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Full Length Article

Combustion tests of grape marc in a multi-fuel domestic boiler

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HIGHLIGHTS

- Issues for energy recovery from grape marc.
- Combustion tests in domestic boiler.
- Determination of combustion efficiency.
- Use of blends with conventional biomasses for optimization of the process.
- Measurements of gaseous and particulate pollutants.

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ABSTRACT

New sources of renewable energy have to be found in order to cope with possible fossil fuel scarcity. Among the renewable energy mix, biomass burning has an almost neutral CO_2 balance, especially when local biomass sourcing is possible. Among the diverse biomass sources, agricultural by-products such as rice husk, corn waste, palm waste, sugarcane, date palm, olive mill wastewater... can be seen as renewable biomass fuels. The present study considers the combustion process of grape marc in a domestic boiler. The optimization of the heat recovery process was mainly carried out using grape marc blended with wood pellets and/or miscanthus. The combustion process was assessed considering the molar carbon ratio ([CO]/[CO] + [CO_2]) and the total heat losses. These parameters have been chosen as they represent respectively the quality of the combustion in terms of CO conversion and the total efficiency of this combustion process. Gas and particulate matter emissions were estimated. It has been observed that the addition of grape marc with mass ratios in the range 25–33 wt% has no significant effect on the combustion efficiency (molar carbon ratio lower than 1.3%) and on the Total Suspended Particles emissions (TSP ranged from 20 to 40 mg Nm^{-3} at 10% O_2) for both mixtures. An efficient combustion of the blend miscanthus/grape marc at weight proportion 50/50 could also be achieved. The homogenization of mixtures of wood pellets and grape marc at 50/50 wt% was difficult to realize and led to relative high CO emissions. Is has also been observed that Nitrogen Oxides (NOx) emissions depend on the nitrogen content of the blend but remaining acceptable (less than 260 mg/Nm^3 at 10% of O_2). The feasibility of grape marc burning at domestic scale was therefore proved.

1. Introduction

Producing energy through biomass combustion is a sustainable process when considering the carbon dioxide balance and the rarefaction of fossil resources. Agricultural waste are valuable surrogate fuels for energy production as they are renewable, available in local circuits and abundant [1]. Therefore, the potential of agricultural by-products as biomass fuels leads to the elaboration of optimization strategies which have to be developed in order to recover the maximal energy and to limit pollutant (gaseous and particle) emissions.

The Alsace Region in France is well-known for wine production. The vineyards approximately cover 15 600 ha in Alsace which represent 1.9% of the total region area and produce 1.2 million of hL of wine per year, among other products. A large quantity of grape marc is thus available in this area. From the factors given by Caceres et al. [2], it is possible to estimate the corresponding dry

Abbreviations: DIN, Deutsches Institut für Normung; ELPI, Electrical Low Pressure Impactor; HHV, higher heating value (kJ kg^{-1}); LHV, lower heating value (kJ kg^{-1}); PM, particulate matter; Q_a, energy loss due to the sensible heat of flue gases (kJ kg^{-1}); Q_b, energy loss due to incomplete conversion of carbon monoxide (kJ kg^{-1}); TSP, Total Suspended Particles; DOP, di-octyl phtalate.

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matter produced in Alsace from grape marc as 30 000 tons per - year. As a matter of comparison, the grape marc residue was calculated in Italy at 500 000 tons of dry matter per year, leading to an interesting re-use of this material for energy recovery. In San Juan province in Argentina, 82 000 tons of grape pomace are produced each year which shows the potential of this waste [2]. Different uses of grape marc have already been referenced such as activated carbon transformation [3], cellulose and hemicellulose extraction [4] and grape marc is known for its antioxidant and biological properties [5]. The wine residue is also interesting for energy recovery. For example, Celma et al. assessed the use of grape marc in Extremadura (Spain) and calculated relevant economical specific costs and on site availabilities for this surrogate fuel [6].

Toscano et al. examined in [7] the physical–chemical composition of grape marc residues in Italy and especially the carbon content. They returned values close to that of wood chips, beech chips or wheat straw.

The thermal behavior of grape marc has previously been studied in the GRE lab through a thermogravimetric analysis under nitrogen or under air and their kinetic data have been obtained [8].

Other authors as Miranda et al. mentioned that grape biomass blended and diluted with other biomasses is available as a possible way to limit pollutant emissions at a thermogravimetric scale [9]. Air pollution comes from many different sources and the use of domestic boilers has already been pointed out as a major contributor for particle mater (PM) emissions [10,11]. This is an issue for biomass combustion. Favez et al. proved that 20 ± 10% of the ambient PM2.5 mass can be attributed to biomass burning during winter in Paris [12]. Similarly, Ward et al. highlighted that more than 82 wt% of PM2.5 in Libby (Montana, U.S.A.) is due to biomass burning [13]. Consequently, the assessment of combustion quality, especially at the domestic boiler scale, has to be performed in order to limit pollutant emissions.

