Process Safety and Environmental Protection xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

Modeling air concentration of fly ash in Belgrade, emitted from thermal power plants TNTA and TNTB

Dušan P. Nikezić[b,*], *Zoran J. Gršić*[c], *Dragan M. Dramlić*[a], *Stefan D. Dramlić*[a], *Boris B. Lončar*[d], *Slavko D. Dimović*[b]

[a] *University of Belgrade, Institute of Physics, Laboratory for Atmospheric Physics and Optical Metrology, Zemun, Belgrade, Serbia*
[b] *University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia*
[c] *Public Company Nuclear Facilities of Serbia, Vinča, Belgrade, Serbia*
[d] *Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia*

ARTICLE INFO

Article history:
Received 26 September 2015
Received in revised form 21 May 2016
Accepted 7 June 2016
Available online xxx

Keywords:
Fly ash
Dust
Ash disposal site
Thermal power plant
Atmospheric dispersion
Gaussian model

ABSTRACT

The aim of the study was to estimate if dust/fly ash emitted into the atmosphere from chimneys and the ash disposal sites of the thermal power plants Nikola Tesla A and B in Obrenovac could increase the concentration of PM_{10} in New Belgrade. TNTA and TNTB are close to Belgrade (population of 2.5 million) and it is important to estimate the amount of the pollution emitted into the atmosphere from these sources. The pollution from chimneys is estimated from yearly amounts of discharge, while the lifting of ash/coal dust was parameterized by the model. The used model is the straight-line Gaussian plume model written in the Fortran programming language. The first estimation was done using mathematical modeling for the idealized situation with prescribed winds and stability. The second estimation was done using the observed meteorological data for the whole year of 2009. With strong winds (over 40 km/h), dust will reach Belgrade in dozens of minutes, while during moderate winds (∼10–30 km/h), it would take about one hour to reach it. In these cases atmosphere is close to the neutral stability class. In case of weaker winds and stable atmosphere, the increase of air dust concentration in Belgrade would start after a few hours (6–10). Regarding the other two sources of pollution, coal handling piles and ash deposit sites, during strong winds (>40 km/h) and neutral stability, fly ash would reach Belgrade in several dozen of minutes.

1. Introduction

Thermal power plants with chimneys are usually a major source of fly ash and pollution for the local region. Depending on the meteorological conditions ash can reach rather long distances. Ash disposal sites and coal handling piles are another major sources of air pollution associated with thermal plants. Therefore, it is important to estimate the concentration of ash/coal dust not only in the vicinity of a thermal power plant but also within a wider region. Wind strength, atmospheric stability and particle-size distribution are three main factors that influence the concentration of fly ash. Due to high variability in wind direction and the state of the atmosphere, the estimation of the concentration can be done using the modelling approach. The verification of a model requires the measurement of local ash concentration and deposition.

The thermal power plants TNTA and TNTB are located approximately 30 km away from the centre of Belgrade in the

* *Corresponding author*. Tel.: +381 11 3408 820; mobile: +381 64 8505 027.
E-mail address: dusan@vin.bg.ac.rs (D.P. Nikezić).

http://dx.doi.org/10.1016/j.psep.2016.06.009
0957-5820/© 2016 Published by Elsevier B.V. on behalf of Institution of Chemical Engineers.

Nomenclature

A	unit less parameter (usually assumed to be equal to 1)
C (x,y,z)	air pollution concentration at grid point (x, y, z) – receptor [$\mu g\,m^{-3}$]
D	displacement height [cm]
g	acceleration of gravity [$cm\,s^{-2}$]
H	effective height of source emission [m]
k	von Karmann's constant (0.4)
Q	source strength [kg/h]
q	instantaneous horizontal (saltation) mass flux [$g\,cm^{-2}\,s^{-1}$]
U (z)	wind speed at height z [$m\,s^{-1}$]
u	average wind speed [$m\,s^{-1}$]
u_*	wind shear velocity [$cm\,s^{-1}$]
u_{*tv}	threshold shear velocity [$cm\,s^{-1}$]
v_s	terminal velocity [$m\,s^{-1}$]
x	downwind distance [m]
y	lateral (crosswind) distance from the plume axis [m]
z	height of the receptor above ground [m]
z_0	roughness height [cm]

Greek symbols

σ_y	diffusion coefficients in y [m]
σ_z	diffusion coefficients in z [m]
ρ	density of air [$g\,cm^{-3}$]

