MODELING OF THE SO$_2$ DISPERSION IN ATMOSPHERE ACCIDENTALLY RELEASED DURING THE OPERATION OF TPP "BOBOV DOL", BULGARIA

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ABSTRACT. The aim of study was modeling of SO$_2$ dispersion, released accidentally in the atmosphere during the TPP "Bobov dol" operation, by means of METI-LIS Dispersion Model. The model was based on the following assumptions: the emission rate of SO$_2$ in atmosphere was constant, the atmosphere conditions (temperature, wind speed, etc.,) on hourly base were constant, and the wind speed was higher than 0.9 m/s. Having in mind the above-mentioned assumptions, it was calculated that emission rate of SO$_2$ in the atmosphere could be 3.57 g /m^3$_N$s if the desulfurization unit for the flue gases treatment of TPP "Bobov dol" doesn't work. SO$_2$ dispersion was modeled in dependence on the atmospheric stability categories which determined the respective values of gas dispersion coefficients (σ_y, σ_z) and the effective plume-rise height (h_e) in the atmosphere The wind rose determined that in the period November 2014-February 2015 in the most cases the plume released in the atmosphere would be transported in north direction to Radomir town by means of the south wind as the prevailed wind speed was up to 5 m/s. However, the model determined that the ground concentration of SO$_2$ would be higher than the Maximum Admissible Concentration (MAC) at a distance of 1-5 km from TPP "Bobov dol" only in the cases when the wind speed and solar radiation are in the range of 1.0-1.2 m/s and 0.015-0.029 kW/ m^2, respectively.

Keywords: sulfur dioxide, modeling, TPP, atmosphere stability categories

МОДЕЛИРАНЕ ДИСПЕРСИЯТА НА SO$_2$, ОТДЕЛЕН ИНЦИДЕНТНО В АТМОСФЕРАТА ПРИ РАБОТАТА НА ТЕЦ „БОБОВ ДОЛ"

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РЕЗЮМЕ. Целта на статията бе да моделира дисперсията на SO$_2$, отделен инцидентно в атмосферата при работата на ТЕЦ „Бобов дол" посредством дисперсионният модел METI-LIS. Използваният модел беше базиран на следните предположения: скоростта на отделяне на SO$_2$ в атмосферата е постоянна, условията в атмосферата (температура, скорост на вятъра и други) са постоянни на часова основа и скоростта на вятъра е по-голяма от 0.9 m/s. Имайки предвид горе-споменатите предположения беше изчислено че 3.57 g /m^3$_N$s биха се отделили в атмосферата, ако инсталацията за пречистване на димните газове на ТЕЦ „Бобов дол" не функционира. Моделиране дисперсията на SO$_2$ беше осъществена в зависимост от категориите стабилност на атмосферата, което определи съответните стойности на дисперсионните коефициенти на газа (σ_y, σ_z) и ефективната височина на издигане на газовия поток (h_e) в атмосфера. Розата на вятъра определи че за периода Ноември 2014-Февруари 2015 година, в повечето случаи отделеният димен поток в атмосферата би бил транспортиран в северна посока към Радомир от южния вятър, чиято преобладаваща скорост бе до 5 m/s. Въпреки това, беше определено че приземната концентрация на SO$_2$ би била по-висока от Предело Допустимите Концентрации (ПДК) на разстояние 1-5 km от ТЕЦ „Бобов дол", само в случаите когато скоростта на вятъра и слънчевата радиация са в границите 1.0-1.2 m/s и 0.015-0.029 kW/ m^2, съответно.

