

MODELING OF THE ATMOSPHERIC DISPERSION OF FINE PARTICLE MATTERS (PM₁₀) RELEASED DURING THE OPERATION OF TPP "MARITZA EAST-2", BULGARIA

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ABSTRACT. The main aim of this article were modeling of PM₁₀ dispersion in the atmosphere released during the operation of TPP "Maritza East- 2" and at what distance their concentration in the ground atmospher could be higher than the relevant Maximum Admissible Concentration (MAC). The model was based on the following assumptions: the lignite consumption and the pollutant's emission rate to the atmosphere were constant, the atmosphere conditions (temperature, direction and wind speed, etc..) were also constant on hourly base, and the wind speed was higher than 0.9 m/s. Having in mind the lignite's ash content and the efficiency of electroprecipitators operation, 2.45 g PM₁₀ /m³s was calculated as the emission rate of the power plant to the atmosphere. PM₁₀ dispersion was modeled in dependence on the atmospheric stability categories which determined the effective plume-rise height (h_e) in the atmosphere at the relevant climatic conditions and the specific values of pollutant dispersion coefficients (σ_y , σ_z). The wind rose for a period July 2015 – January 2016 determined that the plume released in the atmosphere will be transported in north .direction to Nova Zagora town by means of south wind with prevailing wind speed up to 5 m/s. However, the model determined that the ground concentration of PM₁₀ would be higher than MAC during the night and at a distance of 6.25 km from TPP "Maritza East - 2" if the hour lignite consumption was higher than 2250 tone coals/ h as well as the ground wind speed was lower than 5 and 10 m/s for atmospheric stability classes E and D, respectively.

Keywords: particle matters (PM₁₀), modeling, TPP, atmosphere stability categories

МОДЕЛИРАНЕ ДИСПЕРСИЯТА НА ФИННИ ПРАХОВИ ЧАСТИЦИ (PM₁₀) В АТМОСФЕРАТА, ОТДЕЛЕНИ ПРИ РАБОТАТА НА ТЕЦ „МАРИЦА ИЗТОК-2”

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РЕЗЮМЕ. Основната цел на статията бе моделиране дисперсията на финни прахови частици (PM₁₀) в атмосферата, отделени при работата на ТЕЦ „Марица Изток-2” и определяне разстоянието, при което тяхната концентрация би била по-голяма от съответните ПДК. Моделът се базираше на следните допускания: консумацията на въглища и скоростта на отделяне на замърсителя в атмосферата бе постоянна, атмосферните условия (температура, посока и скорост на вятъра) са постоянни на часова база, скоростта на вятъра не е по-ниска от 0.9 m/s. Скоростта на емисията на финни прахови частици в атмосферата (2.45 g PM₁₀ /m³s) беше определена от средното пепелно съдържание на лигнитните въглища и ефективността на пречистване на електрофилтрите. Дисперсията на тези частици беше моделирана в зависимост от класовете стабилност на атмосферата, които определяха ефективната височина на издигане на газовия поток (h_e) в атмосферата при съответните климатични условия и съответните стойности на дисперсионните коефициенти (σ_y , σ_z). Розата на вятъра за периода Юли 2015 – Януари 2016 определиха, че газовият поток, отделен в атмосферата ще се транспортира в северна посока към град Нова Загора, с преобладаваща скорост на вятъра до 5 m/s. Въпреки това, моделът определи че приземната концентрация на финни прахови частици (PM₁₀) би била по-голяма от ПДК през нощта и на разстояние 6.25 km от ТЕЦ „Марица Изток-2”, ако разходът на лигнитни въглища е по-голям от 2250 тона въглища/ час, както и приземната скорост на вятъра е по-ниска от 5 and 10 m/s за атмосферни класове E и D, 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 the 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.

