Journal of the Energy Institute xxx (2016) 1–11

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Study of clean combustion of wood in a stove-fireplace with accumulation

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A R T I C L E I N F O

Article history:
Received 24 October 2015
Received in revised form
26 April 2016
Accepted 3 May 2016
Available online xxx

Keywords:
Clean combustion
Biomass-fired appliances
Stove-fireplace with accumulation

A B S T R A C T

The paper presents the results of works aimed at the reduction of carbon monoxide (CO) emissions to the atmosphere during wood combustion in a stove-fireplace with accumulation (SFA). The first part of the conducted study includes the comparison of combustion parameters of beech wood characterized by varying qualities. The second part encompassed testing different variants of control of the SFA operation. Two signals: the volume of oxygen (O_2) and carbon monoxide (CO) emission were used in the first version of developed controller. These signals were coupled with upper air, bottom air and rear air dampers, controlling the opening and closing of the air throttles depending on the pre-set boundary parameters (minimal set content of oxygen in exhaust gases and the maximal set content of carbon monoxide). The studies conducted so far have confirmed the possibility to reach the exploitation parameters required by the BImSchV 2 and Ecodesign standards.

1. Introduction

Stove-fireplaces with accumulation, which combine convection fireplaces and stoves, may be formally classified as heat accumulating room heaters. The requirements for such appliances have been indicated in the PN-EN 13229 standard, which provides both the requirements regarding the tests and the limits of pollution emissions to the atmosphere. In line with this document, the mean emission of carbon monoxide in the process of combustion should not exceed 3345 mg/Nm^3 (that is about 3000 ppm). The Austrian BImSchV 2 standard is much more restrictive. It provides a maximum value of CO emission at a level of 1250 mg/Nm^3. High requirements are also given in another European document – the 2009/125/EC Directive (Ecodesign). Ecodesign covers all energy converters applied in construction industry and – in most cases – it only provides rules and criteria for establishing requirements relating to these appliances by executive bodies. Specific requirements are provided for appliances which have a significant impact on the natural environment and are characterized by a large share in the European market. This group includes stove-fireplaces with accumulation (which is related to a large potential of limiting the emissions from biomass combustion by applying modern methods of combustion and treatment of exhaust gases). The emissions of carbon monoxide to the atmosphere, in line with Ecodesign, shall not exceed 1500 mg/Nm^3 in case of new appliances.

The increasingly restrictive standards caused the measurement of CO emission to become really important in case of the quality control fireplaces, stoves and stove-fireplaces with accumulation. The importance of such measurements is caused by possible differences in CO emissions dependent e.g. on the way the combustion process is controlled [5].

The formation of various pollutants during the combustion of wood exhibits a quite complicated character. Fig. 1 provides a simplified representation of how the pollutants are formed.

It may be noted that the formation of soot and condensable organic compounds (COC) results from incomplete combustion, and is generally correlated with a local lack of O_2. Incomplete combustion often occurs in a simple, manually controlled furnaces. It may also occur in automatically controlled furnaces in the starting phase of the combustion process or in the case of abnormal operation of the automation system. Clean combustion also depends on the type and the parameters of the fuel. The effect of temperature is also significant.

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http://dx.doi.org/10.1016/j.joei.2016.05.001

Please cite this article in press as: K. Sornek, et al., Study of clean combustion of wood in a stove-fireplace with accumulation, Journal of the Energy Institute (2016), http://dx.doi.org/10.1016/j.joei.2016.05.001

