Renewable Energy 84 (2015) 22–29

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Environmental assessment of crop residue processing methods in rural areas of Northeast China

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ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form
2 June 2015
Accepted 28 June 2015
Available online 9 July 2015

Keywords:
Crop residue
Biomass boiler
Rural area
$PM_{2.5}$

ABSTRACT

The two main processing methods for crop residue in Northeast China are stove burning for house heating and open burning as a waste product. Neither method is appropriate, as large amounts of pollutants released. This paper, therefore, proposes biomass boilers as a source for rural district heating. In a rural area in Northeast China, the $PM_{2.5}$ dispersions by the aforementioned three methods were simulated using the AERMOD model and the environmental impacts were assessed. The results show that the maximum peak concentration (MPC) is 1248 μg/m^3 for stove burning and 90,602 μg/m^3 for open burning; the general average concentration (GAC) is 345 μg/m^3 for stove burning and 1897 μg/m^3 for open burning. These concentration levels greatly exceed the thresholds established by China, the USA, and the WHO. However, the MPC for biomass boilers is only 2.76 μg/m^3, a 99.78% and 99.99% decrease from the stove burning and open burning methods, respectively. The GAC for biomass boilers is 1.3 μg/m^3, a decrease of 99.62% and 99.93%, respectively. Meteorological characteristics greatly influence the dispersion patterns of pollutants. In summary, replacing household heating stoves with biomass boilers is a bio-energy utilization method worth implementing widely to substantially improve the local atmospheric environment.

1. Introduction

Winter in Northeast China is long and cold. Thus, the heating period usually lasts for six months (from mid-October to mid-April), resulting in a huge demand for space heating. Due to advantageous geographical conditions, crops and resultant crop residues are abundant in Northeast China. Current methods of processing crop residues include direct burning in stoves for house heating (hereinafter “stove burning”), direct burning in open fields as a waste product (hereinafter “open burning”), animal feed, plant food, or industrial materials. The former two methods account for 50% and 29% of crop residue processing, respectively [18], which adversely affects the atmospheric environment. Stove burning has other disadvantages as well, including low efficiency and inconvenience to operate. Densification is an appropriate energy utilization technology to apply to crop residues, which could achieve full use of crop residues when used with boilers [19].

At present, most research into environmental impacts of crop residue burning focuses on open burning in large fields using simulations. A US regulatory model, the California Puff (CALPUFF) modeling system is a common tool for these simulations. Yang et al. [17] integrated CALPUFF modeling and the Fire Emission Production Simulator (FEPS) model to simulate the dispersion of PM_{10} from straw burning in Central China; Jain et al. [6] simulated the dispersion of PM_{10} from agricultural field burning in the Pacific Northwest using the ClearSky system; and Choi et al. [2] employed Mesoscale Meteorological Model Version 5 (MM5) and microscale module CALMET of CALPUFF as a modeling system to simulate PM_{10} dispersion from agricultural fires on the US/Mexico border. However, existing environmental assessments of biomass boilers have mainly focused on pollutant emissions. Zhou et al. [21] conducted a test comparing straw fuel and coal. The results show that the energy output of these two fuels is equivalent to a 0.8 t/h industrial boiler, and that the concentration of air pollutants from straw fuel is lower. Liu et al. [8] tested air pollution emissions for new straw boilers according to the Chinese standard testing method for boiler emissions. The results show that carbon monoxide (CO), nitrogen oxide (NO_x), sulfur dioxide (SO_2), and fumes were significantly lower than those from a typical coal boiler. Guo et al. [4] studied the

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http://dx.doi.org/10.1016/j.renene.2015.06.063

emissions effects of a biomass briquette boiler employing tertiary air distribution. The results show that NO_x concentrations can be effectively altered by adjusting the proportions of all three levels of air distribution in the boiler burning room, thus providing a basis for the design and operation of a clean-burning, low-NO_x briquette boiler.

Until now, few studies have looked at environmental impacts of stove burning or pollutant dispersion characteristics of boiler burning of crop residues. This study proposes the implementation of biomass boilers as district heating sources in rural areas of Northeast China. An environmental assessment is accomplished by comparing the results of simulating $PM_{2.5}$ dispersions of the three aforementioned combustion modes (stove burning, open burning and biomass boiler burning) using the AERMOD model.