TPP "Maritza East 2" is the largest thermal power plant in Bulgaria with total install capacity of 1620 MW. The power plant is a part of Maritza East complex which operates on the local lignite coal mined by Maritza East mine. TPP "Maritza East 2" produces about 21 % of total electricity generated in Bulgaria as its portion in comparison to all thermal plant reach about 40 % (South-East European Industrial Market. 2010). The coal lignites utilized by the power plant characterized with low caloric value and higher content of sulfur and ashes. For that reason, TPP "Maritza East 2" is among the top ten largest industrial enterprices in Europe releasing higher amount of contaminants in atmosphere. In order to meet the national and international regulations concerning the concentration of the main contaminants (Ordinance №10, 2003), a lot of funds have been invested during the last ten years in sulfur removal installation and improvement in the way of operation of electroprecipitators for the flue gases treatment.

Table 1.
Main properties of the coals burnt at TPP "Maritza East 2"

Index	Value
Carbon, %	20.0
Hydrogen, %	2.15
Nitrogen, %	0.3
Sulfur, %	2.5
Oxygen, %	7.3
Ash content, %	35.0
Heat value, MJ/ kg	6.5
Total consumption (average), t/ y	11 000 000

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

Index	Value
Outlet flue gases temperature, °C	65
Specific gravity of flue gases, g/cm ³	1.007
Outlet flue gas volume, m ³ / s	893.3
Outlet flue gas, kg/ s	876,4
Emission of PM ₁₀ , kg/s	1.9747
Rate of PM ₁₀ emission generation, g/m ³ Ns	2.445

The main aim of this article were modeling of PM₁₀ dispersion in the atmosphere released during the operation of TPP "Maritza East- 2" and at what distance their concentration in the ground atmosphere could be higher than the relevant Maximum Admissible Concentration (MAC).

Materials and methods

The data about the atmospheric pressure, the direction and wind's speed, temperature, and rate of precipitation in the area of of Radetski village, District of Stara Zagora was collected on hourly base from the bulletins of National Institute of Meteorology and Hydrology at BAS within the period July December 2015. On month base, the data was averaged and the mean temperature, the prevailed wind direction, and the wind speed for both halves of the day were determined.

The PM₁₀ emission generated during the burning of coal in TPP "Maritza East 2" was calculated by means of CorinAir methodology (EAE, 2007). Eleven million tons of coals were accepted as the total amount of coals burnt at the power plant per year. The operating hours were averaged to 5300 hours per year. The data about the utilized coals are presented in Table 1.

The main properties of the generated flue gases and the emission rate of PM₁₀ from TPP "Maritza-East 2" are presented in Table 2. Emission rate of fine particle matters to atmosphere was calculated having in mind the total amount of burnt coals per hour, their ash content and 97.5 percentage efficiency of the electroprecipitators operation being used at the power plant for treatment of flue gases.

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 "Maritza East 2" during the day for the period of observation

Index	Month/ Wind speed (m/s)					
	July - September		October		November - December	
	0-2	2-5	0-2	2-5	0-2	2-5
Southeast direction						
t, ° C	14-30	12.7	-	-	-	-
Stability class	A-B/ B-C	C	-	-	-	-
Southwest direction						
t, ° C	-	-	9-18	3-15	3-15	18-23
Stability class	-	-	A-B/ B	B-C	A/ B/ C	A/ B/ C
West direction						
t, ° C	25-31	5-13	-	-	-	-
Stability class	A-B/ B	B/ C	-	-	-	-
Northwest direction						
t, ° C	20-30	13-18	13-18	18-20	9-16	8-19
Stability class	A	B	A/ B	A-B/ B	A/ B	B/ C

PM₁₀ 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 PM₁₀ to atmosphere was constant;
- 2.The temperature of atmosphere, the wind speed and direction were unchangeable at the relevant climatic conditions;
- 3.The pollutant dispersion carried out in horizontal direction mainly;
- 4.PM₁₀ 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 ≥ 0.9 m/s.

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 135 m height was adjusted by the wind power law (Peterson & Hennessey, 1978).

