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Short communication

Acidity of vapor plume from cooling tower mixed with flue gases emitted from coal-fired power plant

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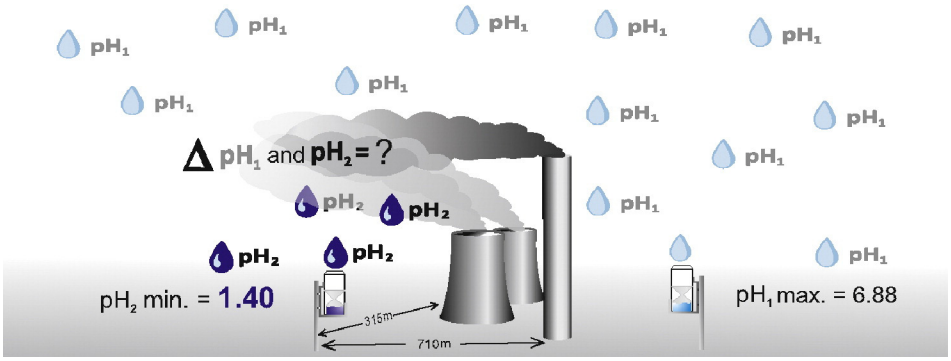
HIGHLIGHTS

- Very acid wet deposition may appear in very close vicinity of coal power plant.
- Coal power plant - pH of flue gas and cooling water plume mixture may reach 1.4.
- Solubility of compounds emitted from power plant may effect wet deposition acidity.

GRAPHICAL ABSTRACT



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ABSTRACT

Acidity of products resulting from the reaction of flue gas components emitted from a coal-fired power plant with water contained in a vapor plume from a wet cooling tower was analyzed in a close vicinity of a power plant (710 m from the stack and 315 m from the cooling tower). Samples of this mixture were collected using a precipitation funnel where components of the mixed plumes were discharged from the atmosphere with the rainfall. To identify situations when the precipitation occurred at the same time as the wind directed the mixed vapor and flue gas plumes above the precipitation funnel, an ultrasound anemometer designed for 3D measurements of the wind field located near the funnel was used. Precipitation samples of extremely high acidity were identified - about 5% of samples collected during 12 months showed the acidity below pH = 3 and the lowest recorded pH was 1.4. During the measurement period the value of pH characterizing the background acidity of the precipitation was about 6. The main outcome of this study was to demonstrate a very high, and so far completely underestimated, potential of occurrence of episodes of extremely acid depositions in the immediate vicinity of a coal-fired power plant.

1. Introduction

Acidification of the environment is considered to be one of environmental threats posed by exhaust emissions from power plants (Hewitt, 2001). The main cause responsible for acid rains is chemical transformations of acidic oxides, especially sulfur and nitrogen oxides. Their

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dominant source is fuel combustion processes especially in coal-fired power plants. Another component of flue gases from coal combustion processes that contributes to the acidification of precipitation is hydrogen chloride. Its main source are chlorides contained in the combusted coal.

Typically, emissions of flue gases from high power plant stacks are attributed to threats caused by acidification of the environment at large distances from emission sources (Schopp et al., 2003; Menz and Seip, 2004; Nyiri et al., 2009; EMEP, 2014). The potential of acid rain formation in the immediate vicinity of the power plants is completely neglected which is reflected in lack of relevant data in literature sources. Observing the positioning and migration of the flue gas plume from the stack and the vapor plume from the cooling tower (usually there is more than one plume) it can be easily noticed that the plumes often begin to mix already at a short distance from their emission source. Such situations may create extremely favorable conditions for a mutual reaction of gaseous acidogenic compounds (mainly SO_2, NO_2) contained in flue gases with highly dispersed, heated water forming the vapor plume emitted from the cooling towers. An important issue from the viewpoint of the acidification processes is that oxidation of SO_2 to SO_3 and NO (non-acidic oxide) to NO_2, which takes place in the liquid phase, is much faster than in the gas phase and thus conduces to the formation of strong acids (Huang et al., 2008; Wilkosz, 2005). The above facts and observation clearly imply that deposition episodes of highly acidic aerosols produced from the reaction of the flue gases contained acidic components with the water contained in the plume from the cooling tower may physically occur even in a very close proximity to the power plant. The shorter distance from the emission points of the flue gas and the vapor from the cooling tower, the higher the spatial compactness of the mixed plumes what evokes high concentrations of acidic components. Taking into account the environmental consequences due to possible extremely high acidity of the precipitation in immediate vicinity of a power plant, the presented study aimed at investigating the potential for the occurrence of such high acidic wet deposition episodes.