Introduction

Coals are widely distributed on the Earth and for long period of time they have been a cheap source of energy which allowed the Industrial society to emerge and develop rapidly for a relatively short period of time. The coal burning is connected with taking of significant amount of carbon, nitrogen, sulfur, and heavy metals and toxic elements from their respective depository reservoirs and their relevant reactive gases and fine particles are the waste products released in the atmosphere. Strong absorptive and/ or acidifying properties of the emitted gases as well as the toxicity of fine particle matters determine the detrimental effect of the coal utilization on the Earth ecosystems at global, regional, and local scale. The regional effect is triggered when by means of dry or wet deposition the relevant pollutants are transported from atmosphere to the earth ecosystems in doses higher than the critical limit which the relevant ecosystems could sustain.

Svante Arrhenius was the first scientist who predicted the global warming having in mind the significant emissions of CO$_2$ generated during the coal burning and their accumulation in the atmosphere (Arrhenius, 1896). However, agreements at International level to reduce the emissions to the atmosphere (Grubb and Depledge, 2001; Review of the Gothenburg Protocol, 1999) and the practical measures for their application have been achieved almost 100 year after that fist publication.

TPP "Bobov dol" is situated in Southwest Bulgaria and it consist of three 210 MW units and 630 MW is the total install capacity of the plant. The power plant was initially designed to utilize the local brown coals characterized with high ash content. In our days, the power plant operates also on the coal supply from other Bulgarian mines-brown coals from Pernik and Pirin mines as well as lignite coals from Sofia Mining Basin. By this way, the heat value of burning coal mix is maintained in the range of 2200-2400 kcal/ kg. The annual output is around 2000 GWh which is generated by the burning

of around 2 million tons of coals enriched with sulfur and mineral part (South-East European Industrial Market. 2010). From the very beginning, electrostatic precipitators have been used at the power plant for the removal of the particle matters from the flue gases. However, the burning of coals enriched with sulfur was the reason for the formation of flue gas enriched with sulfur dioxide which by means of 200 m stack had been released in the atmosphere for a long period of time. For that reason, TPP "Bobov dol" ranked at 68th place among the largest point sources emitting sulfur dioxide to atmosphere in Europe with net release of around 43 ktS per year (Barrett and Protheroe, 1994).

The negotiations between Bulgaria and EU on Chapter 22 "Environment" fixed the transitional periods towards Bulgarian Large Combustion Plants (LCP) which emissions to atmosphere were higher than the relevant Emission Limit Values (ELV). By this process the main technical measures needed for bringing the existing LCPs into compliance with the ELVs was determined – decommission of old coal boilers, installation of desulfurization units, installation of low-emission burners, reconstruction of the existing abatement techniques, switch to fuels with lower S content (Ordinance №10, 2003).

In period of 2010-2015 year, the three units of TPP "Bobov dol" were or are process of rehabilitation which made possible:
- the power plant to start to operate in accordance to the environmental standards for SO_2 applied in EU;
- the installed capacity per unit increased to 223 MW;
- the retirement date postponed after the end of 2020.

As a result of the rehabilitation, a desulfurization unit for the sulfur dioxide catchment from flue gases of unit 1 and 2 was installed. A second desulfurization set-up for unit 3 of TPP "Bobov dol" has to be put in operation to the end of June of 2015. Apart from the sulfur removal, primary and secondary reduction of NO_X in the flue gases and the additional reduction of fine particles matters content by means of additional electrostatic filters is also applied. The treated flue gase is released in the atmosphere at height of 80 m, as the total air flow when all units work simultaneously is about 1100 Nm^3/ s.

TPP "Maritza East-2" was among the first Bulgarians TPP where desulfurization units for flue gas treatment have installed and a lot of practical experience has been gained for these years of operation. It was noticed that the quality of used materials was the main reason some problems connected with the desulfurization of flue gases to arise (Jecheva et al., 2011). As a result, non-treated flue gases enriched with sulfur dioxide are released in the atmosphere accidentally (Dnevnik, 2014).

The main aim of the article is the SO_2 modeling in the atmosphere when it is released accidentally during the operation of TPP "Bobov dol" and what would be the pollutant concentration in the below-lying atmosphere layer at the towns Radomir, Kyustendil, and Dupnitza in dependence on the local climatic conditions.