Results and discussion

TPP “Maritza-East 2” is situated at altitude of 120 m almost in the middle of Thracian valley. For that reason, a lot of towns and villages are situated around the station at a distance within the range of 30 km to the plant. In north direction at a distance of 10.5 km and 24.1 km by air are situated Mlekarevo village and Nova Zagora town, which population are 700 and 24 000 people, respectively. In west direction at a distance of 14 km is situated Radnevo town with population of 13 000 people. Galabovo town is situated at about 24 km from TPP “Maritza-East 2” and it has 8 600 inhabitants. General Toshevo village and Topolovgrad town are situated at a distance of about 14 and 24 km in south/ southeast directions and their population are 400 and 5500 people, respectively (National Statistical Institute. Main Towns Census 2011, 2013).

The studied period, July – December 2015, covered the second part of the year, when TPP “Maritza East 2” worked continuously at a relatively constant coal consumption because of the higher demand of energy (Annual Individual Management Report, 2014). The southeast, west and northwest directions of wind dominated during the day (08-18 h) for the summer months (July-September) as the dominating wind speed was in the range of 2-5 m/s (Figure 1). For the rest part of observed period, the dominating wind directions were south, southwest, and northwest as the typical wind speed was in the range of 2-5 m/s too. Winds with speed higher than 5 m/s were non-typical for the area (with a frequency in the range of 0.8-5.3 %, Table 4). The atmosphere’s temperature was higher during the July and August and the lowest value measured during December. For example, the usual atmosphere temperature during the summer was in the range of 26.3-31.3 °C. In all cases, the west and southwest winds determined the atmosphere temperature with 2.5-3.2 °C higher than temperature measured when the southeast wind dominated. The same tendency was observed during the autumn as the northwest and southwest winds determined the warmer atmosphere in comparison to the temperature measured when south wind dominated. For example, the difference reached almost 4 °C during December.

The incoming solar radiation steadily decreased and the dominance of classes of atmosphere stability gradually changed from A, B (during the summer) to C class (in December) (Table 2). Those processes determined the observed difference in the winds’ speed. For example, the warmer winds with southwest and northwest directions determined higher atmosphere turbulence and wind speed within the range of 3.3-4.1 m/s. The typical wind speed with southeast direction was in the range of 2.3-2.6 m/s. The decreased incoming solar radiation during the autumn determined the lower wind speed (in the range of 2.2-3.48 m/s) in comparison to the speed measured during the summer.

It was found that the class of atmosphere stability F dominated during the summer night, especially in the case when the wind speed was lower than 2 m/s. At higher wind speed and colder temperature of the atmosphere, the dominating classes of atmosphere stability were D and E (Table 5). In comparison to the day period, the seasonal changes in wind speed wasn’t so clearly shown.

Table 5.

Atmospheric conditions at TPP “Maritza East 2” during the night for the period of observation

Index	Month/ Wind speed (m/s)					
	July - September		October		November - December	
	0-2	2-5	0-2	2-5	0-2	2-5
Southeast direction						
t, °C	16-23	15-21	11-15	11-13	5-12	4-11
Stability class	F	E/D	F/E	E/D	F/E	F/D
South direction						
t, °C	-	-	13-14	10-12	7-12	6-10
Stability class	-	-	F/E	E/D	F/E	E/D
Southwest direction						
t, °C	15-22	15-28	12-14	11-13	6-14	2-6
Stability class	F/E	E/D	F/E	E	F/E	E/D

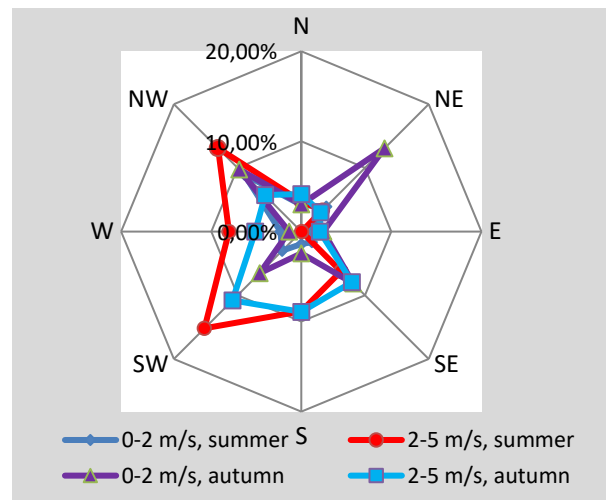


Fig. 1. The typical wind rose of the area around TPP “Maritza-East 2” during the day (08-18 h) for period July-December

