Prediction of the distribution of the pollutants emitted by a waste incinerator in an urban area using numerical simulations

Abstract

In the last years, the problem of the control of the toxic emissions has become of great scientific interest due to the continuous increase of all types of pollutants released into the atmosphere, and because, as it has been proved, the existence of fine particles suspended in atmosphere has a negative impact on the human health. In this context, the meteorological parameters have an extremely important role in evaluating the dispersion of pollutants in various city areas. This paper focuses on the evaluation of the dispersion of the pollutants emitted by Pro Air Clean Ecologic Timisoara incinerator based on meteorological specific conditions and their impact on urban background pollutants concentrations in the city of Timisoara. The transport process of the pollutants was investigated numerically with the CloseView software, using as input data the concentration and the chemical properties of the components detected experimentally at the combustion chimney, the height of the chimney, and the specific meteorological conditions: air pressure and humidity, the velocity and the direction of the wind, for a geometry specific to the city map of Timisoara. This analysis provides relevant information on the distribution of the pollutants and reveals the most exposed zones of the city.

Introduction

Timisoara (45°46' N, 21°26' E) is a city located on the south-eastern edge of the Pannonia plain, and lies at an altitude of 85 m., being one of the largest Romanian cities, with a population over 300 thousands inhabitants and more than 170 thousands automobiles. The air quality in urban areas is determined by the intensity of emissions [1, 2]. The principal sources of pollution are from transportation (emission from traffic), industrial and households. The main pollutants tend to be airborne particles, sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone and volatile organic compounds (VOCs).

The rapid increase of the industrial sector and urban development specific to the present human society is not only an expression of progress, but also a major concern for all of us, especially due to the continuous increase of all types of pollutants released into the atmosphere. Health effects of air pollutants is an old issue in cities and urban areas around the world, but became evident during severe air pollution episodes in the first part of the 21th century [3]. Once the association between the existence of fine particles suspended in atmosphere and their negative impact on the human health has been proved clearly, the problem of the control of the toxic emissions has become of great scientific interest. Recent health effects studies have shown an association between existing levels of fine particles (size, concentration) and health effects such as increased respiratory illness, cardiopulmonary morbidity, and premature mortality [cite]. Incinerator-related activities result in the emission of a host of air pollutants that adversely affect public health and the environment, including nitrogen oxides (NOx), hydrocarbons (HC), particulate (PM), carbon monoxide (CO), which causes lung irritation and aggravates diseases such as asthma, chronic bronchitis, and emphysema. In this context, the problem of obtaining information about the composition and dispersion of different resulted combustion residues is a first and fundamental step. This paper relates to approaches achieved in the frame of collaboration between Physics Faculty of the West University of Timisoara and the waste incinerator plant Pro Air Clean Ecologic Timisoara in the problem of the dispersion of different components from flue gas released during the waste incineration process. The transport process of the components is investigated numerically with the CloseView software. The input programme data are the concentration and the chemical properties of the components detected experimentally in the combustion chimney. Our study takes into account the effect that the height of the combustion chimney, the velocity and the direction of the wind has on the dispersion process. The concentration profiles are calculated for a geometry specific to the city map of Timisoara. This analysis provides relevant information on the distribution of the pollutants and the most exposed zones of the city.

In this paper we take a close view of pollutant dispersion in the environment, how the wind and atmospheric condition affects the dispersion for punctiform emission points. Laying down the results on an graphical map we can picture how specific elements affect different areas in time. Also with harvested data during time we can extrapolate results into forecast pollutants concentration levels.

Data and methods

To evaluate the spreading of pollutants in the atmosphere were used two methods: direct measurements of pollutants concentrations emitted at the incinerator chimney and numerical evaluation of dispersed emitted air pollutants based on mathematical equations. Many types of related software exist but only several of them have global coverage and acceptance. The first step for conducting an air quality study consists in producing an emissions inventory. In general term, emissions inventories provide the total amount of pollutants generated from defined emission sources, for a selected period, nov.01.2014 – nov.30.2014 in our case. In this study the emission factors were selected from a database including incinerator emissions, the wind speed and direction, and meteorological conditions as air temperature, relative humidity and atmospheric pressure. The chimney's height was considered also in the computations. The intensity of emissions: nitrogen oxides (NOx), sulfur dioxide (SO_2), total organic compond (TOC), fine particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), together with meteorological measurements (wind speed and direction, temperature, pressure, humidity) was estimated by merging the information provided by direct measurement (hourly value). The pollutants, one identified, are subject to attributing emission factors

The program has access on an emission values database, a meteorological measurement database everything related with the time of collection. Because the timespan of harvesting data is narrow, the software is very accurate in defining averages in hours, days, weeks, months or even years.

