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Preliminary contribution
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SMOKE AND VAPOR PLUME MERGENCE

Miješanje perjanica dima i vodene pare

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Abstract: Observations at power plants have indicated that vapor plumes emitted from cooling towers frequently merge with smoke plumes released from stacks. Mergence of cooling tower and stack plume leads to formation of acidic compounds which have adverse effects on the environment. Wind speed and direction play an important role in merging smoke and vapor plume. This paper lists some arguments to verify that studies have not sufficiently addressed stack and cooling tower plume mergence. In conclusion, the present authors hope to find more information in the future with regard to vapor and smoke plume mergence.

Key words: stack, cooling tower, plume mergence, wind speed and direction

Sažetak: Opažanja u termoelektranama pokazuju čestu pojavu miješanja perjanice vodene pare nastale nad tornjevima za hlađenje s perjanicom dima izgaranja iz dimnjaka. Miješanje dima i vodene pare dovodi do stvaranja kisele smjese koja utječe na okoliš. Brzina i smjer vjetra imaju značajnu ulogu u procesu miješanja. U radu su nabrojani argumenti koji ukazuju da dosadašnje studije nisu dovoljno obratile pozornost na mješanje dima i vodene pare iznad rashladnih tornjeva. Autori se nadaju da će se ubuduće više pažnje posvetiti problemu miješanja vodene pare i dima.

Ključne riječi: dimnjak, tornjevi za hlađenje, miješanje perjanica, brzina i smjer vjetra.

1. INTRODUCTION

Gases exiting from the tops of stacks rise higher than the stack top when they are either of lower density than the surrounding ambient air (buoyancy rise) or ejected at a velocity high enough to give the exit gases upward kinetic energy (momentum rise) (Valero, 2008).

Cooling towers are used to conserve water and to avoid the discharge of heated water to streams, lakes and estuaries. Hot water from industrial process drips over barriers in a cooling tower and evaporates into the air which travels through the cooling tower. Cooling towers can be tall (~150 m tall and 30 m in radius) natural draft towers in which vertical motions are caused by density differences, or short (~20 m tall and 5 m in radius) mechanical draft towers in which vertical motions are induced by large fans (Hanna et al., 1982).

Moisture and heat fluxes from cooling towers can cause fog or cloud formation and sometimes can induce additional precipitations. Another issue with regard to cooling towers is drift deposition, in which circulating cooling water with drop sizes ranging from 50 to

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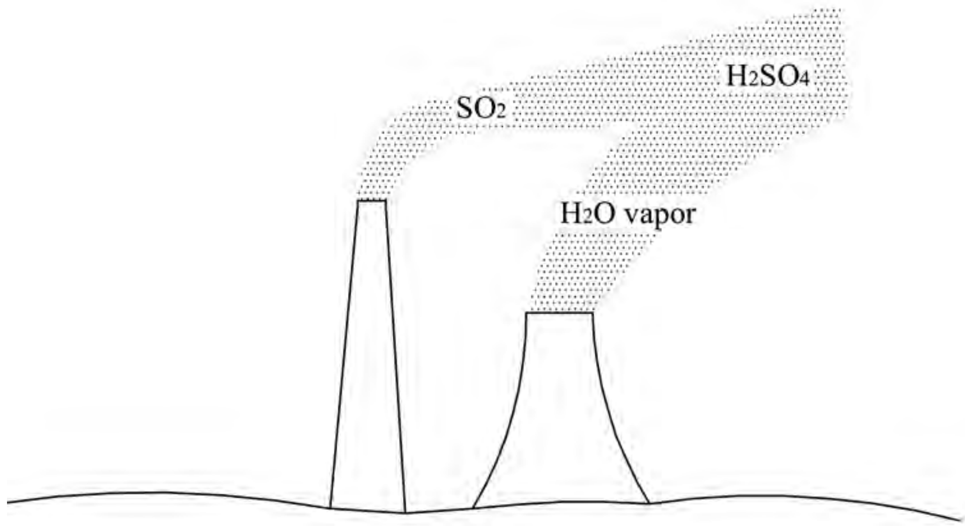

Figure 1. Schematic diagram of stack and cooling tower plume mergence

Slika 1. Shematski dijagram miješanja perjanica iz dimnjaka i hladnjaka.

Figure 2. Satellite image of Amos plant in 2007

Slika 2. Satelitska slika termoelektrane John E. Amos iz 2007. Godine.

Figure 3. Satellite image of Muskingum River plant in 2010

Slika 3. Satelitska slika termoelektrane Muskingum River iz 2010. godine

1000μm is carried out of the tower and may be deposited on nearby environment (Hanna et al., 1982). Cooling tower drift has several important deleterious effects on local environment (Chan and Golay, 1977).