Abbreviations

CB	Center of Belgrade
CFD	computational fluid dynamics
NB	New Belgrade
SW	south-west wind direction
TNT A	thermal power plant "Nikola Tesla A" in Obrenovac
TNT B	thermal power plant "Nikola Tesla B" in Obrenovac
WSW	west-south-west wind direction
vv	wind speed

WSW (west-south-west) direction by the wind rose nomenclature, in a valley, on the right bank of the Sava River. The distance between them is about 15 km. The surrounding area is relatively flat. They have three chimneys with different heights (150 m, 220 m and 280 m). The chimneys are permanent dust sources, also contributing to the amount of ash in their vicinity and the wider area. Each of these chimneys will give very different contribution for different winds and local stability. Under routine operation conditions, TNTA's and TNTB's chimneys release about 3 t/h of the fly ash to the atmosphere. The authors have investigated the gaseous products, resulting in combustion processes for large industrial objects, as well as methods for controlling them (Dramlić et al., 2001; Dramlić and Vukolić, 2003; Dramlić and Adzić, 2003).

Within the project implemented with the Institute for Air Research from Norway, a control station NB was set up in New Belgrade for measuring the level of PM_{10} (Jovašević-stojanović and Bartonova, 2010; Joksić et al., 2010). Based on the meteorological measurements during 2009, three dates were selected when the values of PM_{10} were increased at the control station NB. The applied mathematical model showed that emission of fly ash from TNTA and TNTB could have contributed to the increase of the concentration of PM_{10} at the control station NB. The PM_{10} values were very high in New Belgrade at the location where data were measured (NB) and it was conservatively assumed that major part of pollutants was from TNTA and TNTB (Jovašević-stojanović and Bartonova, 2010; Joksić et al., 2010).

In Fig. 1, circles denote the positions of the chimneys, while crosshatched ellipses are the positions of the two ash disposal sites (CB is the Belgrade city centre). NB (New Belgrade) is the position of the measurement point used for the verification. The calculating domain is 53.5 km × 32.5 km.

The ability of ash disposal sites to emit dust depends on the intensity of spraying their surfaces with water. These sources are active only with strong winds which are necessary for the initial ash lifting from the sufficiently dry surface. With daily monitoring of the status of the "water mirror" on the landfill of ash, size and shape are used as surface source of the ash in the model. The greater sizes of ash disposal site ponds restrain negative influences of ash disposal sites to their environment (Fig. 2). The most influential factor is the wind speed if it is over the threshold limit for dust lifting (Grsić et al., 2010).

Waste ash is transported to the disposal sites by means of hydraulic conveyer tubes, in a liquid configuration, 10 litres of water per kg of ash. The turquoise colour in the image is the "water mirror" and dark gray is wet ash. The rest (50%) is dry ash that was considered as a source of PM_{10} in the research.

2. Materials and methods

Atmospheric dispersion modeling implies the mathematical description of contaminant transport in the atmosphere and it is a very useful field of environmental protection (Leelossy et al., 2014). Several studies were done by the Vinča Institute of Nuclear Sciences, Belgrade, Serbia (Nikezić et al., 2014). In this context, the term dispersion is used to describe the combination of diffusion (due to turbulent eddy motion) and advection (due to wind) that occurs within the air near the Earth's surface. Therefore, the concentration of a contaminant released into the air may be described by the advection–diffusion equation that is a second-order partial differential equation of parabolic type (Stockie, 2011).

It was expected that fine particulate substance suspended in the atmosphere from chimneys could reach the suburbs of Belgrade and even the center of the city under certain meteorological conditions, such as a permanent WSW wind direction. The automatic weather (meteorological) station with mast height of 10 m is located between the chimneys and the ash disposal site of TNTA and TNTB. The station is collecting meteorological data in real time and these data are the input data for the mathematical model. The measurement of meteorological data at an automatic weather station at 45 m above ground is a control measurement for an additional determination of the stability classes and the wind speed at higher levels above the surface. We thereby obtained the vertical temperature profile and wind speed in the surface layer of the atmosphere, which is important for the mechanism of dust lifting and its transport through the boundary layer of the atmosphere. The mathematical model uses these data in the calculation of the lifting of fly ash from the dry parts of the ash disposal sites and its diffusion through the atmospheric boundary layer when wind is strong and for atmospheric

Please cite this article in press as: Nikezić, D.P., et al., Modeling air concentration of fly ash in Belgrade, emitted from thermal power plants TNTA and TNTB. Process Safety and Environmental Protection (2016), http://dx.doi.org/10.1016/j.psep.2016.06.009