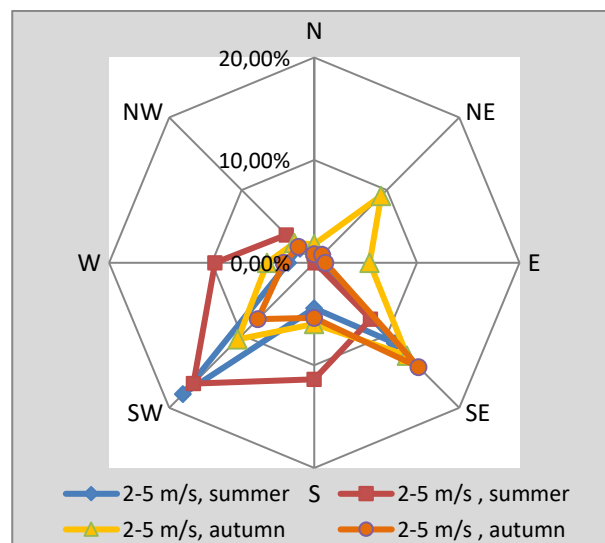


Fig. 2. The typical wind rose of the area around TPP “Maritza-East 2” during the night (19 – 07 h) for period July-December

Table 6.

Mean concentration of PM_{10} ($\mu g/m^3$) in the below ground atmosphere (2 m) in dependence on the atmospheric stability and the distance to TPP "Maritza-East 2"

Stability class	Distance from TPP "Maritza-East 2", km				
	6.25	8.4	15.0	20.0	25.0
A	1.64	3.8	0.77	0.6	0.50
B	8.55	5.00	1.60	0.92	0.59
C	10.43	8.98	2.5	1.52	1.02
D	8.17	8.79	6.75	5.63	4.22
E	0.81	1.80	3.82	4.36	4.07
F	0.02	0.07	0.56	0.83	1.02

Table 7.

Mean concentration of PM_{10} ($\mu g/m^3$) in the below ground atmosphere (2 m) in dependence on the distance to plume's centerline at the relevant climatic conditions (a 8.4 km distance to TPP "Maritza-East 2")

Stability class	Distance from the plume's centerline, m		
	1	25	50
A	1.27	0.68	0.08
B	4.48	1.41	0.07
C	8.98	1.08	0.003
D	9.07	0.08	0.003
E	1.80	0.003	< 0.003
F	0.07	< 0.003	< 0.003

The atmosphere temperature and wind speed were the key factors determined the particle matters dispersion after their emitting to the atmosphere. Both parameters determined what the vertical gradient of air temperature would be. It has direct effect on the rate of pollutants diffusion, which had released in the atmosphere (Briggs, 1965). For that reason, the wind speed at 135 m above the ground (u_s) and the effective plume rise height (h_e) were the key parameters which have been used for the PM_{10} modeling in the atmosphere.

Data about the mean concentrations of PM_{10} in dependence on the distance to TPP "Maritza East 2", the distance to plume's centerline and the stability of atmosphere are presented in Tables 6 and 7.

