Test burn at industrial boiler operated with biomass from radioactively contaminated forest

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Introduction

The remedial action proposed within International Chernobyl Bioenergy Project for radioactively contaminated forest in Belarus aims at collective dose reduction and safe reintroduction of wood resources. This action consists of the following measures: (i) decontamination of forest floor, (ii) introduction of special forestry practice, (iii) rational processing of contaminated wood, and (iv) use of the resulting contaminated forest litter and woody waste as a fuel for steam and power production.

The main concern is whether the conventional combustion technologies are applicable to safe utilization of contaminated biomass without unacceptable additional threat to environment and population health. It is a matter of common knowledge that very fine aerosols, especially sub-micron particles, are responsible for intake of and carrying the volatile metals and radionuclides when a thermal process with relatively high temperature is used. Fine particles are more susceptible to transport and have a higher uptake when inhaled. On the other hand, the actual distribution of these radionuclides versus particulate size and along a duct of industrial scale boiler are not known for certain, neither is the efficiency of radionuclide capture system employed. To address these questions, the special field trial of a baghouse filter coupled with industrial boiler located in contaminated Chernobyl region has been performed.

General Description of Test Installation and Measurement System

The test burn was performed at a wood-fired boiler located in RechitzaDrev Sawmill, Belarus in the zone of contamination of 40-200 Bq/m^2. The boiler with a fixed grate furnace had capacity of 9 tons steam per hour. The 2-stage aerosol capture system was assembled including one inert-type cyclone filter coupled with two bag filters. This system was designed to treat 2,800-3,000 Nm^3 of flue gas per hour and it was mounted in the by-pass circuit incorporated into the boiler's flue gas outlet duct thus treating about 15% of total flue gas flow. The system was equipped with one induced fan with productivity of 6,000 Nm^3/h and pressure head of 5kPa. The baghouse had a filter regeneration system with pulse cleaning by air pressure jets. The exhaust gas was iso-kinetically taken from the boiler's flue gas outlet duct and directed into the by-pass circuit. The flue gas passed through the cyclone and then was evenly distributed between two separate bag filter modules assembled in parallel. A module had a number of filter bags each made in a form of cage fixed to a cell plate on the top of module. After filtration, the flue gas that left the filtration section, returned back into the boiler flue gas outlet duct, and ejected through the boiler stack. The flue gas flow along the by-pass circuit was controlled by the baghouse induced fan and gate-type slide valves.

During the test burn, the following parameters were measured along the by-pass circuit with filters: flue gas flow rate, temperature and pressure, pressure drop in filters, flue gas chemistry (O_2, CO_2, CO, NO_X, SO_X), moisture content, total dust content, and aerosol spectrum. The measurements were also carried out to characterize the combustion process. The samples of flue gas were iso-kinetically extracted from several locations of the facility duct. A portable system was used for total dust sampling and measurement according to the German standard VDI 2066 part 7. For the impactor measurements, two Berner low-pressure impactors were used. These have 10 stages and cut-off diameters from 30 nm up to 16 ?m. The on-line laser spectrum analysis of aerosol fractions was also performed using a laser spectrometer coupled with a diluent. The samples of fuel, radioactive dust and ashes from several locations were taken and then analyzed in laboratory. For radioactivity measurements, the low-background spectrometer with Ge(Li) detector and guard annulus detector made of NaI(Tl) were used to provide gamma-ray spectrometry of the small samples with low activity level. The method is based on anti-coincidence mode that gives the sensitivity of 0.1 Bq/probe in case of two-dimensional geometry, the counting time being 7,200 seconds and less. A similar equipment, which includes a high purity Ge detector was also applied.

Results

It was difficult to provide steady-state combustion using the stoker-grate boiler equipped with a fixed grate combustor. Nevertheless, the representative measurements/samplings were performed in several test regimes when dust load variations were comparatively small. The measurements showed the following:

?? The average dust content of flue gas entering the capture system was 0.40 g/m^3.

?? After the cyclone, the average dust content reduced down to 0.25 g/m^3.

?? After the baghouse, the dust content was 0.0005 g/m^3.

?? Almost 95% of the total number of fine particles had the size of 0.1-0.4 micron. The size distribution of particles between the cyclone and the baghouse filter exhibited a Gaussian-like shape with a GMD of about 250 nm.

?? The radioactivity has a distinct maximum for the fine mode aerosol whereas the mass distribution is bimodal in nature. This pattern can arise from nucleation and aerosol formation of the radionuclides themselves, condensation of radionuclides on small particles, or generation of fine radionuclide particles during combustion.

?? The radionuclide content (^{137}Cs) in the fuel wood chips varied from 80 to 155 Bq/kg.

?? Most of activity was concentrated in fly ash (average specific activity was $15 \cdot 10^3$ Bq/kg).

?? The aerosol samples entrapped by total filters and impactor foils had the maximum specific activity of fine particles up to $57 \cdot 10^3$ Bq/kg.

?? The bottom ash and slag was less contaminated, ^{137}Cs specific activity being $1.6\text{-}2.7 \cdot 10^3$ Bq/kg.

?? In coarse particles collected in cyclone, the activity of $2.0\text{-}4.4 \cdot 10^3$ Bq/kg was detected.

?? The total efficiency of the entire capture system tested was about 99.5%.

Conclusions and discussions

As an important part of contaminated forest remediation strategy, the major issue addressed in this study is whether the existing biomass conversion technologies, e.g. stoker-grate combustion, are applicable to energy valorization of contaminated biomass waste in Belarus. Of particular interest in this context is the extent of emission of radiocesium from the stack. If there is no capture system installed, the investigated boiler routinely fired with contaminated fuel would annually release more than 2 GBq of radioactivity into the environment. As it is shown in this study, the fly ash particles are efficiently filtered in the baghouse filter, and only ca. 0.3 to 0.6% of the volatile radionuclides remains in the stack exhaust. In this case the doses to general public in vicinity of this boiler will be reduced by a factor of 500 and will be well below of permissible level. Although these figures tie in with some general observations by other researchers, the absolute values of the concentration factors are critically dependent on process-specific parameters, and may be associated with their significant variations during a test burn.

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