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Tar fouling reduction in wood pellet boiler using additives and study the effects of additives on the characteristics of pellets

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A B S T R A C T

Fouling of tar in wood pellet boiler reduces its thermal efficiency and demands periodical maintenance to keep its original performance. The fouling of tar in wood pellet boiler was studied along with the physical and thermal characteristics of the pellets. Four different samples were prepared and accessed: a sample of control pellets without additives and three other samples each with 2% additives (dolomite and/or lime). Experiments for each sample were carried out in the pellet boiler for 20 h and fouling of tar is investigated. It is observed that the fouling of tar is drastically reduced in the pellets with additives 1% dolomite plus 1% lime: 76% by area-density (kg/m^2) and 82% by thickness (mm). At the same time, the particle density, mechanical durability, bulk density, and heating value are also found to be improved leading to an improved overall performance of the pellets and the boiler. The pellets with the additives are, therefore, found to be a better option to reduce tar in wood pellet boilers and are recommended.

1. Introduction

The increase in the cost of oil and gas demanded the alternative fuel-burning boiler as the burning of wood is comparatively cheaper [1]. In general, biomass boilers need more periodic maintenance as compared to conventional boilers [2]. The inconsistent properties of wood cause problems in combustion that can be solved by using wood pellets having fairly consistent properties as a fuel [3]. Due to sustainable features of the pellets, its demand is rising globally, and the countries, like the Republic of Korea, which have to import major parts of their primary energy, are formulating the policies to promote its use [4–6].

Higher amount of ash, tar and clinker are produced in combustion due to non-uniform moisture content (MC) in biomass [7]. The fouling of produced tar in heating surfaces of the combustion chamber is a well-known problem in biomass burning. The fouling of tar decreases the thermal efficiency of the boiler by reducing the thermal heat transfer and, after a long period of operation, it can damage the boiler by erosion [8–12]. The study by Euh et al., 2016 [12] has focused on the effects of tar fouling on the thermal efficiency of boilers and found that about 7.26% of efficiency is decreased for 1 mm thickness of tar fouling.

The above-mentioned studies have raised the issues related to tar fouling in biomass combustion. In gasification, extensive research has been conducted regarding the tar emission reduction [13–17]; however, in combustion, no such studies are being reported that have discussed the tar fouling reduction methods.

In this study, materials that foul on the boiler heating surfaces are collectively termed as tars. The reduction of tar in boilers may be achieved by three methods: pretreatment of biomass, treatment during combustion, and self-modification (Fig. 1). The scope of this study is to pretreatment of biomass, as a previous study [18] revealed that on using lime and dolomite in-situ with combustion rather increased fouling as the materials (catalysts) used were also fouled. The pretreatment using dolomite and lime additives in wood pellets is done to reduce tar fouling in wood pellet boiler and the effects of these additives on physical and thermal characteristics of pellets are investigated.

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Abbreviations

RM_{iC}	Increase in raw material cost as of additives used in pellets (%)
C_W	Specific heat of water (J/kg°C)
WC_C	Wood chips cost (USD/ton)
db	dry basis
D_{bw}	Bulk density of pellets (kg/m^3)
h	Height of container (m)
LHV	Lower heating value (kJ/kg)
LHV_P	Lower heating value of pellets (kJ/kg)
MC	Moisture contents (%)
M_C	Mass of the container (kg)
MC_P	MC of pellets (%)
MC_{WC}	MC of Wood chips (%)
M_P	Pellets feed rate (kg/sec)
M_t	Total mass (container and pellets) (kg)
M_W	Flow rate of water (L/sec)
Q_i	Total input power to the boiler (kJ/sec)
Q_o	Total output power from the boiler (kJ/sec)
r	Radius of the container (m)
T_{Wi}	Inlet water temperature to the boiler (°C)
T_{Wo}	Outlet water temperatures from the boiler (°C)
USD	United States dollar
V_C	Volume of container (m^3)
W_C	Cost of Wood (USD/ton)
wt	Weight