Observations at power plants have indicated that vapor plumes emitted from cooling towers frequently merge with smoke plumes released from stacks. Wind speed and direction play an important role in merging stack and cooling tower plume (USEPA, 1979); in contrast, Bajić et al. (1994) found that among the meteorological elements, wind speed and direction were best correlated with the pollution concentration. Propagation and transformation of stack and cooling tower plume is an important problem in environmental protection activities (Haman and Malinowski, 1989). Fig. 1 shows a schematic diagram of stack and cooling tower plume mergence. As shown in the figure, sulfur dioxide (SO_2) emitted from the stack reacts with water vapor emitted from the cooling tower to form sulfuric acid (H_2SO_4) which can corrode metals and building materials (Shafi, 2005). Primary generators of SO_2 emissions are fossil-fueled electric power plants, refineries, pulp and paper mills and any sources that burn sulfur containing oil or coal (Callan and Thomas, 2012). Meanwhile, it must be note that SO_2 is the most damaging among the various gaseous air pollutants (Sharma, 2007).

2. DISCUSSION

Studies have not sufficiently addressed stack and cooling tower plume mergence. To verify this,five arguments can be considered:
First of all, there are little regional studies in

the world with regard to cooling tower and stack plume mergence. Most of these studies are limited to U.S.A. For example, Kramer et al's (1976) results revealed that mergence of stack and cooling tower plume is a common phenomenon at three power plants in U.S.A including Amos, Muskingum River and Mitchell (see Figs. 2-4). In addition, Knudson (1979) reported that mergence of cooling tower and stack plume often occurs at Watts Bar power plant in U.S.A. Moreover, Dittenhoefer and de Pena (1978) found that cooling tower plume often merges with stack plume at Keystone power plant in U.S.A. Furthermore, as shown in Fig. 5 Haman and Malinowski (1989) reported that mergence of cooling tower and stack plume is a common phenomenon at Bełchatów power plant in Poland.

Most of the smoke plume rise formulas such as Holland (1953), CONCAWE (Brummage, 1966), Stone and Clark (1967) and so on are only able to calculate plume rise, while to study stack and cooling tower plume mergence, in addition to plume rise, plume length should be computed.

There is only one formula in the literature for prediction of downwind concentration of pollutants produced due to mergence of stack and cooling tower plume. This formula can be written as follows:

$$C(x,y,z)=M/(\pi\sigma_{yx}\,\sigma_{yz}\,\bar{u})\exp\{-0.5\,[(y/\sigma_{yz})^2+(z^2+Z_M^2)/\sigma_{zx}^2]\}\cosh(zx/\sigma_{yz}^2), \tag{1}$$

where C is the pollutant concentration (gr/m^3), x, y and z are the coordinates in the

Figure 4. Satellite image of Mitchell plant in 2010

Slika 4. Satelitska slika termoelektrane Mitchell iz 2010. godine along-wind, M is the intensity of the mixed plume (g/s), Z_M is the mixing zone height or the effective height of the stack or cooling tower (m), $\bar{u}$ is the mean wind speed (m/s) and the σs are standard deviations from Gaussian distribution (USEPA, 1979).

There is no information in the literature with regard to minimum distance between cooling tower and stack so as to avoid mergence of vapor and smoke plume. However, it is difficult to determine this distance because multiple factors such as wind speed, wind direction, plant layout, etc., affect mergence of smoke and vapor plume.

Visible emissions are composed of small solids or liquid particles or colored gases (USEPA, 1978). Most plumes emitted from modern plants are virtually invisible (Stessel, 1996). Therefore, it can be stated that if the plume emitted from a typical stack is invisible then mergence of this plume with the plume emitted from a typical cooling tower will be invisible too. On the other hand, when mergence of stack and cooling tower plume is invisible then one may think that mergence of smoke and vapor plume does not occur and this is the main reason that in recent years little or no studies have been conducted with regard to cooling tower and stack plume mergence. In principle, most of studies with regard to stack and cooling tower plume mergence are dated back to the 70s and 80s when one could observe mergence of smoke and vapor plume. In contrast, Fig. 6 shows an oil refinery in Croatia

Figure 5. Satellite image of Bełchatów plant in 2014

Slika 5. Satelitska slika termoelektrane Belchatow iz 2014. godine in 2013. As can be seen in the figure, the plume emitted from the cooling tower is partially visible, while the plume released from the stack is invisible; therefore it can be stated that mergence of the stack plume with the cooling tower plume is invisible.

3. CONCLUSIONS

This paper found that studies have not sufficiently addressed stack and cooling tower plume mergence. Hence, the present authors hope to find more information in the future with regard to smoke and vapor plume mergence.

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Figure 6. Satellite image of Sisak oil refinery in 2013

Slika 6. Satelitska slika Rafinerije nafte Sisak iz 2013. godine

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