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# STUDY ON AIR POLLUTION BY CARBON OXIDES EMISSION FROM CEMENT PLANTS

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**Abstract:** The present study aims to analyze the environmental impact of carbon oxides (CO and $CO_2$) that result from co-processing in a cement plant and are released into the atmosphere from a point source, i.e. stack. Using the Screen View software, which computes the Gaussian model of air dispersion, pollutants concentrations were estimated taking into consideration two variables of the receptor, i.e. air temperature and terrain altitude. Air temperature values of 0, 15, and 30 degC were chosen to represent the variations throughout the year, i.e. mean temperatures during the winter, spring/autumn, and summer seasons. Additionally, since the case study refers to a cement plant surrounded by hills, the terrain was considered composed of three sections (35 m, 50 m, and 60 m above base of the stack) on a length of 5 km from the stack. The results were compared with the estimates obtained in the case of flat terrain conditions.

**Keywords:** carbon oxides, air pollution, cement plant, Gaussian model of air dispersion

## 1. INTRODUCTION

Co-processing is a method that has been implemented for more than 40 years in Europe, and for about 20 years in Romania as well, which is applied in cement plants for both energetic and material use of alternative fuels (recoverable gaseous, liquid, and/or solid waste that are not recyclable) [1, 2]. Although this method is sustainable because it reduces the amount of waste deposited, cement fabrication technology produces pollutant gases that are released into the atmosphere, such as dust, $NO_x$, $SO_2$, and CO and $CO_2$ carbon oxides [2].

Several directives published by the Official Journal of the European Union establish the industrial emission limits of waste incineration and co-incineration, such as Directives 2010/75/EU and 2000/76/EC [3, 4]. In particular, for the carbon oxides emissions, the concentration limits at cement kiln stacks that operate in the European Union are given in table 1 [4]. Regarding air quality regulations in Romania, law no. 104/2011 stipulates the value of 10 $mg/m^3$ as the maximum daily value of 8-hour average for carbon oxide CO [5]. This value assesses the environmental air quality in urban areas in order to evaluate the risks associated with human health of air pollutants.

Table 1. Limit values for carbon oxides emission established in EU regulations for cement kilns [4]

| Pollutant | $mg/Nm^3$ | kg/t clinker | t/year |
|---|---|---|---|
| CO | 500-2000 | 1-4 | 1000-4000 |
| $CO_2$ | 400-520 | 800-1040 | 0.8-1.04 million |

Carbon dioxide ($CO_2$) emissions from cement plants can originate from several sources. During clinker production, calcination of $CaCO_3$ leads to the formation of CaO and $CO_2$ [6]. Referring to the ton of cement, the $CO_2$ emission depends on the ratio of clinker to cement, which can vary in the range of 0.5 to 0.95. The type of fuel used can also influence the amount of $CO_2$ formed in the cement kiln. Additionally, electricity use in the cement plant can produce $CO_2$ emissions into the atmosphere. About 5% of global carbon dioxide emissions originate from cement manufacturing [6, 7]. In cement plants, carbon oxide (CO) emissions may result from the incomplete burning of the fuel [8]. Among the factors that influence the production of CO are the temperature of the combustion products that cool below the combustion temperature of CO before its oxidation. Oxygen availability also influences CO formation in that oxygen may not be sufficient or is not mixed enough with fuel [8].

Continuous monitoring of emissions is used to determine the concentrations of pollutants at the exit of stacks in cement plants [4]. After air dispersion of the pollutants, computational models can estimate environmental pollution at certain distances from the source of emission [9]. The Gaussian plume model is well described in the literature and is implemented in several software which gives the solution to the pollutant concentration equation [9].

This study aims to analyze the air dispersion of carbon oxides (CO and $CO_2$) produced by co-processing in a cement plant and released from a point source, i.e. stack. Using the computational model Screen View, the pollutants profile concentrations were estimated at ground level, along an elevated linear distance of 5 km length from the emission source, which represents the hills surrounding the cement plant.


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Comparisons are made with estimates of concentration of pollutants deposited on flat terrain and in function of air temperature.

## 2. CASE STUDY

The Screen 3 model implemented in the ScreenView software, which is based on the Gaussian model of air dispersion, estimates the concentration at ground level, under the pollutant plume centerline, in specific points, or along a linear distance. It is known that the maximum concentration occurs under the centerline location of the plume [10]. The Gaussian model equations are well known and presented in many references, such as [9-11]. Therefore, the concentration estimates presented next in this study are given as one-directional variation depending on the distance from the emission source, up to 5 km.

The pollutants analyzed in the present study are the carbon oxides CO and $CO_2$ that were measured in the cement kiln stack, before being released into the atmosphere [12]. In the model, the emission source is considered to be the 'point' type with the geometric characteristics given in table 2. Additionally, measured data on effluent properties, which were also used as input data in the Screen 3 model, are given in table 2 [12].

