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ON THE DISPERSION OF GASES DISCHARGED TO THE CHIMNEY OF A THERMAL POWER PLANT

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ABSTRACT

This paper presents a theoretical study on the dispersion of gaseous pollutants from a natural gas thermal power plant in the event of a malfunction. Using the Gaussian model, the dispersion of nitrogen oxides generated by such a thermal power plant was evaluated across different atmospheric stability classes. This allowed for an assessment of whether the concentration of this pollutant meets the maximum permissible limits established by Romanian laws, as well as an identification of the affected areas.

KEYWORDS: dispersion, gaussian, nitrogen oxides, atmospheric stability

1. Introduction

Currently, the air pollution situation is causing concerns at all levels of society, having a significant impact on public health, the environment and the economy. Most specialists in the field believe that we can talk about significant anthropogenic air pollution starting with the first industrial revolution, 1760-1840, when the steam engine was perfected and the use of coal was widely used, especially in the textile industry. This revolution marked a turning point in the evolution of human society, transitioning from an agrarian and artisanal economy to one based on industry and mechanized production. From this point forward, people’s hopes for a better life took on new dimensions, given the advantages brought by the Industrial Revolution. However, one of the side effects of this industrial development was the release of gaseous pollutants into the atmosphere, such as SO_2, CO, CO_2, NO_x, VOCs, PM, and others.

At European level the Directive 2008/98 CE imposes that “by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70% by weight”. Considering the harmful effects on human health and beyond, the phenomenon of air pollution has drawn the attention of authorities, leading to the implementation of measures aimed at regulating this field. The link between air pollution and related diseases dates to 400 BC, with Hippocrates addressing this topic in his writings [1]. Gradually, due to the continuous increase in air pollution, various legislative norms were introduced to reduce this type of pollution. For example, in England, the Smoke Abatement Act was passed in 1273 [1].

Awareness of the link between air pollution and its environmental issues led to international measures, culminating in the Human Environment Summit in Stockholm in 1972 under the auspices of the United Nations. Representatives from 113 participating countries adopted a declaration containing 26 fundamental principles regarding environmental protection. Following this event, other international summits addressing topics in this area occurred periodically; however, agreements among signatory countries have not succeeded in halting the rise in air pollution.

It is up to all of us to recognize the danger that this phenomenon poses to ourselves and to future generations.

2. Urban Air Pollution

Urban agglomerations have emerged as an inherent effect of human societal development, offering advantages such as easier access to services, education, healthcare, and culture. However, they also have disadvantages, including air pollution.

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In Romania, an important source of air pollution comes from activities related to heating homes during the cold season and providing hot water.

In other words, the abandonment of centralized heating systems in many Romanian cities resulted in the shift of pollution from outside to inside the city, leading to a series of adverse consequences for urban residents.

In addition to contributing to the transformation of cities into "heat islands," they also have a negative impact on human health by emitting toxic gases such as NOx and CO.

Natural gas-fired thermal power plants have become an important source of urban air pollution in recent years, especially in localities where centralized hot water distribution systems have been dismantled.

3. Evaluation of Flue Gas Dispersion from a Heating Plant Using the Gaussian Model for a Continuous Source

Typically, methane gas-fired boilers are not considered polluting if CO_2 emissions are excluded. However, in cases of wear or faulty combustion, they can become significant sources of pollution. Under these conditions, understanding the dispersion of flue gases from such a plant is of particular interest.

As a case study for this scenario, we will consider the thermal power plant located in a historic building in the municipality of Braila, which currently houses the Faculty of Engineering and Agronomy, Fig. 1.

The heating plant responsible for supplying thermal energy is equipped with two GAS XP60CE burners, each with a capacity ranging from 232 to 522 kW, Fig. 2.