Materials and methods

The data about the atmospheric pressure, the direction and wind`s speed, temperature, and rate of precipitation in the area of Bobov Dol, Radomir, Kyustendil and Dupnitsa was checked on hourly base from the bulletins of National Institute of Metereology and Hydrology at BAS within the period November 2014 – February 2015. These data was averaged for each month and the mean temperature, the prevailed wind direction and the wind speed for both halves of the day were determined.

Table 1.
Main properties of the coals burnt at TPP "Bobov dol"

Index	Mine "Bobov dol"	Mine "Pernik"
Humidity, %	18.0	18.0
Ash content, %	38.0	25.0
Sulfur, %	1.6	1.5
Heat value, kJ/ g	11.7	18.0
Consumption, t/y	1 040 000	960 000
Total consumption, t/ y	2 000 000	

Table 2.
Main properties of flue gases generated during the burning of coal at TPP "Bobov dol"

Index	Scenario	
	1	2
Outlet flue gases temperature, °C	59	170
Specific gravity of flue gases, g/cm^3	1.013	1.307
Outlet flue gas volume, m^3/ s	1140	1383
Outlet flue gas, kg/ s	1125	1166
Emission of SO_2, kg/s	0.13	2.75
Rate of SO_2 emission generation,g/m$^3_{NS}$	0.17	3.57

The SO_2 emission generated during the burning of coal in TPP "Bobov dol" was calculated by means of CorinAir methodology (EAE, 2007). Two million tons of coals were accepted as the total amount of coals burnt at the power plant per year, and to simplify the calculation it was accepted that 52 % and 48 % of that amount was mined at Bobov dol and Mine Pernik, respectively. The data about the utilized coals are presented in Table 4 and 5.

The main properties of flue gases and the emission rate of SO_2 are presented in Table 2, where two scenarios were evaluated. Scenario 1 considered the dominating situation where the flue gas desulfurization unit works properly and 95 percent of the generated sulfur dioxide is removed efficiently. Scenario 2 considered the accidental release of non-treated flue gases in the atmosphere.

SO_2 modeling in the atmosphere was carried out by means METI-LIS Dispersion Model (Kouchi et al., 2004). It was based on the following hypothesis:
1. The emission rate of sulfur dioxide to the atmosphere was constant;
2. The wind direction and wind speed were constant at the relevant climatic conditions;
3. The pollutant dispersion was carried out in horizontal direction mainly;
4. SO_2 didn`t undergo any transformation in atmosphere at a distance up to 30 km in relation to the point source of pollution;
5. Wind speed was $\geq$ 0.9 m/s.

Table 3.
Atmospheric stability categories according Pasquill

Wind speed at ground levels, m/s	Daytime				Nighttime
	Solar radiation Q (x 0.01 kW/ m^2)				
	60<	30-59	15-29	1-14	
< 2.0	A	A-B	B	D	F
2-2.9	A-B	B	C	D	E
3-3.9	B	B-C	C	D	D
4-5.9	C	C-D	D	D	D
> 6.0	C	D	D	D	D

Table 4.
Atmospheric conditions at TPP "Bobov dol" during the day for the period of observation

Index	Month/ Wind speed (m/s)					
	November		December		January	
	0-2	2-5	0-2	2-5	0-2	2-5
Northeast direction						
t, ° C	4-11	12.7	-	-	-	-
Stability class	A-B/ B	C	-	-	-	-
Southeast direction						
t, ° C	6-8	-	-	-	-	-
Stability class	A-B/ B	-	-	-	-	-
South direction						
t, ° C	5-9	10-11	4-5	2-3	2-5	2-4
Stability class	A-B/ B	B/ C	A-B/ B	B/ C	A-B/ B	B/ C
Southwest direction						
t, ° C	-	-	5-7	-	-	-
Stability class	-	-	A-B/ B	-	-	-

The pollutant dispersion in atmosphere was calculated by Gaussian dispersion equation (Beychok, 2005) having in mind the relevant climatic conditions and the effective plume rise height (he). The latter was determined by the Briggs equation (Briggs, 1965). The correction of wind-speed elevation at 200 m height was adjusted by the wind power law (Peterson & Hennessey, 1978).