The way of presenting data is graphical, in a triangle of dispersion and the data in clear that was used in computation (concentration, wind speed and direction). Also have the possibility of choosing types of data like cumulative concentration, averages or instantaneous data.

In figure 1 an overview of the schematic of the problem is given, regarding the source of pollutants and distance from source related to wind direction. Each wind direction has associated its own Cartesian coordinate system with (x,y) axis.

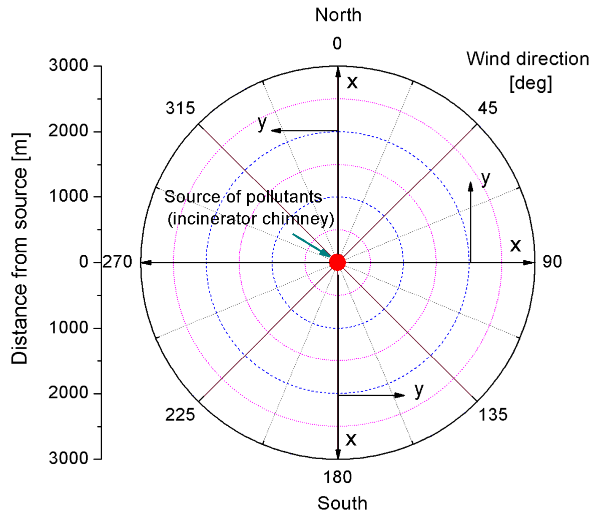


Figure 1: Overview of the schematic of the problem, regarding the source of pollutants and distance from source related to wind direction. Each wind direction has associated its own Cartesian system with (x,y) axis of coordinates.

Computational base take in consideration a lot of elements important in dispersion: wind speed and direction, type of weather, time of day/night, type of sky like cloudy or clear. The height of the chimney is 10 meters.

Detailing the way of using is in the direction of wind, dispersion have a Gaussian concentration depending of the wind speed. But the dispersion in the side of the main stream has different values depending of the type of weather. This kind of dispersion is called diffusion and is simplified presented in Table 1, which estimates the wind stability class:

Table 1: The estimation of wind stability class

Wind	l > 700 W/m^2	350 < l < 700	l < 350 W/m^2	Night Cloudy	Night Clear
< 2 m/s	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

Weather stability class are 6 class types (from A to F) depending of wind speed and sky types (like clear or cloudy) to help choose the correct dispersion coefficient on specific distances from emission source.

Results and discussion

The interest of study is to evaluate the area affected by smoke plume or other sources and the way it is spread depending of concentration in the emission point. Measurement in the field correlated with measurement on chimney and prediction of spreading constructed a clear picture of how chemical compounds settle down on earth level.

In this work we have done a global evaluation of pollutants spreading in the atmosphere in the vicinity/around the incinerator for a period of a month (nov.01.2014 – nov.30.2014), as a function of their concentration at the exit of the incinerator chimney. The main data input were the wind speed and direction, chimney’s height and meteorological conditions (air temperature, humidity and pressure). Figure 2 presents number of days of measurements for the considered period corresponding to wind default directions, were angular range of 22.5 degrees was considered.

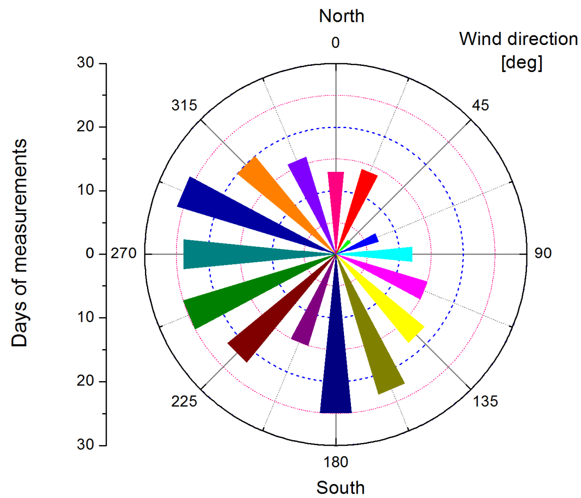


Figure 2: Days of measurements in a month corresponding to wind direction

In figure 3 is presented a wind rose, as resulted from applying the main measured data input: the mean values of wind speed and default wind direction for the considered period (nov.01.2014 – nov.30.2014), with hourly and daily mean values.