Fig. 1. *The headquarters of the Faculty of Engineering and Agronomy in Braila: 1. Heating Plant Room; 2. Flue Gas Stack*

Fig. 2. *Heating Plant*

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3.1. Mathematical Model

To evaluate the dispersion of the exhaust gases from this plant into the atmosphere, the Gaussian model for continuous sources will be applied. Assuming the wind direction aligns with the OX axis, the evolution of the plume will follow the pattern shown in Fig. 3.

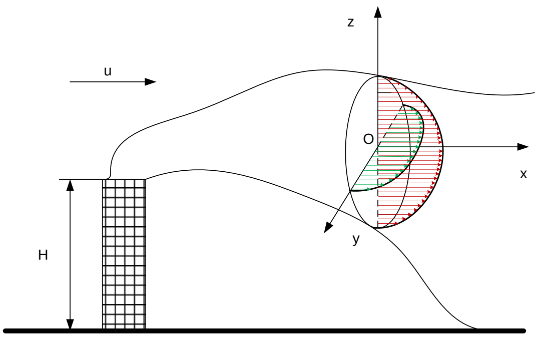

Fig. 3. *Dispersion of the pollutant plume*

Given that pollutant dispersion along the OX direction can be neglected relative to advection, the well-known Gaussian equation characterizing the pollutant concentrations emitted from the chimney can be expressed by equation (1):

$$\boldsymbol{C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u} e^{-\frac{y^2}{2\sigma_y{}^2}} \left\{ e^{\left[-\frac{(z-H)^2}{2\sigma_z{}^2}\right]} + e^{\left[-\frac{(z+H)^2}{2\sigma_z{}^2}\right]} \right\}}$$

where:

Q - pollutant emission rate, μg/s;
x, y, z - coordinates of the axis system;
z - the height at which the concentration of the pollutant is assessed;
u - wind speed;
H - chimney height;
σ_y, σ_z - dispersion parameters, it was considered that the dispersion is insignificant in the Ox direction in relation to the distance travelled in the wind direction.

3.2. Stability of the atmosphere

Atmospheric stability is an important factor in the dispersion of pollutants. In a stable atmosphere, air tends to remain at the same altitude, while in an unstable atmosphere, air can exhibit upward and/or downward movements.

The stability classes were defined according to the Procedures for Evaluating Air Quality Impact of New Stationary Sources, EPA [4], Table 1.

Table 1. *Atmospheric stability classes*

Surface wind speed (m/s)	**Daytime insolation**			**Nighttime**	
	Strong	**Moderate**	**Slight**	**Thin overcast > 4/8 low cloud cover**	**< 3/8 cloud cover**
< 2	A	A- B	B	-	-
2- 3	A- B	B	C	E	F
3- 5	B	B- C	C	D	E
5- 6	C	C- D	D	D	D
> 6	C	D	D	D	D
A: very unstable, B: unstable, C: moderately unstable, D: neutral, E: stable, F: very stable					

3.3. Dispersion Parameters

Since, in this case, the wind speed is constant and the emission of flue gases is steady, the dispersion parameters have been evaluated based on the relationships established by Briggs-McElroy-Pooler for urban conditions, Table 2.

4. Simulation of an Emergency Situation

A failure scenario was simulated in which the plant in question does not operate within nominal parameters, releasing harmful gases into the atmosphere, specifically nitrogen oxides (NOx). The Gaussian model for continuous sources was used to evaluate the dispersion of nitrogen oxides discharged from the plant's chimney under different atmospheric stability classes.

The numerical solution of the equation evaluating the Gaussian dispersion of the considered pollutant was carried out under the following assumptions: wind speed and direction are constant; the emission rate of the pollutant is constant; meteorological conditions in the horizontal direction