RESULTS AND DISCUSSION

TPP "Bobov dol" is situated at altitude of approximately 690 m and it is surrounded by the Konyavska Mountain. In north direction at a distance of 20 km by air is situated Radomir town, which population is within the range of 14 000 people. In southeast and southwest direction at a distance of 14.5 and 27.0 km by air are situated Dupnitza and Kyustendil towns with 37 000 and 47 500 inhabitants, respectively.

The studied period, November 2014-February 2015, covered approximately the second part of the autumn and the first part of the winter, when TPP "Bobov dol" worked continuously because of the higher demand of energy. During the day (08-18 h), the south wind was dominated distinctively which determined the positive daily air temperature even during December and January (Table 4). The incoming solar radiation steadily decreased and for that reason, the ration A-B: B: C stability classes of atmosphere changed from
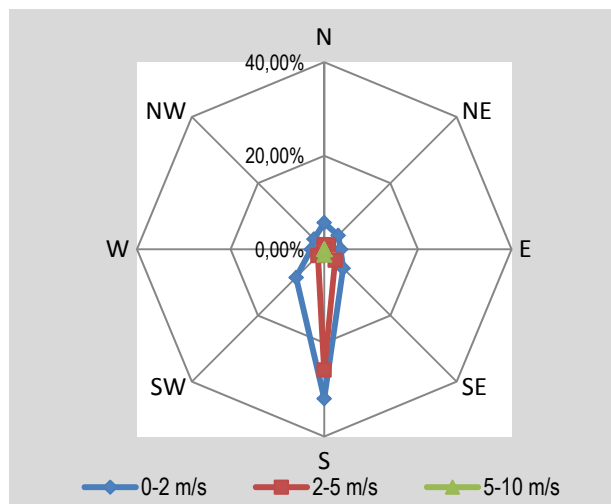

Fig. 1. The wind rose of the area around TPP ''Bobov dol'' for the day (08-18 h)

almost equal for November to the sole domination of classes B and C for January. In the same way, the averaged air temperature changed from +10 - +11 °C for November to +2.8 - + 4.8 °C. Regardless of the month during the studied period, the dominant speed of south wind was in the range of 0-2 m/s, as lower incoming solar radiation was as higher was the wind speed. In January, there was uncommon period in which the lower incoming solar radiation was combined with south wind with speed higher than 6.5 m/s. That combination determined Class D of atmosphere stability.

During the day, winds with northeast, southwest and southeast direction was also detected and Classes A-B and B were the sole stability classes which they determined (Figure 1). By means of southwest and southeast winds the air temperature was higher than the air temperature measured when the south wind prevailed. However, the wind speed in both cases was lower than the speed of south wind.

The south wind was also dominating during the night (19-07 h) and its prevalence reached up to 50 % for December. Understandingly, the mean air temperature during the night was lower in comparison to the air temperature measured during the days for the relevant months. Something more, when the sky wasn`t covered by clouds for the period December-January, even negative air temperature was measured (Table 5). In dependence on the sky`s cloud cover and the wind speed, only E and F stability atmospheric classes was determined during the night. The wind speed for both classes was changed in a narrow range as the sky`s cloud cover was higher (> 50 %) the wind speed was higher too. In January, there was uncommon period in which matching of the sky`s cloud cover higher than 50 % and south wind with speed higher than 6.5 m/s determined Class D of atmosphere stability.

Northeast, east, and southeast were another directions of wind speed during the night as the south, southwest, and southeast winds were with higher speed (Figure 2).