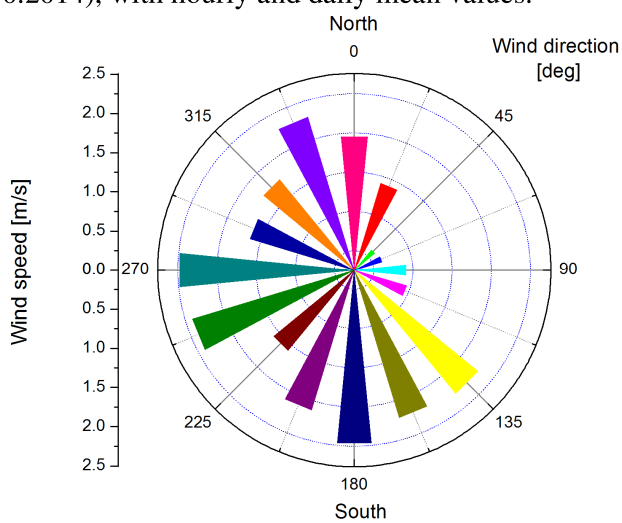


Figure 3: Wind rose with mean values of the wind speed taken hourly and daily in a month depending on the wind default directions.

Figure 4 presents the main window of CloseView software. From here we can choose which kind of average we want, on what pollutant on a specific period of time. Also shows the atmospheric conditions in current time with all relevant elements like wind speed, direction and weather conditions.

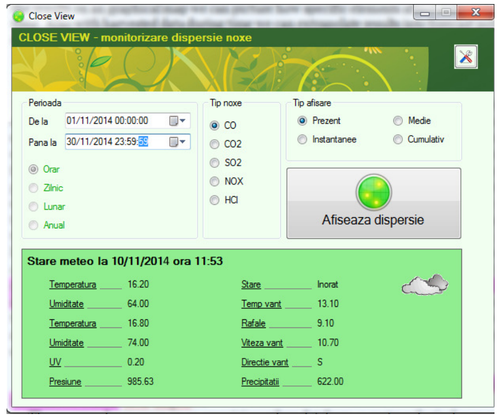


Figure 4: The main window of CloseView software, from that can choose the pollutant on a specific period of time, and shows the atmospheric conditions in current time with all relevant elements like wind speed, direction and weather conditions.

Figure 5 presents dispersion maps of specific pollutants emerging from the source in the N-S and W-E directions of the wind. We can see how concentrate or fade are the footprint of pollutant depending of concentration on chimney and wind speed.

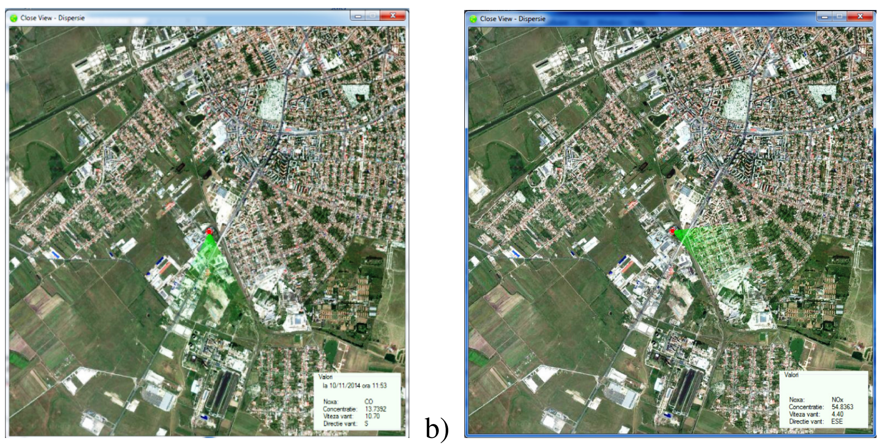
a)  b)

Figure 5: Dispersion map of pollutants emerging from the source in the N-S a) and W-E b) directions of the wind.

It is very clear that the wind direction make chemicals to lay strongly in the direction of wind. If a predominant wind blows more time in the same area, the mark of pollutants increases in that direction.