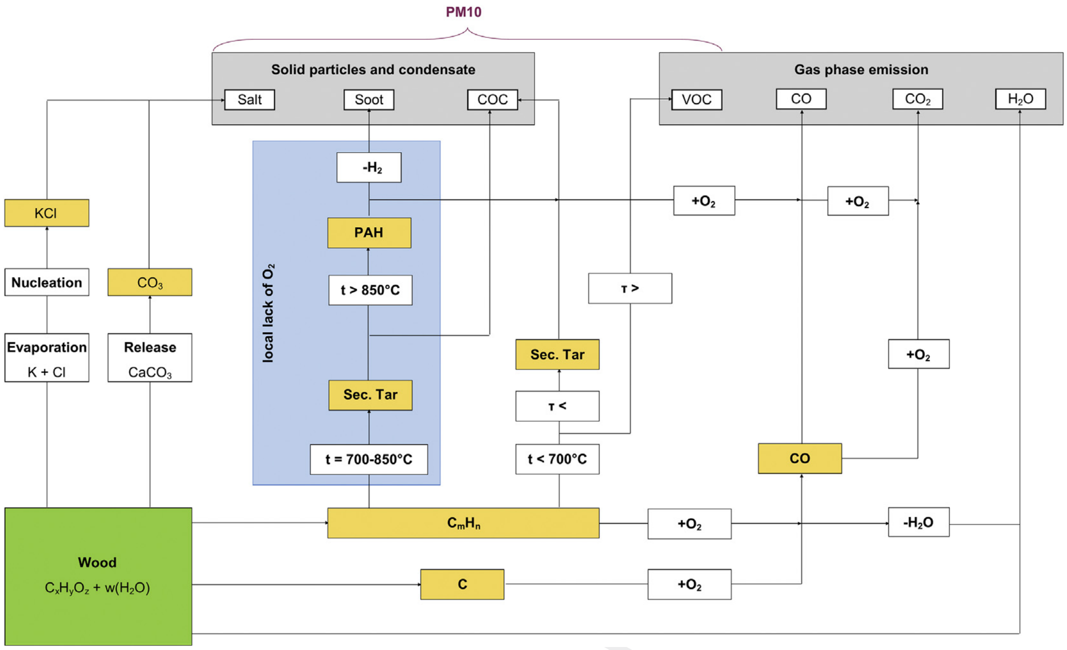

Fig. 1. Diagram of contaminants formation in the combustion of biomass (own work based on Ref. [8]).

The direct tests confirm the strong dependence of the CO and dust emission from heating appliances with their construction and the level of automation. Really low emission may be achieved by means of good mixing of flue gas with air (e.g. CO <50 mg/m^3 or C_xH_y <5 mg/m^3, at 11% O_2). However, more precise control of the combustion process requires the use of a CO or lambda probe connected to an appropriate controller [8].

The increasing demands in the field of reduction of CO emissions to the atmosphere make it necessary to improve the operating parameters of the existing and developed heating appliances. The high potential of low-emission combustion of wood in stove-fireplaces with accumulation is related to the optimization of the furnace geometry and the geometry of the fuel bed, as well as improvements in the control method of combustion process. Clean combustion also depends on the type and the parameters of the fuel.

The geometry of the combustion chamber is yet another very important factor influencing the CO emission. This is mainly due to the spatial distribution of the inlet air flow and the combustion temperature. Also the geometry of the fuel bed has a significant impact due to area of contact of the oxidizer with the fuel and the size of the available combustion chamber. The impact of the geometry of the fuel bed in the fireplace on the quality of the combustion process has been previously analyzed by our team [13]. In the analysis, a numerical model of the combustion process has been developed. The developed for simulating the process of the CO oxidation was based on the k-epsilon model of turbulences and eddy dissipation model of combustion. The reaction rate was limited by the Arrhenius equation, including the impact of the temperature on the process. The “Monte Carlo” model of the radiation has been applied.

The simulation involved homogenous combustion during the post-combustion of the gasification products represented by the CO. The fuel bed was treated as a CO source dependent on the external surface of the wood pieces. It has been shown that the location of the fuel bed in the central part of the combustion chamber causes an accumulation of the gasification products in that region and results in subsequent problems with the efficient post-combustion of the CO. It has been shown that the geometry of the fuel bed impact corresponds to a level of ca. 7% of CO emission. The external area of the wood load and its weight were recognized as additional factors having an impact on the combustion. This is because an increased amount of wood results in a shorter path required by the gasification products to reach the outlet from the region of the combustion and the shorter time of presence of such substances in the area characterized by appropriate conditions for the post-combustion.

The amount of fuel loaded into the furnace should also be taken into account – the height of the fuel bed is not without significance. It is really important to note that the use of fuel characterized by the same properties in the same device does not guarantee the same parameters of the heating unit operation. A significant reduction of the pollutants emission is possible e.g. by normalizing the method of the wood loading to the furnace. The most efficient post-combustion of the CO is possible by using a comprehensive approach consisting in the use of the recommended geometry of the fuel bed, the appropriate design of the air feeding system as well as the geometry of the combustion chamber.

The second part of modeling analysis concerned the comparison of two types of wood. The first part of the work described in Ref. [14] was devoted to the detailed study of the decomposition process using the TGA method for small samples of the fuel. Subsequently the combustion of the selected fuel was performed in the fireplace. The areas of the most effective combustion process were identified by means of the analysis of the concentrations of CO, CO_2 and O_2 in the furnace area that were obtained in the CFD simulation. The process of the thermal decomposition of the fuel was represented by the concentration of CO, which was the highest in the lower area of the furnace, directly above the fuel bed. In the central part of the furnace, where the CO started to mix with the oxygen, the combustion process was more efficient. This resulted in a higher concentration of CO_2 at the top, under the deflector. The concentration of O_2, which was the highest on the sides of the combustion chamber, denoted the areas where the reaction process is not effective. It has been shown that softwood and hardwood exhibited different contents of the three pseudocomponents, i.e. the hemicelluose, the cellulose and the lignin. The differences resulted in

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