CROP RESIDUES AS FUELS FOR SMALL SCALE HEAT GENERATION IN SERBIA – POTENTIAL, ISSUES AND PERSPECTIVES

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Abstract

Crop residues represent significant source of renewable energy in agricultural regions and their energetic utilization could contribute to decreased energy dependence on fossil fuels, increased utilization of local, low-cost fuels, facilitate sustainable development of rural communities, improve air quality and decrease negative environmental impact of energy sector. Total potential of biomass in Serbia amounts to 12.5 million tons a year, and in Vojvodina (northern Province) 9 million tons or 72%. Within than, crop husbandry in AP Vojvodina generates more than 6 million tons of biomass waste every year. Most common crop residues in Serbia are wastes from cereal cultivation, such as wheat straw, corn stover and corn cobs, soy straw, etc., corn being the most cultivated crop. Despite their significant energetic potential, combustion of crop residues is associated with several issues, such as increased gaseous and particulate emissions, ash sintering/melting, fouling in the combustion chamber, etc. By applying discussed primary and secondary measures for increasing combustion efficiency and reduce emissions, crop residues can be utilized as fuels for small scale heat generation in agricultural regions.

Introduction

Biomass is the renewable energy source (RES) with the biggest potential in Serbia, amounting to 64% of total RES potential in Serbia. Biomass originates from forestry, wood processing industry, agriculture, municipal solid waste etc. In Vojvodina, the northern part of Serbia, and a predominantly agricultural region, residues from cereal cultivation and the most abundant and important biomass source. Furthermore, commercial production of biomass (or energy crops) for energy purposes is not yet common practice in Serbia. Having in mind that significant amounts of waste biomass must be disposed of in an adequate manner, and that solid biomass wastes have considerable heat value and energy content, thermochemical conversion of solid agricultural wastes presents promising way of solving two issues [1]. Crop residues could be utilized for heat generation in small and medium sized consumers in rural communities, since they could be sourced locally, are cheap, renewable, and sustainable, moreover since crop residues are wastes from agricultural sector and there is no competition with food cultivation. On the contrary, thermo-chemical utilization of crop residues for energy generation simultaneously manages bio waste and minimizes the amount of organic waste to be landfilled. However, thermochemical utilization of crop residues is associated with several operational and environmental issues. Given the fact that these solid fuels contain ten times higher amounts of ash than woody fuels, and significantly higher K, Na, and Cl contents, combustion of agricultural residues is associated with ash sintering and slag formation, fouling and corrosion in the combustion chamber, and elevated PM emissions. Therefore, these fuels cannot be combusted in conventional units for woody fuels, causing blockages, malfunctions and process interruptions. Main approaches for mitigating and/or eliminating aforementioned issues are discussed in this paper.

Against this background, the aim of this paper is to give overview or crop residue potential for energetic utilization in Serbia, issues associated with combustion of crop residues, possibilities for improvement and perspectives for future research.

Results and discussion

The total potential of biomass in Serbia amounts to 12.5 million tons a year, and in Vojvodina 9 million tons or 72%. Of this amount, 1/4 of biomass can be plowed back into the soil or as bedding for the production of manure, with the purpose of increasing fertility of the soil, 1/4 can be used for the production of fodder, 1/4 for the production of heat energy and 1/4 for other purposes [2]. Out of the total amount of biomass intended for heat production in Serbia (3.880,57 x 10^3 tons) tons), 2.794 x 10^3 tons could replace an equivalent amount of 948.6 x 10^3 tons of extra light fuel oil. This is the amount of diesel fuel consumed by the entire agricultural production in Vojvodina [2]. Overview of energy potential of biomass in Serbia is given in table 1.

Table 1. Overview of most common agricultural biomass wastes generated in Serbia (available for energy production) [2]

Nb.	**Type of biomass**	**Potential for energy purposes (10^3 t)**	**Lower heating value (MJ/kg)**
1	Wheat straw	743.75	14
2	Corn stover	1787.5	13.5
3	Corn stover of seed corn	21.56	13.85
4	Corn cobs	357	14.7
5	Sunflower stover	200	14.5
6	Sunflower shells	30	17.55
7	Barley straw	103.13	14.2
8	Soy straw	80	15.7

In AP Vojvodina crop husbandry generates more than 6 million tons of biomass waste every year, most of which is corn residue (stalk and cobs) with 54.8%, then wheat straw with 18.7% and sunflower residue (stalk, head and husk) with 13% [1, 2]. Despite their significant energetic potential, combustion of crop residues is associated with ash related operational problems (i.e. ash melting and sintering, fouling in the combustion chamber, corrosion of heat transfer tubes) as well as increased particulate matter (PM) emissions, ash sintering/melting, fouling in the combustion chamber, corrosion etc.

