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# THE ANALYSIS OF GASEOUS POLLUTANTS DISPERSION IN HILLY TERRAIN

## ANALIZA ROZPRZESTRZENIANIA SIĘ ZANIECZYSZCZEŃ GAZOWYCH NA TERENIE PAGÓRKOWATYM

**Abstract:** The emission of a dangerous substance overlaps in vicinity of wide-range ground-based objects. Consequently, part of the process of dispersion pollution is determined by the flowing conditions and is shaped by their presence and distribution. However, under real conditions, complexes systems of terrain obstacles exist. A subject of interest among many authors is the flow and dispersion of pollutants surrounding single elements such as a hill or a building. This type of research enables a better understanding of the flow and propagation of pollutants on terrain with complex topography. The aim of the present work is the investigation of the influence of the complex character of a velocity field, particularly its periodic composition (non-stationary blowing) as well as rotating structures generated by obstacles such as hills on the propagation of various types of gaseous pollutants. The base of analysis represents the evolution of the carbon dioxide concentration in profiles surrounding hills or different locations in relation as well to the height of the source emission. By propagating a gaseous tracer in a oscillating flow from a source located in a flush zone, a source's location relative to circulation zones of increased level turbulent fluctuations of flow velocity can be determined.

**Keywords:** pollutant dispersion, gaseous pollutions, experimental and numerical modeling, hilly terrain

## Introduction

The experimental and numerical simulation of flow over hilly terrain have concerned significant scientific interest during the last decades [1, 2] because of the important implications of the problem in many fields (suitable site for wind power plants, fire propagation, pollutant dispersion, erosion processes). The dispersion process of pollution takes place in flow conditions formed by presence the various ground-based objects. However, in complex systems and exist due to terrain conditions, a subject discussed by many authors is flow and pollution dispersion of small elements in a surrounding (natural topological features like hill, building) [1–3]. Such researchers

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are the first step to better understanding the flow and dispersion on terrain consisting of complex topographies. The tests of structured wind flow in mundane zones, which are comprised complex topographies, contribute series of information relevant for the most recent aerodynamics problems. Among other things, they relate to the dispersion of pollution, fire propagation, wind erosion and local condition researches which favor wind energetic. The last herein mentioned aspect forms the particular motive for wind flow analysis in the oscillating flow. Flow features around single hills have both an influence conditions as inlet conditions and medium geometry. The collection of the mentioned factors can cause big differences in the kinematics within the jet stream which in general case sets detachment phenomenon, recirculation and adherence. The problem of wind flow over oscillating flow was taken in a series of work which involved both researches led in natural all-terrain condition, experimental modeling, and also numerical simulations. Most quoted work belong to Jackson and Hunt [2], presents analytical solutions for the hill shape, numerical Peterson models [4], Lenelin and others [3] and experimental results of Ferreira [5], Cao [6], Lubitz [7] and Kim [8–9]. Several studies have been reported on the flow over hills using RANS and LES methods [10–15]. Turbulent flow over a steep hill contains relatively complex mean-flow characteristics such as separation and reattachment. The center of this research was mainly focused on deformation profiles of wind velocity flow according to apparition of symmetrical hills a low inclination [10, 13]. Geometry which was taken in most analyses does not appear to lead to strong detachment and recirculation zone. This constrains compliance of offered calculation methods [5] and experimental model consistency with a real wind field along the hill. Practical value of results of research denigrates the lack of information about general currents in nature, unfavorable aerodynamic modeled flow features. The study of flow and dispersion over two- and three-dimensional hills are presented in publications of Araya [16, 17], Tsai [18], Chatzipanagiotidis [19] and others. The present analysis undertakes the problem of the detachment and recirculation cause strong fluctuations in velocity zones and change flow wind directions. The main attention has been put on an effect of oncoming wind oscillations on the velocity field structure around the single sinusoidal 2D hill in the context of pollution dispersion.

## The methods of experiments

The program of the study consists of wind-tunnel experiments carried out in an open-circuit wind tunnel at the Institute of Thermal Machinery of the Czestochowa University of Technology. The geometries of the analyzed cases are sketched in Fig. 1. The role of tap gas source, from the scoring source (pipe) from pointing source was played by carbon dioxide with a flow outlet velocity equal in approximation of undisturbed flow velocity, above layer zone. To measure the concentration of $CO_2$ analyser Guardian plus was used. Analyzed model of the hill was installed on a medium aerodynamic tunnel in the Aerodynamic Laboratory of Czestochowa University of Technology upon which the layer zone of thickness $\delta$ = 0.1 m was generated, and profile velocity shape typical for an open ground with poor vegetation.