2. Methods

2.1. Study area and study period

The study area consisted of four villages in the Northeast China Plain in the range between 44°55′N, 127°10′ and 44°57′N, 127°13′E. Surface conditions of the region are shown in Fig. 1 and the demographic information of the four villages is summarized in Table 1.

In Northeast China, the average daily temperature usually drops below 5 °C in mid-to-late October, when district heating begins in the local area. By this time, straw leaves also become completely air-dried and open burning commences. Therefore, the study period was established as Oct. 20–29, 2014, to compare the stove burning and open burning of crop residues. The average temperature during the study period was 3.9 °C.

2.2. Brief introduction to AERMOD modeling

The *Guidelines for Environmental Impact Assessment-Atmospheric Environment* (hereinafter "*Guidelines*") published by the Ministry of Environmental Protection [9] recommend AERMOD, ADMS, and CALPUFF modeling systems to predict atmospheric environmental impacts. AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) is applied for an assessment range of 50 km, in which it is advantageous compared to the other systems [16]. The prediction objects for AERMOD modeling include point sources, area sources, and volume sources. In addition, AERMOD has an extensive application range, including rural and urban areas, simple and complex terrains, and elevated and low sources. According to the characteristics and pollutant sources of the study area, AERMOD was chosen as the prediction software.

Table 1
Basic information of villages.

Village	Number of households	Residential area (m^2)
A	81	103,972
B	62	52,483
C	111	107,709
D	120	118,038
Summation	374	382,202

The input data of AERMOD consist of meteorological, topographic, and pollution data. The components and nexus of the input data are illustrated in Fig. 2.

2.3. Natural conditions and prediction grid division methods

This study obtained the surface and high-altitude meteorological data from a weather station near the study area. Digital Elevation Model (DEM) files were obtained from the topographic database of AERMOD, which covers the complete study area from 126°E, 44°N to 127°E, 45°N.

The *Guidelines* specify the division method for a prediction grid (see Table 2). The prediction grid division is contingent on mass concentration distributions. In areas with high concentrations, grid spacing should not exceed 50 m. This study employed a right angle axes grid. Grid spacing was set to 50 m in the area 1000 m within the source center and 500 m in the area more than 1000 m from the source center. Take The distribution grid of stove burning for example, the distribution of grid is shown in Fig. 3.

2.4. Simulation design and evaluation index

The simulation in this study consists of three scenarios. Scenarios 1 and 2 are stove burning and open burning of crop residues, respectively. In Scenario 3, crop residues are processed into briquettes by densification and burned in hot water boilers.

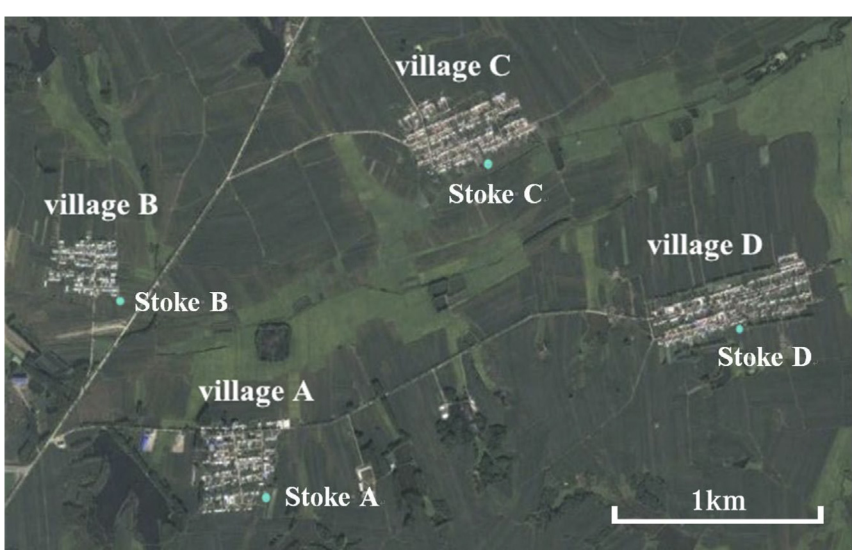

Fig. 1. Surface conditions of studying area and the locations of boiler chimneys.