These data shown that during the day, when the classes A, B, and C dominated, the pollutant's dispersion in atmosphere carried out on the x axis mainly. 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 model predicted wind speed at 135 m in the range of 6.45 – 6.98 m/s and 6.04 – 16.66 m/s for A and B classes, respectively. These values determined the buoyancy induced plume rise height (Δh) value in the range of 163 – 172 m as the plume rise height was higher when the temperature of atmosphere was lower. At that conditions, the emitted flue gas elevated easily in vertical direction before its dispersion in horizontal direction started. The fine particle matters dispersed in horizontal direction solely and for that reason, the applied model predicted their higher concentration at lower distance to TPP "Maritza East 2" (Table 6). However, the pollutant concentration predicted by this model for the prevailing atmospheric conditions of the observed period was quite lower

in comparison to the MAC. The northwest, west, and southwest winds dominated during the day for the period of observation and the southeast, east, and northeast were the directions for pollutants transportation to Topolovgrad town, General Toshevo village, and Boyadjik village, respectively. The class C is classified as a slightly unstable and it was typical within the range 11.3-17.5 % of the daily time of observed period. The southeast, south, and southwest wind connected solely with the appearance of that class of atmosphere stability in the area. The typical wind speed was in the range of 3.4-3.8 m/ s. In that case, the wind speed at 135 m and the buoyancy induced plume rise height (Δh) would be in very narrow range (19.1–32.9 m/s and 35.0–70.3 m), respectively. At these climatic conditions, the used model predicted the maximum concentration of PM_{10} in the below ground atmosphere in comparison to the other classes stability of atmosphere occurring during the day.

The class D is classified as neutral and during the autumn it was more typical (about 19.2 %) in comparison to the summer. The typical wind speed at below ground atmosphere was in the range of 3.4-3.8 m/ s and the main winds directions were southeast, south, and southwest. At these conditions, the typical maximum concentration of PM_{10} measured at a distance of 8.4 km was in the range of 8-10 $\mu g/ m^3$.

The classes of atmospheric stability E and F appeared during the night and the are correlated with minimal vertical transfer of masses and energy. For that reason, these classes are classified as stable and at these conditions the dispersion of PM_{10} in atmosphere carried out in a thin layer of atmosphere on the x axis at a significant height above the ground. For that reason, the model predicted the highest concentration of PM_{10} in the ground layer of atmosphere at a higher distance to TPP "Maritza East 2" in comparison to the already discussed classes. The model predicted the maximum concentration of pollutant at classes of stability E and F at distance 15-25 km from the source in the range of 4.8-5.6 $\mu g/ m^3$ and 0.46-1.2 $\mu g/ m^3$, respectively, (Table 6). The class E dominated in July (23.8 %) and its appearance correlated with the southeast wind. The typical atmospheric conditions connected with this class were temperature and wind speed in the range of 19 – 22 °C and 11 – 15 m/ s, respectively. In the period October – December, the atmosphere temperature and wind speed dropped to the values within in the range of 13 – 2.5 °C and 1.8 – 3.6 m/s, respectively. The southwest wind determined these atmospheric conditions.

The class F reflected the most stable atmospheric conditions which appeared during the night. For that reason, this class of stability dominated during the summer (July and August) and December when the typical atmospheric conditions for the relevant season had reached. For example, class F appeared in the range of 38.8 – 41.1 % for the summer night. The southeast and southwest winds determined the average temperature and winds speed in the range of 21.3 – 25.6 °C and 2.47 – 2.72 m/s, while in December the value were in the range of 4.7 – 5.2 °C and 1.4 – 2.5 m/ s. In dependence on the season, the wind speed at 135 m and the buoyancy induced plume rise height (Δh) varied in a wide range: 20.1 – 49.8 m/s and 59 – 33 m, respectively.

The radial dispersion of PM_{10} carried out on the x axis and for that reason the pollutant concentration decreased significantly at higher distance from the plume's centerline (Figure 4).

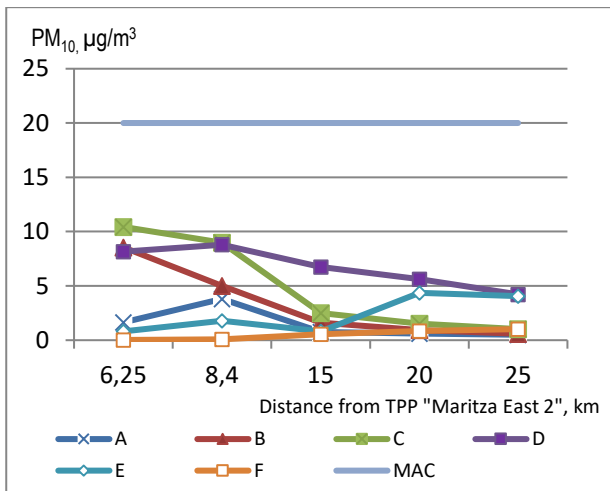


Fig. 3. Mean concentrations of PM₁₀ in the below ground atmosphere (2 m) in dependence on the climatic conditions and the distance to TPP "Maritza-East 2"