These classes of atmospheric stability correlated closely to the vertical gradient of air temperature which has directly effect on the rate of pollutants diffusion released in the atmosphere by means of point or line source of pollution (Briggs, 1965). For that reason, the wind speed at 200 m above the ground (u_s)

and the effective plume rise height (he) were the key parameters for the SO₂ modeling in the atmosphere.

Table 5.

Atmospheric conditions at TPP "Bobov dol" during the night for the period of observation

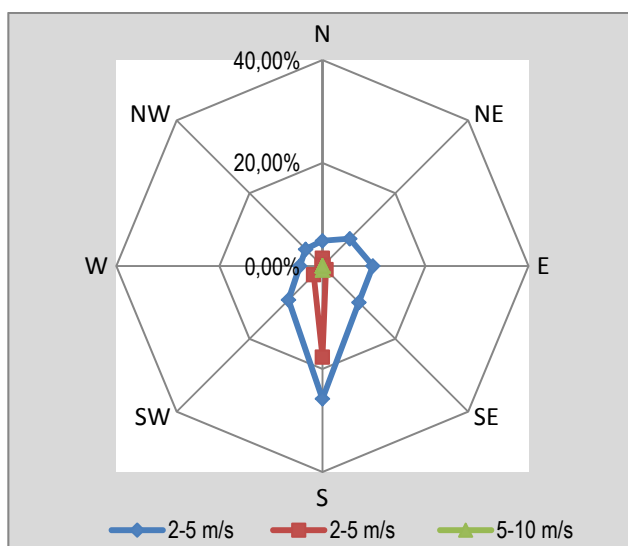| Index	Month/ Wind speed (m/s)					
	November		December		January	
	0-2	2-5	0-2	2-5	0-2	2-5
Northeast direction						
t, ° C	5-11	-	-	-	-	-
Stability class	E/ F	-	-	-	-	-
Southeast direction						
t, ° C	6-8	-	-	-	-	-
Stability class	E/ F	-	-	-	-	-
South direction						
t, ° C	5-6	5-9	3-7	(-1)-(-5)	1-3	(-2)-0
Stability class	E/ F	E/ F	E/ F	E/ F	E/ F	E/ F
Southwest direction						
t, ° C	-	-	4-5	-	-	-
Stability class	-	-	E/ F	-	-	-

Fig. 2. The wind rose of the area around TPP "Bobov dol" during the night (19 – 07 h)

All calculations made regarding the SO₂ dispersion in atmosphere when flue desulfurization unit at TPP "Bobov dol" works properly (Scenario 1) shown that the pollutant concentration at all classes atmosphere stability would be considerable lower than Maximum Admissible Concentration (MAC) of the pollutant on daily basis, in spite of the lower height of release of the treated flue gas in the atmosphere.

All calculations below concern the SO₂ dispersion in atmosphere when flue gases generated at TPP "Bobov dol" wouldn`t be treated (Scenario 2).

The classes A and B are classified as unstable and they are related to higher or average incoming solar radiation and wind speed up to 3.9 m/s. Having in mind, the mean wind ground speed values for each month, the wind speed at 200 m in the range of 1.24 – 2.07 m/s and 1.63 – 3.67 m/s for A and B classes, respectively, would be. These values related to the

following ranges of 39.8 – 27.3 m and 32.3 – 17.6 m for the buoyancy induced plume rise height (∆h), respectively, which shown that almost the insignificant difference in the wind speed determined the significant difference in the effective plume rise when the hot released flue gas would be released in the atmosphere with significantly lower temperature and wind speed. Sulfur dioxide was dispersed in horizontal direction solely and at a distance of 5 km from TPP "Bobov dol" its highest concentration in the below ground air was predicted by this model (Table 5, Figure 3). However, the pollutant concentration determined by this model for the prevailing atmospheric conditions of the observed period was quite lower in comparison to the MAC. The additional calculation which was made shown that if the ground level wind speed dropped below 1.0-1.2 m/s, the ground air concentration of sulfur dioxide at 2.5 km from the point source would be higher than the permissible level of 350 µg/m³. The south wind which was the most typical wind during the observed period would transported the pollutant in north direction and its concentration in Radomir (situated at 20 km from TPP "Bobov dol" by air) would be in the range 4.0-6.5 µg/m³. The pollutants dispersion at these climatic conditions would be carried out in horizontal as well as radial directions and as a result sulfur dioxide concentration would steadily decreased from the plume`s centerline (Table 6, Figure 4).