In the next figures, the resulted concentration curves of dispersed pollutant concentrations are presented, taking into account the hourly and daily mean values at incinerator chimney. In this dispersion study an area of 40 km^2 was considered, with the source in the center of the bidimensional coordination system. Figures 6 and 7 present concentration of pollutants at soil level versus distance from emission source, computed for North to South and South to North of wind direction.

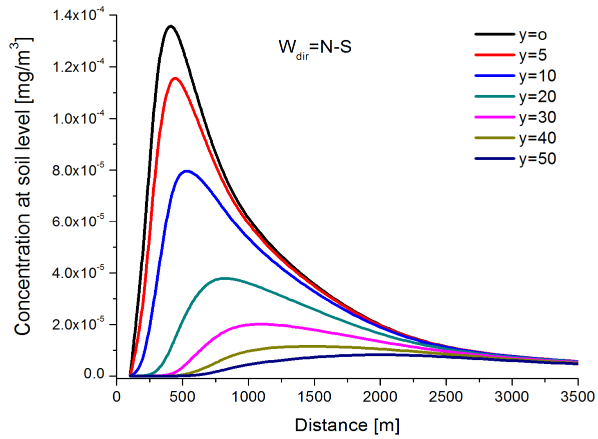


Figure 6: Concentration of pollutants at soil level versus distance from emission source, computed for North to South of wind direction (180 degrees).

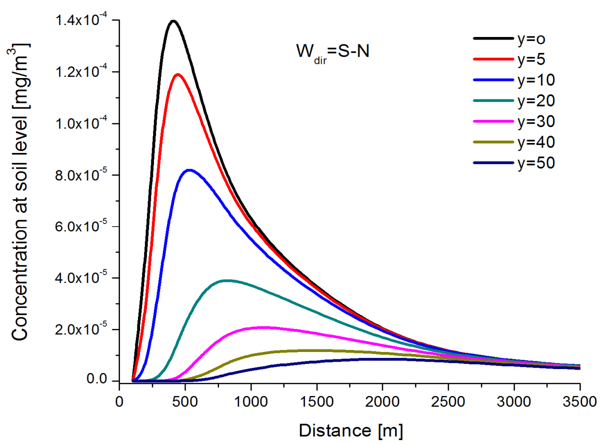


Figure 7: Concentration of pollutants at soil level versus distance from emission source, computed for South to North of wind direction (0 degrees).

Figures 8 and 9 present concentration of pollutants at soil level versus distance from emission source, computed for West to East and East to West of wind direction.

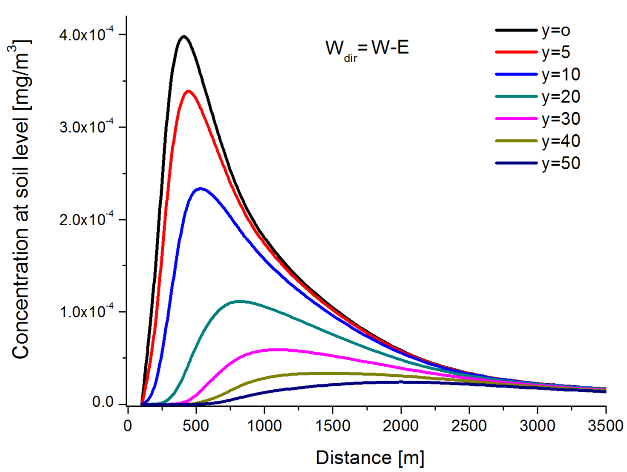


Figure 8: Concentration of pollutants at soil level versus distance from emission source, computed for West to East of wind direction (90 degrees).

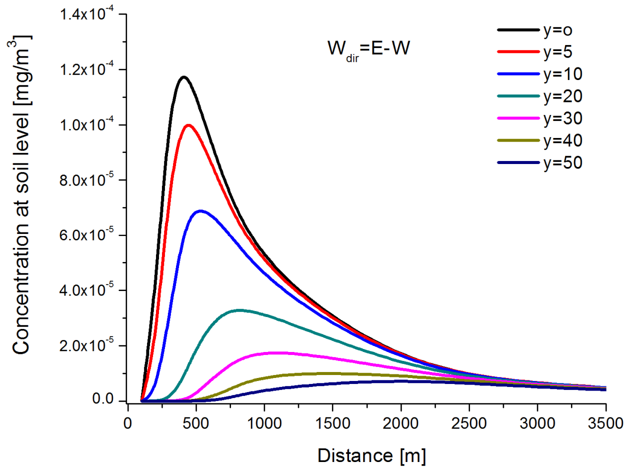


Figure 9: Concentration of pollutants at soil level versus distance from emission source, computed for East to West of wind direction (90 degrees).