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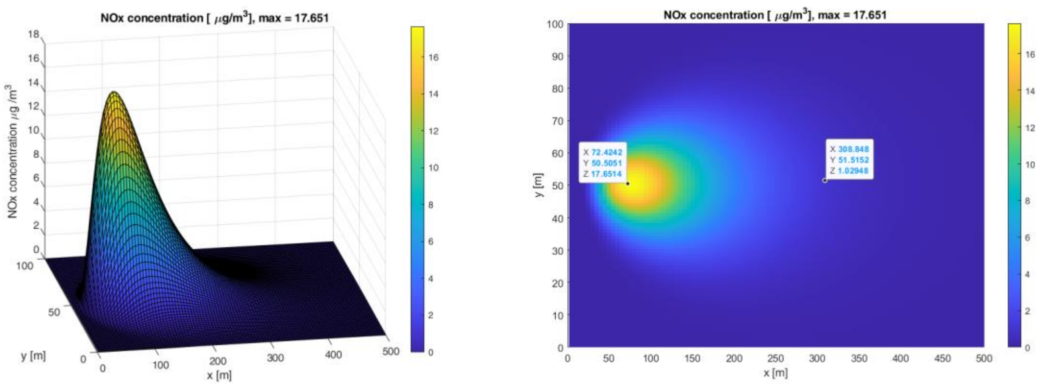
(OX) are constant; the atmospheric stability class is constant; the mixing height is constant; the pollutant does not undergo chemical reactions over short distances; NOx mass flow rate, r = 1.62 g/m^3; exhaust gas flow rate, Q = 473.4 m^3; exhaust area, S = 0.24 m^2; height of the exhaust chimney, h = 17 m; gas temperatures at the exit of the chimney, T = 137 °C. The Matlab programming environment was used for the graphical representation of the pollutant plume, considering different combinations of atmospheric stability classes and wind speed [6-8].

Table 2. *Dispersion coefficients: Analytical formulas of Briggs-McElroy-Pooler*, [5]

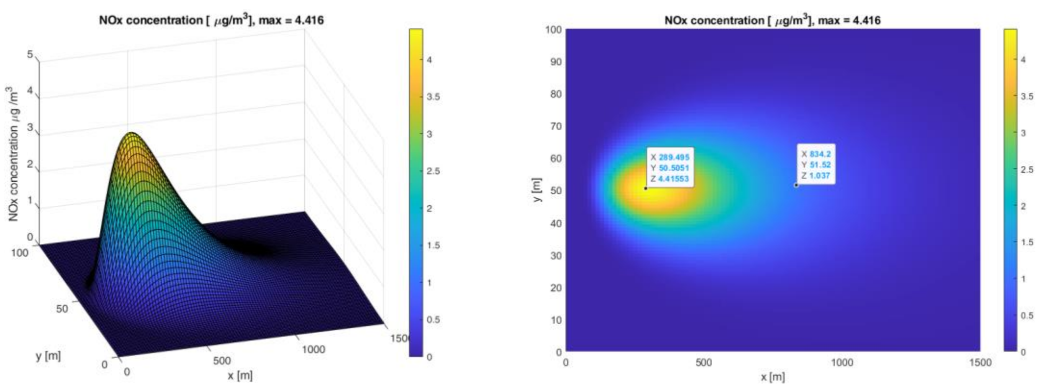
Briggs-McElroy-Pooler		
Stability	σ_y	σ_z
Urban conditions		
A - B	$0.32\,x\,(1 + 0.0004\,x)^{-1/2}$	$0.24\,x\,(1 + 0.001\,x)^{-1/2}$
C	$0.22\,x\,(1 + 0.0004\,x)^{-1/2}$	$0.20\,x$
D	$0.16\,x\,(1 + 0.0004\,x)^{-1/2}$	$0.14\,x\,(1 + 0.0003\,x)^{-1/2}$
E - F	$0.11\,x\,(1 + 0.0004\,x)^{-1/2}$	$0.08\,x\,(1 + 0.00015\,x)^{-1/2}$

For the same atmospheric stability class, A, but with different wind speeds, it is observed that the maximum pollutant concentration occurs at the lower speed, specifically 17.6 μg/m^3 at 72 m from the source, Fig. 4. When the wind speed is 2 m/s, the maximum concentration decreases to 4.4 μg/m³, occurring at 289 m from the source, Fig. 5. The same graphical representations show that as wind speed increases, the area affected by the pollutant also expands. For a pollutant concentration of 1 μg/m³, the difference between the points where this value is reached is approximately 500 m greater when the wind speed is 2 m/s.