The class C is classified as a slightly unstable and it was typical at about 25 % of the daily time of observed period. The south wind determined solely this class of atmosphere stability, as the ground wind speed was in the range of 2.85-3.80 m/s and between 4.52-6.00 m/s was the variation of the wind speed at 200 m height, respectively. At these climatic conditions, the buoyancy induced plume rise height (∆h) would be in the range of 12.25-14.75 m. This would determine lower concentration of sulfur dioxide at a closer distance to TPP "Bobov dol" in comparison to the stability classes A and B, and at a distance to the power plant higher than 10 km the pollutants concentration would be higher than the concentration determined for the classes A and B. Meanwhile, the speed of radial pollutant dispersion in the atmosphere steadily decreased and at a distance higher than 25 m from the plume`s centerline the pollutant concentration would be drop significantly (Table 6, Figure 4).

The class D is classified as neutral and it was the only class observed during the day and night when the sky cloud cover was higher as well as the wind`s speed was higher than 5 m/s. In that case, the wind speed at 200 m and the buoyancy induced plume rise height (∆h) would be changed in very narrow range (13.17–13.25 m/s and 6.6–7.0 m), respectively. At these climatic conditions, the accidentally released plume would be dispersed in the atmosphere in horizontal and vertical directions solely with higher rate which would determine the highest ground level concentration of sulfur dioxide at a distance of 10 km from TPP "Bobov dol" (Table 5). At the same time, the variation in the pollutants concentration in vertical direction at the same distance would be also in a narrow range (Figure 5).

The classes E and F were observed during the night and both classes related to the stable atmospheric conditions expressed with minimal vertical transfer of masses and energy. The northeast, southeast, and southwest winds associated

Table 5.
Concentration range of SO$_2$ ($\mu g/m^3$) in the below ground atmospheric layer (2 m) in dependence on the atmospheric stability and the distance to TPP "Bobov dol".

Stability class	Distance from TPP "Bobov dol", km					
	2.5	5.0	10.0	15.0	20.0	30.0
A	176-285	56.7-94	15.2-25.4	6.9-11.6	4.0-6.6	1.0-3.0
B	134-288	45.7-93.4	12.2-25.1	5.1-11.4	3.2-6.5	1.4-2.9
C	103.4-133.7	67.4-88.8	24.3-32.2	12.3-16.3	7.4-9.9	3.6-4.8
D	0.9	12.4	20.7	17.7	14.4	9.8
E	< 0.05	0.4-0.9	4.7-13.2	6.3-18.4	9.4-28.4	8.3-27.5
F	<0.05	<0.05	<0.05	<0.05	<0.05	0.5-0.9

Table 6.
Radial concentration of SO$_2$ ($\mu g/m^3$) in the below ground atmospheric layer (2 m) at a distance of 20 km to TPP "Bobov dol" and at different climatic conditions.