Due to similar behaviours that appear on the all directions we consider that the examples presented so far are relevant enough how the pollutants spread.

Can be noticed that, in all cases, the concentration of pollutants at ground level initially increases quite sharply with distance up to a maximum value, then decreases slowly, and became insignificant after distance of 2500 m.

Figures 10 and 11 present concentration variation of pollutants at soil level as a function of the distance *y* to the wind axis, at different distances *x* from emission source, computed for North to South and South to North of wind direction.

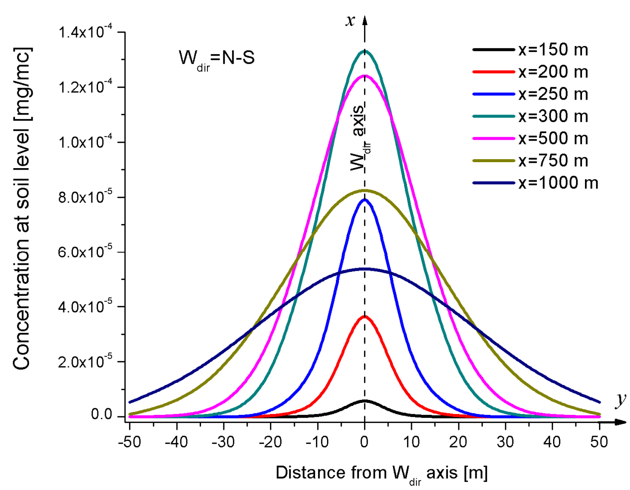


Figure 10: Concentrations of pollutants at soil level function of distance *y* from wind axis, at different distances *x* from emission source, computed for North to South of wind direction.

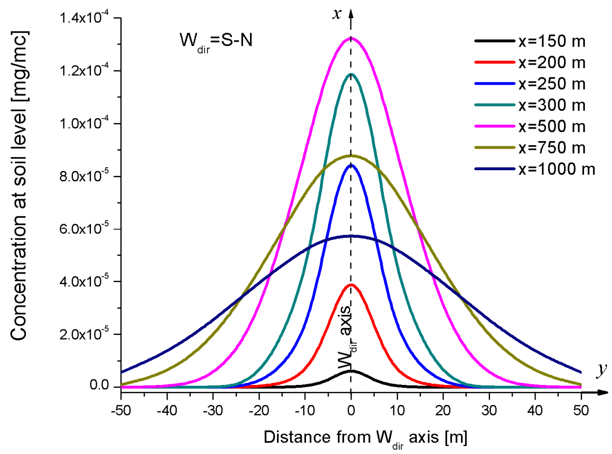


Figure 11: Concentrations of pollutants at soil level function of distance *y* from wind axis, at different distances *x* from emission source, computed for South to North of wind direction.

One observes that the pollutants concentration along *y* axis has a Gaussian behaviour. Its shows that the footprint is strongly in the vicinity of emission point and decreased along the wind direction. The way of decreasing is affected by speed and other atmospheric condition, and of course the concentrations in the emission point have a great effect on footprint area. Anyway, it's seems that all pollutants tending to lay down completely after a distance that is related with the chimney height. On an chimney of 10 meters, after 2000 meters seems that pollutants concentration are very small to none.

Due to similar behaviours that appear on the all wind directions we consider that the examples presented so far are relevant enough how the pollutants spread.

Conclusions

This paper relates to approaches achieved in the frame of collaboration between Physics Faculty of the West University of Timisoara and the waste incinerator plant Pro Air Clean Ecologic Timisoara in the problem of the dispersion of different components from flue gas released during the waste incineration process. Where have done a global evaluation of pollutants spreading in the atmosphere for an area of 40 km^2 in the around the incinerator for a period of a month (nov.01.2014 – nov.30.2014), as a function of their concentration at the exit of the incinerator chimney. The main data input were the wind speed and direction, chimney's height and meteorological conditions (air temperature, humidity and pressure), taking into account the hourly and daily mean values. The resulted concentration curves of dispersed pollutant concentrations at soil level are presented, versus distance from emission source, computed for different orientations of wind direction. In all cases, the concentration of pollutants at ground level initially increases quite sharply with distance up to a maximum value, then decreases slowly, and became insignificant after distance of 2500 m.

Acknowledgments

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