a. 3D representation *b. 2D representation*

Fig. 4. *Dispersion of the pollutant plume for atmospheric stability class A and wind speed v = 0.5 m/s*



a. 3D representation b. 2D representation

Fig. 5. *Dispersion of the pollutant plume for atmospheric stability class A and wind speed v = 2 m/s*

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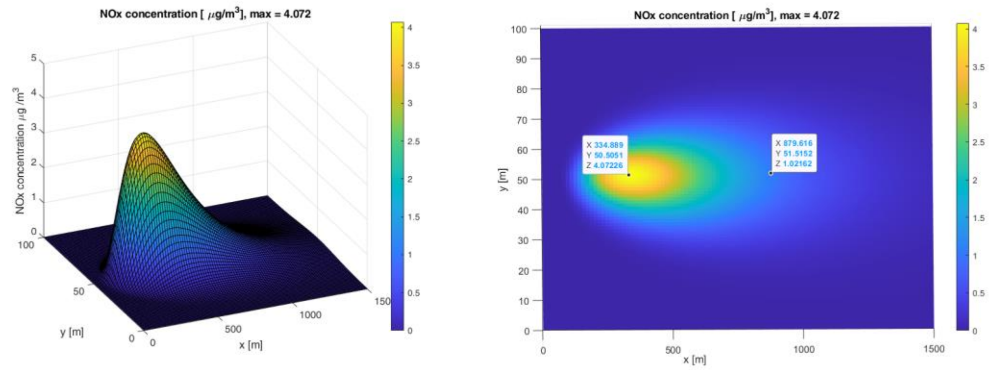
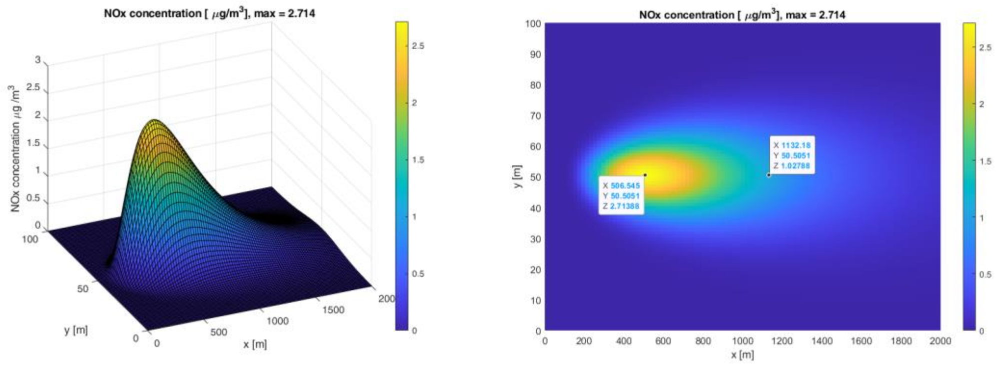
For atmospheric stability class C and a wind speed of 2 m/s, the maximum pollutant concentration and the distance from the source at which a concentration of 1 µg/m³ is reached are very similar to those observed for atmospheric stability class A at the same wind speed, Fig. 6.

For stability class C and a wind speed of 3 m/s, the maximum ground-level concentration is only 2.71 µg/m^3 at 506 meters from the emission source, while a concentration of 1 µg/m³ is reached at 1132 meters, Fig. 7. For atmospheric stability class D and a wind speed of 6 m/s, the maximum pollutant concentration decreases to 0.88 µg/m^3, reached at1273 m from the source, Fig. 8.