Stability class	Distance from the plume`s centerline, m				
	1	25	50	75	100
A	4-6.7	3.5-5.8	2.3-3.8	1.1-1.8	0.4-0.7-
B	3.2-6.5	2.5-5.1	1.2-2.5	0.3-0.8	<0.05
C	7.5-9.9	4.8-6.3	1.2-1.6	0.1-0.2	<0.05
D	14.4	5.2	0.2	<0.05	<0.05
E	9.5-28.4	1.5-4.6	<0.05	<0.05	<0.05
F	0.2-0.4	0.05	<0.05	<0.05	<0.05

almost equally to both atmospheric classes. However, the winds associated with class F had speed higher with 20-40 % than the winds associated with class E. For example, 1.1-1.2 m/s was the typical ground level speed of northeast and southeast winds which related to class F and the winds speed at 200 m and the buoyancy induced plume rise height (Δh) would be in the range of 14-15 m/s and 6-6.5 m, respectively. In contrast, 0.8-0.9 m/s was the typical ground level speed of both winds related to class E and 4.3 m/s and 11.3 m would be the meand values for the wind speed at 200 m and the buoyancy induced plume rise height (Δh), respectively.

The south wind, which was dominating in the area of TPP "Bobov dol" also during the night, determined such kind of climatic conditions associated with clear dominance of class E over class F. Nevertheless, the wind speed for both classes was almost equal. For example, the mean value of south wind speed associated with class F was in the range of 1.3-1.5 and 2.3-2.9 m/s, while the values of the same wind related to class E were in the range 1.1-1.3 and 2.6-2.8 m/s. Despite the higher difference of the wind`s speed related to class F and the higher variance of the wind speed at 200 m (between 16.5-36.0 m), the values of buoyancy induced plume rise height (Δh) was in a narrow range (between 3.15-5.75 m). In relation to class E, the wind speed at 200 m was in range of 5.5-14.00 m/s, while the buoyancy induced plume rise height (Δh) varied in a wide range (6.5-13.0 m).

For atmospheric classes E and F the pollutant`s dispersion would be realized at a higher height and for that reason relatively lower concentration of sulfur dioxide would be expected to be detected at ground level layer. For example, the highest concentration of sulfur dioxide for class E would be in
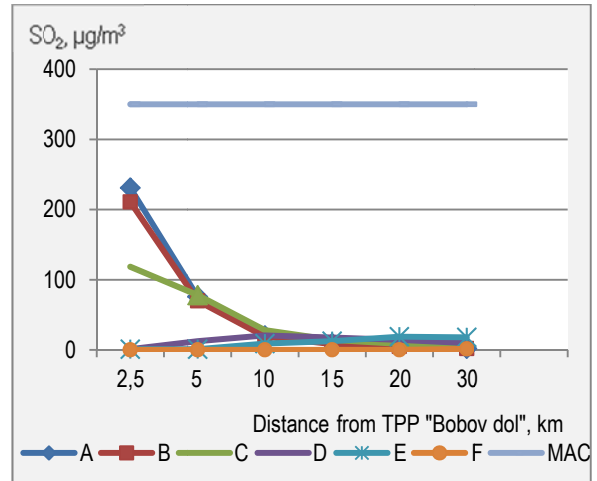

Fig. 3. Mean concentrations of sulfur dioxide in the below ground atmospheric layer (2 m) in dependence on the different classes climatic conditions and the distance to TPP "Bobov dol"
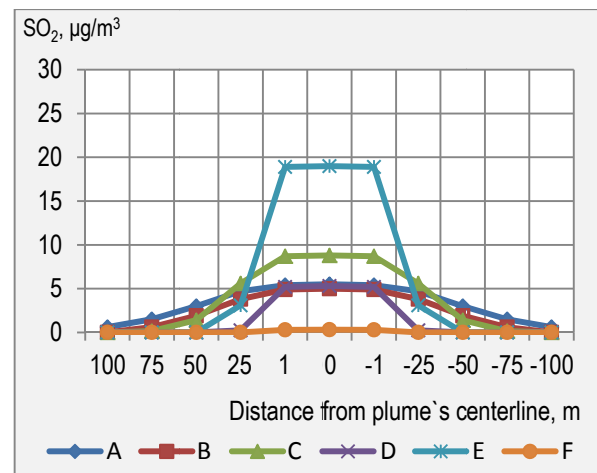