Table 2. Data about the point emission source and the carbon oxides emission through the stack

| Description | CO | $CO_2$ |
|---|---|---|
| stack built height, in (m) | 140 | |
| stack diameter at the top, in (m) | 4.4 | |
| effluent velocity, in (m/s) | 7.5 | |
| effluent temperature, in (degC) | 150 | |
| effluent flow rate, in ($m^3$/h) | 409520 | |
| pollutant concentration in effluent, in (mg/$m^3$) | 274.52 | 439.55 |
| pollutant rate of emission, in (g/s) | 31.23 | 50 |

Some data presented in table 2 were calculated based on the experimentally determined ones. Therefore, the emission rate of the pollutants (in g/s) is calculated by multiplication of experimentally measured values of effluent flow rate (in $m^3$/s) and pollutant concentration in effluent (in mg/$m^3$) [13]. Furthermore, the velocity value of the effluent (in m/s) is calculated by the fraction between the measured effluent flow rate value (in $m^3$/s) and the cross-sectional area of the stack (in $m^2$).

Table 3. Data on the receptor

| Description | Value |
|---|---|
| terrain elevation, in (m) | 0, 35, 50, 60 |
| maximum distance from the stack, in (m) | 5000 |
| air temperature, in (degC) | 0, 15, 30 |

In table 3 are given input data about the receptor. These data were chosen and represent the variables of the pollutant concentration estimates by the Screen View software. The air temperature values of 0, 15 and 30 degC were chosen to represent the variations throughout the year, i.e. mean temperatures during winter, spring/autumn, and summer seasons. Since the case study refers to a cement plant surrounded by hills, the elevation of the terrain was modelled using several sections, on a distance of 5 km from the stack.

Based on the terrain altitude values from the topographic map of the studied cement plant given in figure 1 [14], it may be observed that all around the stack base line and up to 5 km of distance, the terrain height does not exceed 60 meters. So, in the model that allows linear estimates of the concentration, the 'hill' was computed as a three section structure as shown in figure 2. These sections are: 35 meters above the stack base on a distance from stack between 200 meters and 1 km, next, 50 meters height for a distance up to 3 km, followed by a height of 60 meters up to 5 km distance. In the Screen 3 model, these values were set using the option of 'simple elevated terrain'. This option is available if the surrounding terrain does not exceed the construction stack height [10]. In addition, to compare the results, estimates with flat terrain condition are considered.

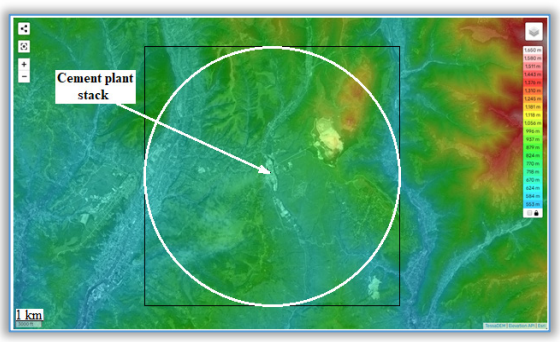


Figure 1. Topographic map of analyzed area [14]. A circular area with a 5 km radius is highlighted around the cement plant stack

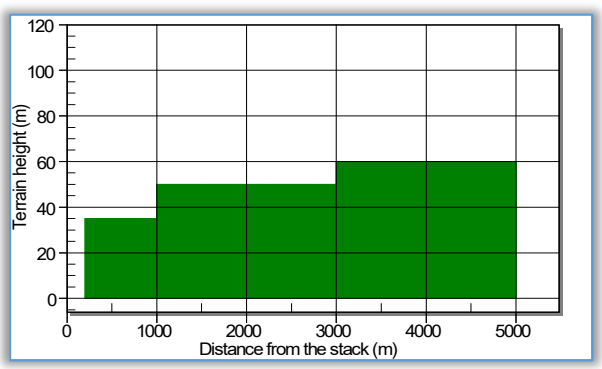


Figure 2. Modelled terrain height vs. the distance from the stack


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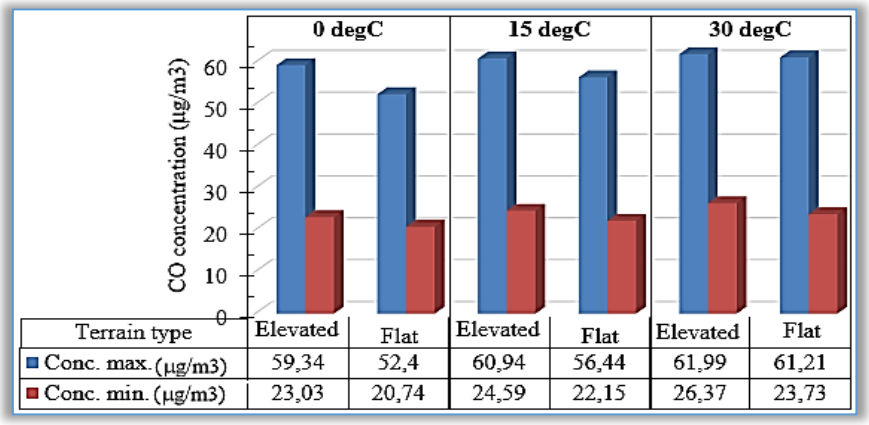
For the determination of the dispersion coefficients, it was considered that the emission source is located in a rural area.