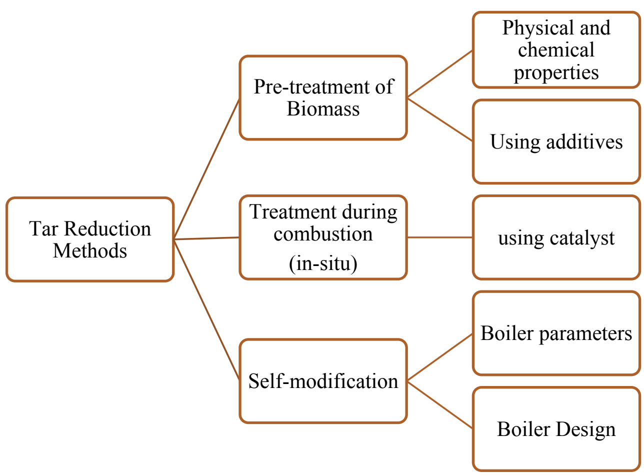

Fig. 1. Tar fouling reduction methods in Boiler.

2. Materials and methods

2.1. Tar formation

Cellulose, hemicellulose, and lignin components of the biomass break down into primary tar in the pyrolysis stage, in the temperature ranging from 200 to 500 °C [19]. In biomass gasification, the produced gas mainly contains CO, CO_2, H_2O, CH_4, together with organic (tars), inorganic impurities (H_2S, HCl, NH_3, alkali metals) and particulates released as shown in Eq. (1) [20]. Tars can condense or polymerize into more complex structures on exit pipes, heat exchangers or on particulate filters leading to choking and attrition. It reduces the total efficiency and results in an increased cost of the process [20]. Increasing temperature in the boiler converts low-order hydrocarbons into high-order hydrocarbons and larger polycyclic aromatic hydrocarbons (PAH) [19].

2.2. Additives use

Based on the performance of catalysts used in the gasification process and economic analysis [21–25], dolomite and lime were chosen to reduce tar fouling in the wood pellet boiler. Based on the Korean and European pellets standards, in this study, 2% additive was used to make pellets [26,27].

Dolomite is an alkaline earth metal oxide called calcium magnesium carbonate ($CaMg(CO_3)_2$) [28] and is an inexpensive disposable catalyst [29]. It generally contains CaO (30 wt%), MgO (21 wt%), CO_2 (45 wt%), and traces of SiO_2, Fe_2O_3, and Al_2O_3 [25]. Calcium oxide (CaO) is commonly known as lime and is prepared by the thermal decomposition of limestone ($CaCO_3$).

The dolomite of diameter in the range from 0.25 to 0.7 mm was obtained from the local market at the rate of 0.50 USD/kg and its MC was measured to be 0.11%. Similarly, lime of the average diameter 0.084 mm (0.11% MC, 0.68 USD/kg) was obtained and used in the study.

2.3. Production of wood pellet

The wood pellet was produced in Daegue, near Geumho Park (35°89′74″ N, 128°52′14″ E), and the Forest Practice Research Institute (37°75′90″ N, 127°17′09″ E) in Pocheon-si, using the same mobile wood pellet plant and raw materials. The *Pinus densiflora* wood chips of average MC 21.15% (see MC measurements method in section 2.3.1) was used as raw materials. The cost of the wood chips was 72.08 USD/ton. The chips were crushed to give sawdust-like powder and dried. The additives are then mixed with an electric blender. A mobile pellet plant with a designed capacity of about 300 kg/h was used for pelleting that produces pellets of about 6 mm diameter. Four different types of sample pallets are made: control pellets (without additive), pellets with 2% dolomite, pellets with 2% lime and pellets with 1% dolomite plus 1% lime, each about 120 kg. The pellets thus produced were then allowed to cool in room temperature and packaged separately in plastic bags.

$$\begin{aligned}\text{Biomass} + O_2(\text{or } H_2O) &\rightarrow CO, CO_2, H_2O, H_2, CH_4 + \text{other hydrocarbons}\\ &\rightarrow \text{ash} + \text{tar} + \text{char}\\ &\rightarrow HCN + NH_3 + HCl + H_2S + \text{other sulfur gases}\end{aligned} \quad (1)$$