]. Consequently, the use of renewable resources, in particular biomass, has an important increase in the last decade.

In order to expand the resource of efficiently and environment friendly fuels used in energy production, two combustion tests were conducted: one with the classical biomass "natural forest chips" and the second with a mixture of natural forest chips and sewerage sludge. These fuels were combusted in a biomass moving grate automatic boiler. The emissions performances of CO, CO_2, NO_x and TSP were studied. They were measured below the regulation limits for both fuels meaning that the biomass waste could be combusted for energy production in such facilities below 5 MW without modification of the system. Smoke cleaning devices are also performant even with the waste biomass.

Despite the fact that the mass of ash collected is much larger with the mixture wood chips and sewage, there was not much difference in the deposition of the ashes into the different parts of the boiler between the two tests.

If SO_2 is below the regulation limit, its emissions should be controlled as NO_x by suitably adjusting the ratio of sludge in the mixed fuel in order to deal with standard limits.

Further tests could be considered with the same biomass and different mixing ratios. Moreover, future studies could focus on other different types of biomass such as wood waste and the resulting pollutants emissions. In order to help expanding more the biomass resource and thus make a further step towards "waste-to-fuel" purpose, other pollutants can be added to the classic tracked ones such as Polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs).

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. International Energy Agency (2020). *Key world energy statistics 2020*.
2. Ministry of ecological transition (2020). Biomass energy. https://www.ecologie.gouv.fr/biomasse-energie.
3. Phan, C., Plouhinec, C. (2020). Chiffres clés des énergies renouvelables. *Édition*.
4. Nussbaumer, T. (2010). *Overview on technologies for biomass combustion and emission levels of particulate matter*. Verenum Press Zürich, (Switzerland).
5. The European Parliament and The Council of the European Union (2004). Directive 2004/107/EC. https://eur-lex.europa.eu/legal-content/FR/TXT/HTML/?uri=CELEX:32004L0107.
6. The European Parliament and the Council of the European Union (2008). Directive 2008/50/EC. https://aida.ineris.fr/consultation_document/863.
7. Cesprini, E., Resente, G., Causin, V., Urso, T., Cavalli, R. et al. (2020). Energy recovery of glued wood waste–A review. *Fuel, 262,* 116520. DOI 10.1016/j.fuel.2019.116520.
8. Lavric, E. D., Konnov, A. A., Ruyck, J. D. (2004). Dioxin levels in wood combustion—A review. *Biomass Bioenergy, 26,* 115–145. DOI 10.1016/S0961-9534(03)00104-1.
9. Vesterinen, R., Martti, F. (1996). Organic emissions from co-combustion of RDF with wood chips and milled peat in a bubbling fluidized bed boiler. *Chemosphere, 32,* 681–689. DOI 10.1016/0045-6535(95)00343-6.
10. Zhang, H., Lv, C., Li, J., Qin, W., Hu, Y. et al. (2015). Solid waste mixtures combustion in a circulating fluidized Bed: Emission properties of NO_x, dioxin, and heavy metals. *Energy Procedia, 75,* 987–992. DOI 10.1016/j.egypro.2015.07.322.
11. Moreno, A. I., Font, R., Conesa, J. A. (2016). Characterization of gaseous emissions and ashes from the combustion of furniture waste. *Waste Management, 58,* 299–308. DOI 10.1016/j.wasman.2016.09.046.
12. Nussbaumer, T. (2003). Combustion and co-combustion of biomass: Fundamentals, technologies, and primary measures for emission reduction. *Energy Fuels, 17,* 1510–1521. DOI 10.1021/ef030031q.
13. The French National Institute for Industrial Environment and Risks (INERIS) (2018). https://aida.ineris.fr/consultation_document/41025.
14. European Commission (2014). Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions, A policy framework for climate and energy in the period from 2020 to 2030.