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Original article

Urban dew formation efficiency and chemistry in Poland

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ABSTRACT

The measurements of dew formation efficiency and chemistry were performed in Poland in September 2009, as a part of a longer, two-year sampling campaign. Pairs of sites, representing centers of major Polish cities and rural conditions in three different regions, were compared. With the aim to get more detailed landuse-oriented characteristics of dew, two additional sites were set close to Wroclaw. Collection of dew at each site was made by means of flat, insulated, passive radiative condenser, 1 m^2 in area. The analysis has included a number of physico-chemical variables, i.e.: dew water volume, pH, conductivity (σ), concentration of some major anions: F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{3-} and cations: Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+. The dew formation efficiency at the rural stations is about two times higher than in the nearby city centres and such regularity is complex in its origin. The results show generally low contamination of dew (16.8–132.6 μS cm^{-1}) in comparison to literature examples, but definitely more acidic (pH ~5.0). The urban dew is characterized about two times higher contamination than nearby rural and independently of the place of collection the dominant ions are NO_3^-, SO_4^{2-} and Ca^{2+}, all anthropogenic in origin. The sources of dew pollution have mostly regional character or alternatively urban emissions effectively contaminate dew even several tens of kilometers away. The urban dew pH is higher than rural, but dew is potentially acidic and corrosive at the level of urban canopy.

1. Introduction

The formation of dew occurs when water vapor in the atmospheric air condenses on a cool surface below the temperature of the dew point. However, for centuries the genesis of this phenomenon was not so obvious (Möller, 2008) and only in the middle of the 20th century Monteith worked out the contemporary definition (1957). Dew formation occurs mainly by heterogeneous nucleation, as stated, among others, in Beysens (1995, 2006). The efficiency of dew formation depends on surface properties, on which it is formed (Nikolayev et al., 1996; Briscoe et al., 2005; Agam and Berliner, 2006), as well as on atmospheric conditions (Zangvil, 1996; Muselli et al., 2002).

Nowadays, a significant growth of interest in possibilities of using alternative sources of drinking water is observed (Schemenauer and Cereceda, 1991; Abualhamayel and Gandhidasan, 1997; Wahlgren, 2001; Mileta et al., 2004; Olivier, 2004; Beysens et al., 2006a; Clus et al., 2008; Clus et al., 2009). One of such examples is an attempt to get potable water by condensation of dew from ambient air. In recent years pilot studies were conducted in this field (Muselli et al., 2002, 2006a; Beysens et al., 2007; Clus et al., 2007a; Sharan et al., 2007a). In India and Morocco, these experiments were carried out on a large scale (Clus et al., 2007b; Sharan et al., 2007b; Clus et al., 2010; OPUR, 2011).

The growth of interest in using dew as a source of drinking water determined the need of analyzing its quality (Beysens et al., 2006b; Muselli et al., 2006b; Lekouch et al., 2010, Lekouch et al., 2011). Additional argument to undertake such actions appeared when first results of conducted investigations presenting the chemical composition of dew were published (Yaalon and Ganor, 1968; Foster et al., 1990). The above mentioned research studies have indicated relatively high concentration levels of pollutants in dew compared with other hydrometeors (e.g. precipitation or fog) (Mulawa et al., 1986; Wagner et al., 1992; Jiries, 2001; Singh et al., 2006). The significance of the problem is confirmed by the fact that the frequency of dew appearance is relatively high. Many research studies conducted in the Mediterranean zone by means of

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passive condensers point out that there are about 25–50% days with dew appearance annually (Kidron, 2000; Mileta et al., 2004; Beysens et al., 2006a; Clus et al., 2010). Similar measurement findings in the equatorial zone were stated by Clus et al. (2008). Research studies conducted by authors in the area of Poland, representing the temperate climate, closely refer to the above mentioned results, where the number of days with reported occurrence of the dew accounted for more than 40% of the year (Gałek et al., 2015). Moreover, Beysens et al. (2006b) and Uclés et al. (2014) indicate that the number of days with dew can even reach 75–80% annually. It is estimated that deposition of pollutants through dew can be comparable to deposition through atmospheric precipitation in some areas (Polkowska et al., 2008). The high contamination of the dew results from a relatively long duration of the dew and both, gases diffusion into solution from the atmosphere and dissolution of dry deposits subjected to continuous sedimentation (Beysens et al., 2006b).

Pollutants present in dew can be particularly harmful during morning evaporation due to their rising concentration (Garratt and Segal, 1988). Corrosive properties of the dew have devastating effects on metal elements, on which it formed (Xu et al., 2001; Okamoto et al., 2003). Investigations in this field were carried out in Santiago (Chile) by Rubio et al. (2001). They stated that steel and copper elements, on which dew is formed, undergo significant corrosion. It is particularly important because these metals are widely used in the urban development, such as metal roofing, window sills, electrical cables, broadcasting equipment, monuments, cars, bridges.