2. Material and methods

Measurements were carried out in the vicinity of a coal-fired power plant, from which the flue gas plume was discharged through a 162 m high stack. The height of the cooling towers was 120 m. All six power units with a total capacity of 1150 MW were equipped with installations for flue gas desulphurization using wet lime technology. The technology applied to control nitrogen oxides was based on staged fuel and air supply to a three-zone combustion chamber. Flue gas dedusting processes were carried out using bag filters in two blocks of 125 MW and electrostatic precipitators in the remaining 4 blocks of 225 MW each. Within 12 months when the measurements were carried out dust emission from the power plant was 668 Mg, the emission of sulfur dioxide was 5120 Mg and NOx - 8275 Mg.

One of the reasons which may justify the lack of measurement data to assess the acidity of aerosols which are reaction products of components present in the flue gas emitted from a coal-fired power plant with the water in plume from the cooling tower may be the difficulty in collecting samples of such a mixture. In the presented study rainfall was used as a medium that enabled sampling of the plumes reaction products. The samples were collected in a precipitation funnel (Fig. 1) which was located outside the power plant, but in its close proximity: 710 m from the stack and 315 m from the nearest cooling tower. Taking into account the aim of the study, the cases when the precipitation occurred at the same time when the wind directed the mixed vapor and flue gas plumes over the precipitation funnel were the most interesting ones for analysis. To identify these cases an ultrasound anemometer designed for 3D measurements of the wind field, located a few meters from the funnel at the height of 5 m, was used. Data on wind directions were recorded every 3 s. The funnel was placed on a tripod stand 1.5 m above the ground to avoid contamination of samples by soil particles during heavy rain. Daily rainfall samples were collected in bulk collectors: 5-L polyethylene bottles with 360-mm diameter polyethylene funnels, pre-washed with high quality deionized water. After each collection of the rainfall its volume was measured and pH was determined using CX-731pH meter with an automatic temperature compensation before its filtration through 0.45 μm cellulose membrane filters.

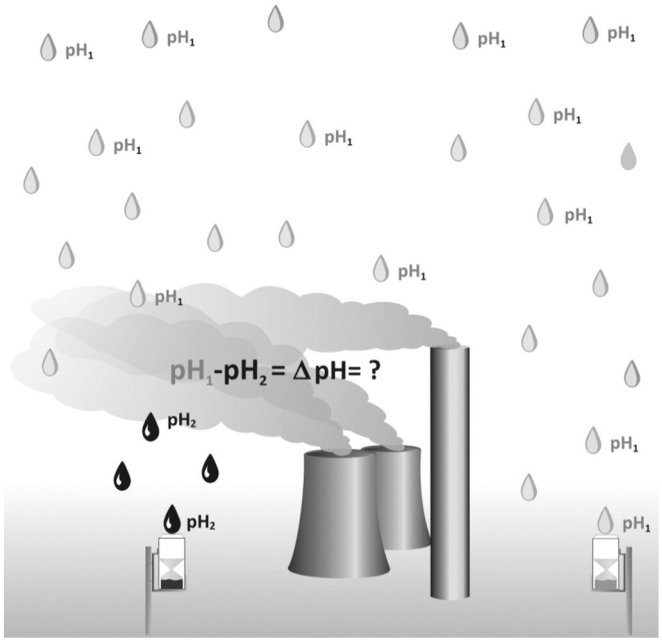

Fig. 1. Schematic diagram of acidity measurements of mixed flue gas and water vapor plumes.

Fig. 1 presents two situations: case 1 when the funnel was directly under the plumes and collected samples containing components from both mixed plumes together with rain droplets and case 2 when the wind moved the plumes in the direction opposite to the location of the funnel and in consequence the collected precipitation samples did not contain components from the both mixed plumes. The physicochemical properties and the chemistry of the atmospheric precipitation samples collected in case 2 were assumed to provide the characteristics of the local background properties. The impact of the plumes emitted from the power plant on the atmospheric precipitation acidity was assessed by comparison of the relevant background values (case 2) with the values obtained in the analyzes of precipitation samples collected in case 1. Therefore, the pH_1 symbol in Fig. 1 refers to the local background pH value of the atmospheric precipitation which, as mentioned earlier, served as a medium enabling transfer of the components contained in mixed plumes into the precipitation funnel. The pH_2 symbol in the Fig. 1. is a resultant value of the background pH (pH_1) and pH of the mixture of vapor (water) emitted from the cooling tower and relevant components of the flue gas plume.

Apart from the pH analysis, contents of alkali metal ions and ions of cadmium and lead were determined in the samples collected in the precipitation funnel. Each sample was vacuum filtered through nitrocellulose membrane filters with a pore size of 0.45 μm. A portion of the above filtrate was acidified to pH 1–2 with nitric acid(V) and analyzes to determine the content of dissolved metals in the precipitation sample. Additionally, the residue on filters were mineralized in nitric acid (V). Mineralization of the samples was carried out in a closed system, using Anton Paar Multiwave 3000 digestion system. Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} cations were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). For determination of cadmium and lead electrothermal atomic absorption spectrometry (ETAAS) was used.