Fig. 4. Mean radial concentrations of the sulfur dioxide concentration at a distance of 20 km from TPP "Bobov dol" for the below ground atmospheric layer (2 m) in dependence on the climatic conditions
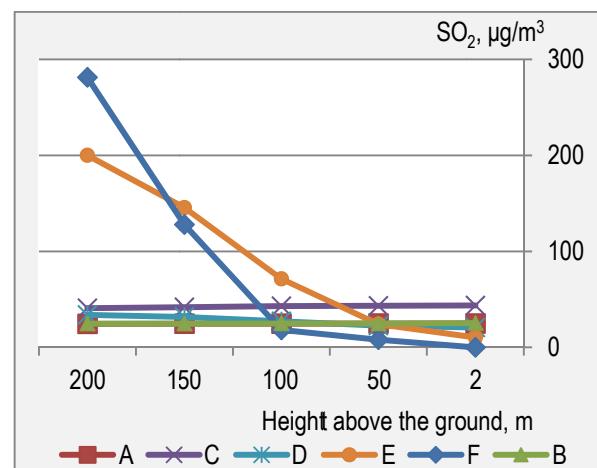

Fig. 5. Vertical variation of the sulfur dioxide concentration at 10 km distance from TPP "Bobov dol" in dependence on the difference classes climatic conditions

the range of 27-29 µg/ m³ at a distance of 20-30 km from the power plant. Something more, all ground concentrations of the pollutant for the observed period and for all area in characterization never would exceed 1 µg/ m³ when climatic conditions are within the frame of class F (Table 5). For that, the accidental release of sulfur dioxide in the atmosphere during the night would have a negligible negative effect on the health of inhabitants of Radomir, Dupnitza, and Kyustendil. The main reason was the minimum vertical dispersion of the pollutant from the higher height of atmosphere to the ground level as this process would be lowest for class F in comparison to all other classes of atmosphere stability. As a result, the radial pollutant transport would be also negligible and the pollutant concentration would be dropped rapidly only at a few meters aside from the plume`s centerline (Table 6, Figure 4). Meanwhile, the pollutant concentration would be increased at a higher level above the ground and even at average and longer distance (15-30 km) from TPP "Bobov dol" would be in the range of 75-250 µg/ m³. In such case, the main negative effect of the sulfur dioxide, accidentally released in the atmosphere during the night, on these towns would be washout of the diluted sulfuric acid and its wet deposition on the short-distance situated towns and terrestrial ecosystems as acid rains. That conclusion is in accordance to the data of the National Institute on Hydrology and Metereolgy at BAS which regular monitoring in the area shown that pH of rains in Kyustendil are with the lowest pH in comparison to the rains` pH measured in the other Bulgarian towns where similar monitoring is also applied (Monthly Hydrometereological Bulletin, 2014).

Conclusions

1.   The south wind with speed 0-2 and 2-5 m/s was the most typical wind for the area around TPP "Bobov dol" during the day and night for the period November 2014 – January 2015.

2.   All kind of Pasquill`s atmospheric stability classes was determined for the period of monitoring as the most typical classes during the day were A and B, and classes E and F – during the night.

3.   The combination of lower incoming solar radiation and wind speed lower than 2 m/s, which was typical for class B, determined the highest concentration of SO_2 in the below ground atmosphere at a distance of 2.5 km from TPP "Bolov dol" when its desulfurization technique is not working. Only if the wind speed would be lower than 1.0-1.2 m/s at the moment of pollutant`s emitting, its concentration at that distance would be higher than Maximum Admissible Concentration (MAC) of SO_2 on hour basis. However, Radomir, Dupnitsa, and Kyustendil are situated at a longer distance from TPP "Bobov

dol" and direct negative effects on the health of their inhabitants would be not expected if the SO_2 is released accidentally in atmosphere for a short period of time.

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