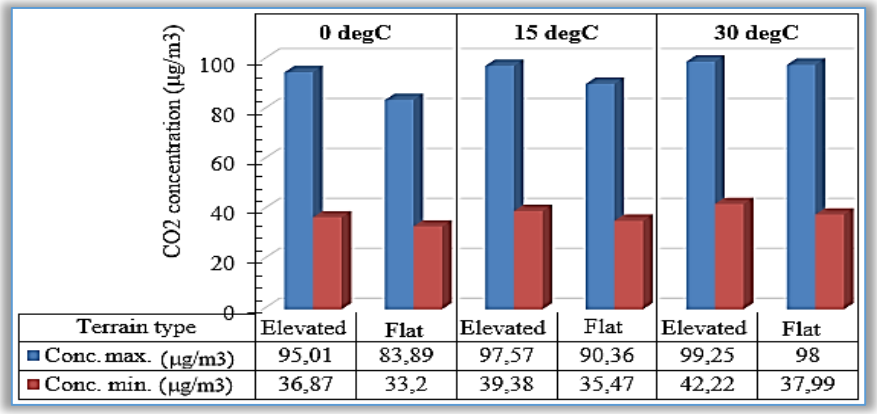
## 3. RESULTS AND DISCUSSION

Figures 3 and 4 show the values estimated with Screen View software on the maximum ground-level concentration of CO and $CO_2$ (in $\mu g/m^3$), depending on the receptor properties, that is, the topography of the surrounding terrain (elevated with three sections or flat terrain) and the air temperature. All minimum concentration values of pollutants were estimated at a distance from the stack of 5 km. Concerning the distance from the stack, where the maximum ground-level concentration was estimated, in the case of elevated terrain, for the both pollutants, it was 1000 m at 0 degC, 953 m at 15 degC and 1100 m at 30 degC. So, the maximum concentration is expected to be deposited on the first section of the elevated terrain. In the case of flat terrain, these distances are: 1002 m at 0 degC, 980 m at 15 degC, and 956 m at 30 degC.




| Terrain type | Elevated | Flat | Elevated | Flat | Elevated | Flat |
|---|---|---|---|---|---|---|
| Conc. max. (µg/m3) | 59,34 | 52,4 | 60,94 | 56,44 | 61,99 | 61,21 |
| Conc. min. (µg/m3) | 23,03 | 20,74 | 24,59 | 22,15 | 26,37 | 23,73 |

Figure 3. Estimates of CO concentration depending on the receptor properties (the topography of the surrounding terrain and the air temperature)




| Terrain type | Elevated | Flat | Elevated | Flat | Elevated | Flat |
|---|---|---|---|---|---|---|
| Conc. max. (µg/m3) | 95,01 | 83,89 | 97,57 | 90,36 | 99,25 | 98 |
| Conc. min. (µg/m3) | 36,87 | 33,2 | 39,38 | 35,47 | 42,22 | 37,99 |

Figure 4. Estimates of $CO_2$ concentration depending on the receptor properties (the topography of the surrounding terrain and the air temperature)

Analyzing the concentration estimates from figures 3 and 4, it is observed that for both pollutants and in each of the case studies, the values increase with the increasing air temperature value. As a general consideration, this variation is explained by the decrease in the buoyant flux of the pollutant plume with increasing air temperature [13, 15]. As the temperature difference between effluent and atmospheric air decreases, buoyancy decreases, and the pollutant is deposited at ground level at a higher concentration [15]. Moreover, pollutant concentrations decrease in the case of flat terrain compared to elevated terrain. This may be explained by the increase in buoyancy undisturbed by the surroundings, which favors air dispersion [10, 11].

Although the emission conditions of the two pollutants (effluent temperature and velocity) and of the receptor (air temperature) were identical, the influence of the initial pollutant concentration (at the stack exit) on the estimated values is evident. However, under the presented conditions, over the entire considered range (up to 5 km away from the source), the concentration values do not exceed the short-term limit value required by the legislation.

## 4. CONCLUSIONS

This study presents an analysis of air dispersion of carbon oxides (CO and $CO_2$) and quantitative estimates of ground-level concentration using the Screen 3 model. The input parameters are experimental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determinations at a cement plant from Romania, and the air dispersion model is complemented with variables such as elevation of the surrounding terrain and air temperature. Given the input data about the emission and the receptor, the estimates showed that the maximum concentration of pollutants increases with elevation of the terrain, and also with air temperature. Estimates of pollutants concentration at 5 km from the source revealed much lower concentration values in the case of flat terrain. Neither the emission limit values of carbon oxides CO and $CO_2$ (given in table 1), nor those imposed for the receptor, exceed the values given in current legislation.

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