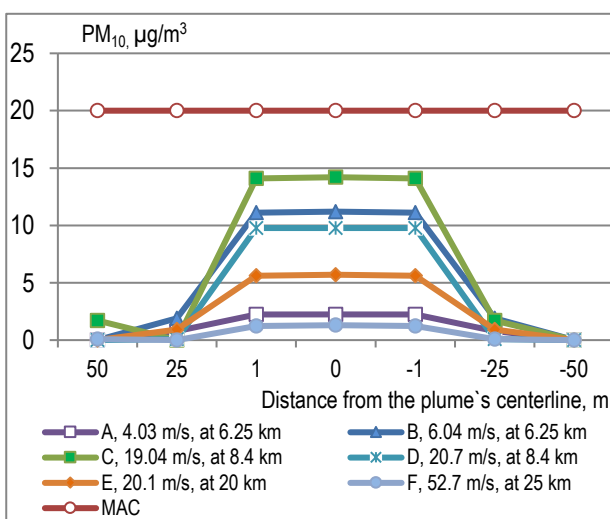


Fig. 4. Mean radial concentrations of PM₁₀ concentration in the below ground atmosphere at a different distance to TPP "Maritza-East 2" in dependence on the climatic status

The next task of that study was to determine at which climatic conditions the concentration of PM₁₀ in the below ground atmosphere could reach the relevant Maximum Admissible Concentration of 20 µg/m³. That calculations were restricted to classes of atmosphere stability B, C, and D for whom the model predicted the highest concentration of PM₁₀ in the below ground atmosphere. The results shown that with lowering the temperature of atmosphere at these classes, the wind speed (u_s) decreased too and the below ground concentration of the pollutant increased. For example, at 5.4 m/s for class B and 15.2 m/s for class C the predicted concentration were 11.2 and 13.3 µg/m³. For class D, at the lowest temperature of atmosphere, (9.9 °C) and value of 23.3 m/s for u_s , the model predicted below ground concentration of of PM₁₀ at distances of 6.25 and 8.4 km from TPP "Maritza East 2" 13.00 µg/m³ and 12.74 µg/m³, respectively.

These results shown that at the regular coal consumption (at about 2075 t/h) and operation of electroprecipitators at TPP "Maritza East 2", the rate of fine particle (PM₁₀) emission to atmosphere was 2.445 g/m³ns. However, the pollutant concentration was lower than the relevant MAC at all climatic conditions at all distance up to 25 km from the point of its

emitting. If the power plant increased the coal consumption by 70-75 % on the hour base, the concentration of PM₁₀ higher than the relevant MAC would be measured at distances of 6.25 and 8.4 km and at unstable conditions of atmosphere (classes B and C).

Conclusions

1. The southeast, south, and southwest winds with speed 0-2 and 2-5 m/s were the most typical winds for the area around TPP "Maritza East 2" during the day and night for the period of observation July – December 2015.
2. All kind of Pasquill's atmospheric classes of stability 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 applied model predicted that at coal consumption of 2075 t/hour, the higher concentration of fine particle matters (PM₁₀) in the below ground atmosphere could be expected at distances of 6.25 and 8.4 km for atmospheric classes B and C. The atmospheric conditions associated with class D determined the higher concentration of pollutant at the same distances to TPP "Maritza East 2". However, the predicted concentrations in all cases were considerably lower than the relevant Maximum Admissible Concentration (MAC) with a value of 20 µg/m³.

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