Another negative factor associated with dew occurrence is its potentially positive impact on the generation of tropospheric ozone, which has strong oxidizing properties in big agglomerations damaging urban plants and most of meterials used in urban development. This process results from formation of HNO_2 mainly by heterogeneous gas reactions occurring on wetted surfaces (Acker et al., 2005). Alicke et al. (2003) and Acker et al. (2008) pointed out that this compound in urban areas can provide approximately 20–30% of free radicals (OH). Moreover, Acker et al. (2006) stated that photolysis of HNO_2 in the first hours after sunrise is a source up to 80% of hydroxyl radicals. These processes accelerate the beginning and increase the efficiency of tropospheric ozone formation, especially in the morning (Acker et al., 2006).

Due to the intense pollution in big agglomerations, these areas are potentially exposed to high concentrations of pollutants in dew. However, taking Guangzhou (China) as an example, Ye et al. (2007) showed that frequency and efficiency of dew formation in the urban areas are lower than outside. Some research studies were also conducted in this field in Vancouver (Canada) by Richards (2002). By means of a hardware landuse model in the 1/8 scale, it was shown that dew formation in the urban area proceeds spatially in an irregular way. Regardless of meteorological conditions and type of material, on which dew is formed, the sky view factor, i.e. the proportion of the sky hemisphere 'visible' from a point on the surface, appears to be crucial. Measurements indicate that the dew formation in the vicinity of buildings and trees is much less efficient than in the open area or at the level of roofs (Richards and Oke, 2002). These results indicate a very complex system of urban versus rural areas, where one point can be treated as representative of a larger territory. Taking general decrease in the frequency and intensity of dew phenomenon in urban areas into consideration, it is necessary to include it in the discussion of the significance of pollutant deposition through dew.

One of the factors to be considered in examining the adverse impact of pollutants accumulated in dew on vegetation and other rapidly cooling materials in the city, is their ability to nocturnal radiation of energy. It depends, among others, on sky view factor, which significantly increases with increasing height above the ground. As shown in the investigations conducted by Richards (2005), the frequency and efficiency of dew formation in the urban area at the height of the roofs, which are a kind of open space, are much higher than those noticed at the ground surface. Moreover, the urban roof level dew frequency and efficiency often is even higher than in rural areas. Under these circumstances, the dew phenomenon becomes a potentially important pollutant and can be harmful to the upper parts of tree crowns and equipment placed on the roofs of the buildings. It should be noted, however, that the concentration of pollutants at this level may significantly differ from that measured at low height above the ground. This is particularly important because the dew phenomenon occurs mainly under the conditions of relatively low atmospheric turbulence (Garratt and Segal, 1988).

In the last three decades, several research campaigns concerning dew chemistry were carried out in urban areas. However some of them focused on the specific issue associated with the chemical composition of dew. One of the most extensive investigations concerning dew chemistry in urban areas was conducted in Santiago, Chile (Ortiz et al., 2000; Rubio et al., 2002, 2006, 2008). These studies pointed out the high pH value of dew samples and high concentration of NO_2^-, SO_4^{2-}, NH_4^+ and Ca^{2+} ions as well. For many years, investigations concerning dew chemistry were also carried out in Japan (in Yokohama, Osaka, Tokyo) (Okochi et al., 1996, 2008; Takeuchi et al., 2001; Takenaka et al., 2003). According to Okochi et al. (1996) in Yokohama, the dominant dew pollutants were NH_4^+, Ca^{2+} and SO_4^{2-} ions at significantly diverse pH value. A great majority of the investigations conducted in Japan focused on organic components of dew (Matsumoto et al., 2005; Okochi et al., 2005, 2008). Research campaigns carried out in Poland (Gdansk, Krakow, Wroclaw) (Polkowska et al., 2008), in France (Bordeaux) (Beysens et al., 2006b), in Jordan (Amman) (Jiries, 2001) and in Israel (Jerusalem) (Berkowicz et al., 2004) indicated raised concentration levels of Ca^{2+} and SO_4^{2-} (determination of SO_4^{2-} only in Jerusalem). In all above mentioned places, pH values were relatively high (6.3–7.1), whereas concentrations of pollutants were significantly higher in dew than in rain water in the case of Poland and Jordan.

The main aim of this research study is to determine whether dew can be a substantial source of contamination in the urban area in comparison with rural sites. To achieve this goal, the level of concentration of major ions in dew collected from urban and rural condensers is compared. An important part of this study is the inclusion of observations of dew frequency. Moreover, the alkalization/acidification characteristic of dew in the urban area and its potentially corrosive character in Polish big cities are investigated.

2. Material and methods

2.1. Sampling site and time

Investigations, described in this work, concerning dew efficiency and chemistry were conducted for two years from February 2008 to February 2010. Measurement periods at individual sites differed substantially (Table 1). In order to achieve the possibly objective comparison of the results, a hybrid method was adopted. It means that both the measurement findings obtained during 11 days from Sept 18, 2009 trough Sept 28, 2009, when the investigations were carried out at all sites, and results obtained for the entire measurement series, were taken into account. This procedure enabled to eliminate the problem of seasonal variations in pollution concentration, as well as to avoid the problem of potentially small representativeness of the short series.