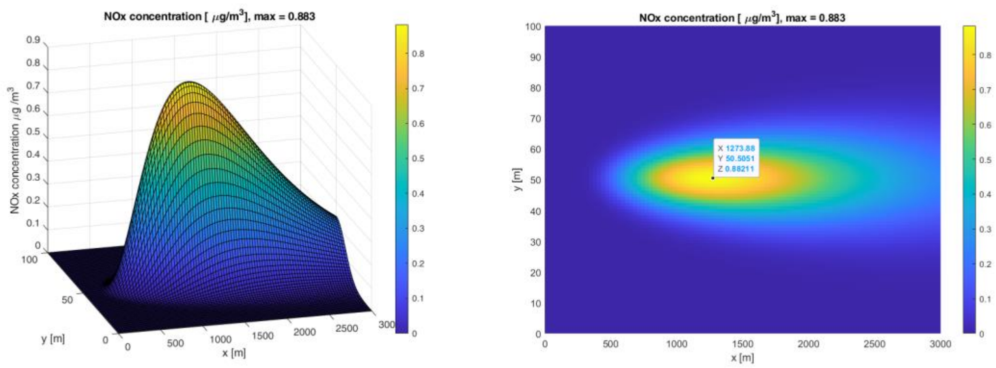
a. 3D representation *b. 2D representation*

Fig. 6. *Dispersion of the pollutant plume for atmospheric stability class C and wind speed v = 2 m/s*



a. 3D representation b. 2D representation

Fig. 7. *Dispersion of the pollutant plume for atmospheric stability class C and wind speed v = 3 m/s*



a. 3D representation b. 2D representation

Fig. 8. *Dispersion of the pollutant plume for atmospheric stability class D and wind speed v = 6 m/s*

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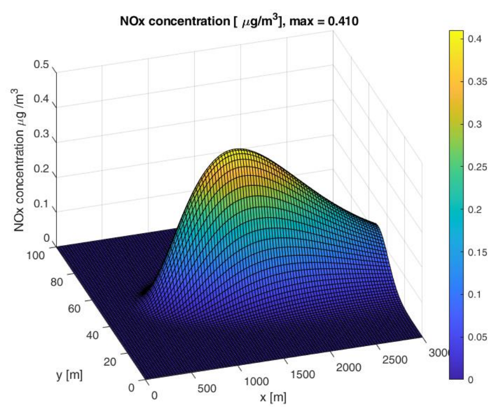
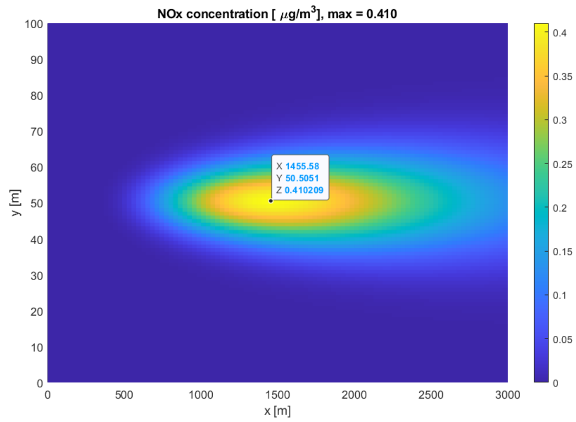
For atmospheric stability class E-F and a wind speed of 5 m/s, the maximum pollutant concentration decreases to 0.41 μg/m^3, reached at a distance of 1455 meters from the source, Fig. 9.



a. 3D representation



b. 2D representation

***Fig. 9.** Dispersion of the pollutant plume for atmospheric stability class E-F and wind speed 5 m/s*

5. Conclusions

The NOx concentration determined in the considered cases is below the maximum permissible values regulated in Romania by law no. 104/2011 on ambient air quality. This theoretical study is particularly important when planning the placement of a system that generates atmospheric pollutants with pathogenic effects on human health, as the Gaussian model allows for the evaluation of pollutant dispersion based on operating conditions and atmospheric stability class. Additionally, this model can be used to simulate the dispersion of gaseous pollutants in the event of malfunctions in combustion systems at various continuously operating installations.

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