Burning wine residues in a domestic biomass boiler can be considered as an alternative pathway for grape marc reuse. Winemakers could thus use part of this waste produced during wine production as an on-site biofuel.

The present investigation is part of the project OUI Biomasse (INTERREG IV 'Innovations for Sustainable Biomass Utilization in the Upper Rhine Region), which aimed at developing the use of biomass as a renewable energy source and/or raw material in the Upper Rhine Region. This project brought together scientists from Germany, France and Switzerland studying all aspects of the biomass value chain to come up with alternative development scenarios, analyse their potential impact in terms of sustainability criteria and to draft guidelines for the sustainable use of biomass. Within this framework, the present study focuses on grape marc combustion for a low environmental impact. The objective is to analyse the energy recovery of grape marc in a domestic scale boiler focusing on the gas and particulate matter emission factors.

2. Materials and methods

2.1. Sample preparation and characterization

The wine residue tested in this study was collected directly after the pressing step and delivered by a winemaker located in Orschwir (Alsace, France). The residue was produced from Gewürztraminer grape. The grape marc may contain stalks, skins and seeds. As they were collected before the fermentation step, the by-products were then full of natural sugar. The sugar concentration within the corresponding juice was equal to 213 g/L.

Two different biomasses were used for the combustion experiments involving multi-fuels: miscanthus giganteus produced in Ammertzwiller (Alsace, France) and DIN CERTCO wood pellets, purchased from SOFAG (Arc sous Cicon, France). In order to get reference values for the thermal performances of the boiler and for the subsequent emissions, conventional biomasses usually used in energy recovery such as beech chips were also burnt.

The physical and chemical characterizations of the different samples were performed. The ultimate analysis of the different samples was carried out by the Institut des Sciences Analytiques (Centre National de la Recherche Scientifique, Villeurbanne, France) in order to determine carbon, hydrogen, oxygen, nitrogen and sulfur weight fractions, according to the standard EN ISO 16948 [14]. The samples were characterized following the standards EN 14774 for the moisture [15], EN 14775 for ash content and BS EN 14918 for lower heating value (LHV) [16,17]. A calorimetric bomb (C 200 from IKA) was used in order to determine the higher heating value (HHV). The lower heating values (LHV) were calculated based on free ash and water contents.

In the current study, grape marc and different blends were burnt in a multi-fuel boiler and their thermal and environmental performances were compared to that of DIN CERTCO wood pellets, miscanthus and beech wood chips burnt in preliminary experiments. Because the moisture content allowed in the boiler must be less than 30–35%, raw grape marc samples (denoted as RG) have first to be dried in order to reduce their residual humidity from 67% to 27%, thus obtaining a fuel (dry grape denoted as DG) compatible with the dedicated boiler. Conventional fuels are denoted as BC for Beech wood chips, M for Miscanthus and WP for wood pellets. All the samples tested in the boiler and their acronyms are gathered in Table 1.

Blends of miscanthus/grape marc and DIN wood pellets/grape marc in weight proportion 75/25, 67/33 and 50/50 were tested in the boiler. These proportions allow producing a blended fuel compatible with the boiler and presenting a maximal humidity of about 35% without drying. Two types of blend mixtures were prepared in loose contact or tight contact. The loose contact blends were obtained by a simple mechanical mixing of the two materials. They were prepared in a container (200 L) by hand mixing with a stick during 30 min. The loose contact blends were quite heterogeneous due to the presence of grape stalks and of agglomerates of humid grape marc. Due to this heterogeneity, it was not possible to stabilize the combustion of such blended samples and the results obtained will not be presented hereafter. The tight blended samples were prepared grinding together the grape marc and the co-combustible in order to obtain a homogenized blended mixture. The materials were fed into a cutting mill type RETSCH SM 300 with a grid of 20 mm. The grinding process mainly reduced the size of the stalks and split the agglomerates. The size distribution of the other components of the fuel did not considerably change but the mixing was clearly better. These tight contact mixtures are denoted in Table 1 as WP/G 67/33, WP/G 50/50, M/G 75/25, M/G 67/33 and M/G 50/50.

2.2. Combustion tests

Combustion tests were performed in a multi-fuel boiler (HKRST-FSK) supplied by REKA (Aars, Denmark) and equipped for combustion analyses. A schematic description of the boiler is given in Fig. 1. The boiler nominal thermal performance ranges from 30 to 40 kW depending on the fuel. The boiler basis is a moving step grate, which allows using almost every biomass fuel as the grate motion prevents slag formation. The boiler and the fitted hopper are located on a balance. Hence the mass losses (miscanthus/wood pellets/wood chips/grape marc) occurring during the combustion process are recorded. This allows calculating the consumption rate of the biomass. Water circulates in the double wall of the combustion chamber and in the fire tube heat exchanger. The primary combustion chamber is equipped with a fireproof lining on the