Despite its significant potential, energetic utilization of biomass is not straightforward, especially when taking into account negative environmental influence of combustion and PM emissions on air quality. In comparison with wood, crop residues have higher share of critical elements such K and Cl, and about ten times higher ash content, resulting in considerably lower ash melting temperatures (i.e. unfavorable ash melting behavior) [3, 4]. High share of ash and PM-forming elements in crop residues are the consequence of nutrients needed for plant growth, meaning that the deposition of trace elements within the organic matter of annual crops is often strongly influenced by the utilized mineral fertilizer [5]. This behavior might vary considerable between different crop species as well as specific crop components, various climatic conditions, different plant production measures and varying management schemes [6]. Contamination of inorganic impurities incorporated into the organic material due to harvesting processes as well as due to transportation and storage procedures may add up to this [7]. Problematic elements K, Cl, and S build several gaseous compounds during combustion at high temperatures. After saturation, cooling or chemical reaction with other elements gaseous compounds can condense and become PM [3]. Alkalis are mostly released as gaseous hydroxides, chlorides, and sulfates during combustion. K is the key element regarding PM generation and it causes formation of problematic species at different temperatures. K-salts (KCl, K_2SO_4 und K_2CO_3) are the primary components of the sub-micrometer particulate matter in the flue gas from biomass combustion [3, 8, 9]. Regarding ash sintering/melting, melting point of K-silicates lies in the range 750-1,400 °C, depending on K and Si content. Compounds containing trace amount of Na, i.e. K-Na-Si eutectics have even lower melting points, as low as 540 °C [10]. These molten compounds show acidic effects and accelerate corrosion and deposition by sticking of non-melted particles to the layer of melted particles [11]. Furthermore, when K_2SO_4 is produced, during reaction between KCl and SO_2, corrosive HCl is released in the furnace. In addition to this, KCl and K_2SO_4 account for 80 to 90 wt.% of total inorganic aerosol amount [3].

There are two general approaches to increase combustion efficiency and reduce pollutant generation, primary and secondary measures. Primary measures include modification of combustion and/or fuel, including improvement of the fuel feeding system, the fuel bed arrangement grate design, air supply strategy, burning chamber geometry, process control concepts, fuel conditioning etc. Since current automated pellet stoves and boilers cannot combust agricultural residues successfully due to high ash content and ash melting, combustion units have to be modified. High ash content causes problems during ash removal process as well as clogging of air feeding system. Second ash related problem is sintering/melting on the grate, which could possibly be resolved using vibrating grates, water-cooled grates etc., by preventing agglomeration of the ashes on the grate or reducing temperature in the bed zone. Among most important primary measures are air staging, provision of intensive mixing of the combustion and the flue gases in the secondary combustion chamber, long enough residence time in the secondary combustion zone at temperature above 800 °C. These measures can be implemented in all types of common residential biomass combustion systems (stoves, boilers) [12]. It should be noticed that primary measures increase combustion efficiency as well as decrease pollutant emissions, especially pollutants resulting from incomplete combustion (e.g. unburned hydrocarbons). From fuel conditioning perspective there are various approaches to reduce and/or minimize ash related operational problems during agricultural residues combustion, including fuel leaching, fuel blending and using metal/mineral additives. Additives are especially useful in abating two issues: sorption of alkali metals in the ashes to reduce PM emissions, and bind alkalis with earth alkalis in high temperature melting silicates (e.g. kaolinite).

Secondary measures include fuel gas treatment using cyclones, baghouse filters, electrostatic precipitators (ESPs), catalysts, scrubbers etc. Secondary measure have been successfully applied in large scale plants, however due to high price relative to heat generator price, they are still not common practice in small scale combustion devices. Not all separation principles are also used for small capacities. For example, the principle of the flue gas scrubber is only used for larger installations. Cyclones are rarely used in very small biomass combustion plants. They are particularly useful, when coarse ash particles caused by air movement in the bed (eg feed grate) are carried away into the exhaust gas. For ESPs various separation performances have been demonstrated in bench tests, depending on the type, they average between 50 and 80%. A distinction is made between deep and surface filters in the filter separators. In the case of very small firing capacities, built-in ceramic inserts (deep filter) are used in the combustion chamber (for fireplace and stoves). The cleaning is carried out thermally by burnout or through removal and manual cleaning. Conventional surface filters are, on the other hand, problematic due to the possible dew point drop and the condensation of organic particles (risk of sticking). By using metal with an internal electrical heating of the filter cartridge these problems could be reduced. However, research is still being performed in this area [13, 14].

No emission limit values for the combustion of crop residues exist in Serbia. However, updated emission limit values for solid fuel combustion include woody biomass combustion (from 2016). They are classified according to unit capacity and age, as presented in the following table.

Table 2.

	Pollutant	Fuel type	Heat capacity (kWth)	ELV (mg/Nm^3)
Existing units	Carbon monoxide - CO	Log wood,woody briquttes/pellets	50-150	4000
	Particulate matter	Log wood		150
New installations	Particulate matter	Log wood, excluding woody briquttes/pellets	≥ 4	100
		Woody briquttes/pellets	≥ 4	60
	Carbon monoxide - CO	Log wood, excluding woody briquttes/pellets	4-500	1000
		Woody briquttes/pellets	4-500	800

Emission limit values for small scale biomass combustion in Serbia [15]. However, it is expected that the emission limit values for crop residue combustion will also be included and controlled by the legislation in the near future.

Conclusion

From the aforementioned reasons, research should be focused on development of specialized heat generators designed for the combustion of fuels with high ash content and low ash sintering temperature, on one hand. Modification and adjusting of combustion units requires further research, although significant efforts have been undertaken and progress has been achieved. On the other hand, low-cost fuel conditioning measures (additives, leaching and pelletizing) could improve the quality of fuel by artificially bringing composition of agro fuels closer to the composition of woody biomass and “imitating “ its behavior, whereas pelletizing reduces transport and storage costs and creates fuel of standardized quality and uniform properties. Combination of stated measures would lead to the development of highly efficient combustion devices with lowered emissions of pollutants, tailored to the crop residues as fuels.

Since biomass represents the crucial and most abundant RES in Serbia, research in the field of crop residue combustion in small scale heat generators could facilitate its wider use, more efficient utilization and reduced emissions of pollutants.

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