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Particulate matter emissions from combustion of wood in district heating applications

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ABSTRACT

The utilization of wood biomass to generate district heat and power in communities that have access to this energy source is increasing. In this paper the effect of wood fuel properties, combustion condition, and flue gas cleaning system on variation in the amount and formation of particles in the flue gas of typical district heating wood boilers are discussed based on the literature survey. Direct measurements of particulate matter (PM) emissions from wood boilers with district heating applications are reviewed and presented. Finally, recommendations are given regarding the selection of wood fuel, combustion system condition, and flue gas cleaning system in district heating systems in order to meet stringent air quality standards. It is concluded that utilization of high quality wood fuel, such as wood pellets produced from natural, uncontaminated stem wood, would generate the least PM emissions compared to other wood fuel types. Particulate matter emissions from grate burners equipped with electrostatic precipitators when using wood pellets can be well below stringent regulatory emission limit such as particulate emission limit of Metro Vancouver, Canada.

Contents

1. Introduction

Recent efforts towards reducing greenhouse gas emissions have led many countries to utilize renewable energy sources for heat and power generation purposes. Among renewable sources, wood

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biomass is considered as a greenhouse gas neutral energy source; therefore governments have been implementing policy measures to increase the share of wood biomass in their countries' primary energy source basket.

In countries where abundant sources of biomass are available, producing all or part of energy requirements of communities from biomass is now a well established concept. Sweden is a good example among countries with established market for utilizing various forms of wood biomass in community heat and power applications [1]. Despite its wide application, there are concerns about potential negative human health impacts of certain pollutants concentration in the air from combustion of wood fuel for energy generation in populated areas.

Scientific evidences show that human exposure to airborne particulate matter emissions can have far severe health implications than many other airborne pollutants [2]. Samet et al. [3] found correlation between the level of PM_{10} concentration in the ambient air and the rate of death. Pope et al. [4] concluded that long-term exposure to fine particulate matter from combustion would have approximately a 6% and 8% increased risk of cardiopulmonary and lung cancer mortality, respectively. Exposure to ultra-fine particulates (0.01–2.5 μm – PM_{25}) could increase the risk of severe respiratory disease [5]. Also, the chemical composition of particles influences the severity and type of health effects.

Uncontrolled wood combustion will emit a variety of air pollutants to the atmosphere [6]. Van Loo and Koppejan [7] list primary emissions of wood combustion as: carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non methane volatile organic compounds (NMOC), nitrogen oxides (NO_x) and nitrous oxide (N_2O), ammonia (NH_2), sulphur oxides (SO_x), particulate matters (PM), trace elements of heavy metals, dioxins and furans-polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Concerns with wood combustion for community energy generation in a populated area are mostly related to particulates found in the flue gas [8]. Among the toxic chemical compounds that can be found in the combustion of material with chlorine content are dioxins and furans. Dioxins and furans are among ultra-fine particles (below 1 μm in diameter) emitted to the atmosphere from wood combustion. Dioxins and furans in air, water, soil and food causes negative health effects, such as carcinogenicity, immunotoxicity, and disturbance of lipid metabolism in humans [9]. It has been consistently observed that human exposure to dioxins and furans increases the mortality rate in all cancer types including rectal and lung cancers [10]. Negative effects on endocrine and reproductive system are among the most sensitive effects of dioxins and furans [11]. Trace elements of metals, such as sodium, potassium, cadmium, lead, mercury, and arsenic that can be found in the wood combustion flue gas particles in very small amounts have toxic effects on human [8]. Therefore, monitoring and controlling both concentration and composition of particulate matters in the air should be of the highest importance for municipal authorities [8].

Usually each regional district has regulatory emission limits in place for point source emitters in order to maintain the desirable local air quality. In 2008, Metro Vancouver introduced air contaminant discharge bylaw within the region. The regulations divided the boiler and heat producing systems into three categories of small (<3 MW), medium (3–50 MW) and larger than 50 MW systems. This regulation, sets the maximum total filterable particulate matter emission at 18 mg/m^3 (at 20 °C, 101.325 kPa, dry gas, and 8% O_2).[1] For rural applications, the maximum particulate matter is set at 30 mg/m^3. An urban facility is defined as a boiler or heater operating within 500 m of more than 20 residential or business premises, schools, hospitals, and such a like. The regulation sets the limits for nitrogen oxides at120 mg/m^3, and carbon monoxide at120 mg/m^3 for new or modified systems and 200 mg/m^3 for the existing boilers [12]. This regulation defines wood products as wood pellets, hog fuel, mill ends, wood chips, bark, shavings or sawdust and industrial residue of wood that has not been treated with glue, paint and preservative, or do not contain foreign substances harmful to humans, animals or plants when combusted (e.g. salt laden wood). Composition of particulates is highly important when considering human toxicity effects of airborne pollutants [13]. Most regulations impose limits on mass concentration measures of particulate emissions regardless of their specific chemical composition.

The primary aim of this study is to provide measured ranges of particulate emissions from the literature on systems that can typically be used for district heating applications. The secondary objective is to provide insight into factors influencing particulate matter emission levels from typical size district heating systems (from ~500 kW to ~10 MW) utilizing wood combustion. Special attention is paid to the effects that combustion condition and natural variations of wood composition would have on the particulate matter emission levels from wood combustion.

2. Particulate matters from wood combustion

Primary particulate emissions from wood combustion are from two main sources: (1) particulates from complete combustion including inorganic material in the flying ash, and (2) particulates from incomplete combustion including soot, condensable organic particles (tar), and char [14].

It has been reportedly shown that particulate mass concentration in the flue gas of complete wood combustion has two distribution peaks (coarse peak and fine peak) [15–18]. Sub-micron flying ash particles (<0.5 μm) are produced from vaporization of easily volatilized ash components (S, Cl, Na, and K) and the heavy metal zinc [19]. Coarse particles are formed from residual flying ash particles ejected mechanically from the fuel bed and are carried by the flue gas upwards [19] or intractable ash compounds of Ca, Mg, Si (if present) [20].

Incomplete combustion is a result of unfavorable combustion conditions such as inadequate mixing of air and fuel in the combustion chamber, low combustion temperatures, or short residence times [7]. Under incomplete combustion, submicron organic particles (soot <0.5 μm) can be produced [19]. Boman et al. [15] tested 6 different pellet fuel types in three different commercial pellet burners (10–15 kW) and observed that ultra-fine particles (<1 μm) constitute 89.5% ± 7.4% of total PM emissions from the systems, 28–92% of which were products of incomplete combustion. Advanced industrial wood combustion technologies which are available today can achieve more complete burnout of wood fuel and produce less incomplete combustion emissions compared to small scale and old type burners through maintaining desirable combustion condition [7]. Wood fuel properties [21] and combustion technology [22] affect composition as well as amount of particulate matter emissions leaving the combustion chamber.

2.1. Wood properties and particulate emissions

The European Standardization Committee for solid biofuels (CEN/TC 335) defines the quality of wood biomass by its physical properties and chemical content. Physical properties of wood biomass include moisture content, density, calorific value, ash content, and volatile matter content. The elemental content of wood biomass consists of C, H, N, S and Cl, water soluble Cl, Na and K con-

[1] Mass concentration of particulate emissions in the flue gas is stated in mg/m^3 with the reference condition (temperature and pressure). The mg/N m^3 unit represents mass concentration under normal gas condition (0 °C, 101.325 kPa).