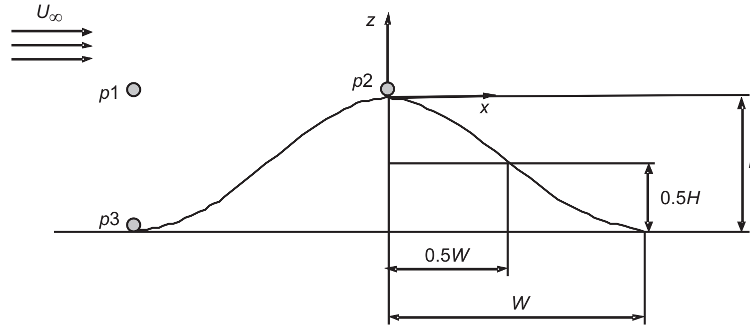


Fig. 1. Scheme of hill model with marked location of emission $CO_2$ source

The mean velocity of the boundary layer zone amounted to $\overline{U}_\infty$ = 13 m/s with profile described by the power low (1):

$$\overline{U}_0(z) = \overline{U}_\infty \cdot \left(\frac{z}{\delta}\right)^\alpha \tag{1}$$

where $\delta$ is the depth of boundary layer, $\alpha$ = 0.166 is the power law exponent, which corresponds to the velocity profile for open terrain with low vegetation.

The shape of tested hill model is described by the relationship (2):

$$z_s = \frac{H}{2}\left\{1 + \cos\left[\left(\frac{\pi}{2}\right)\left(\frac{x}{0.5W}\right)\right]\right\} \tag{2}$$

where $H$ = 60 mm, $W$ = 100 mm (Fig. 1). Measurements were conducted for three different locations ($x = x_s$ $z = h_s$) and their emissions (Fig. 1), namely:

($p1$) $x_s = -W$, $h_s = 1H$;
($p2$) $x_s = 0$, $h_s = 1H$;
($p3$) $x_s = -W$, $h_s = 0$.

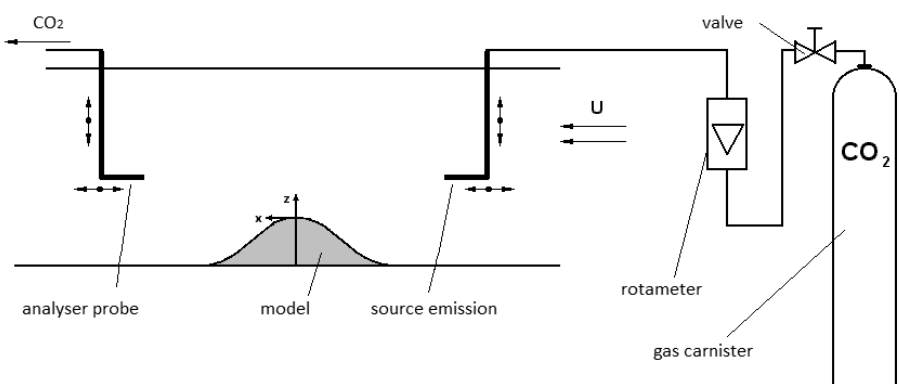


Fig. 2. Scheme of measuring testing bench with mounted researched object

The measuring probe was mounted on a support, which enables establishment of vertical concentration $CO_2$ profiles for chosen stream $x$ = const set in localizations: $x = 0$; 0.6$W$; $W$; 2$W$; 3$W$; 4$W$ (Fig. 2). All measurements were done in a tunnel axis.

## The flow and dispersion characteristics

The aerodynamic outline of the object which enabled the detection of surrounding characteristic zones with strong diversified features, namely the area of increased velocity flow above the top of the hill and recirculation region of flow behind the hill (Fig. 3). Significant from the point of view of gaseous pollutants dispersion, the increase of wind speed over the hill surface is observed in their top zone.

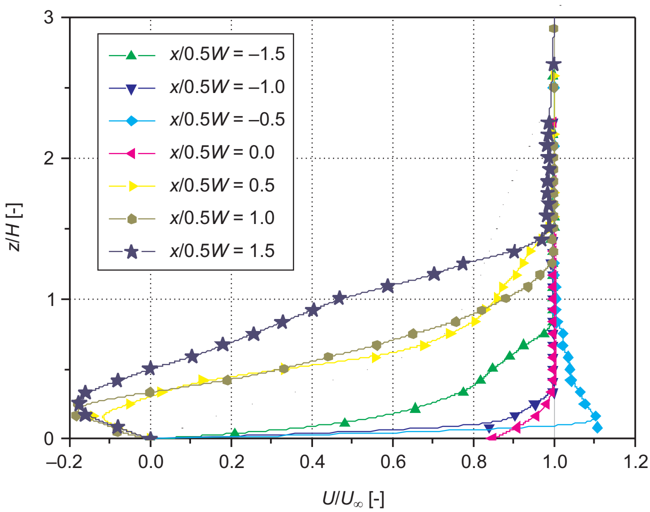


Fig. 3. Evolution of average velocity profile component in flow around hill

Important information for wind engineering is also the distribution of the turbulence intensity in the flow around object. Maximum turbulence intensity occurs at the surface of hill in top and recirculation zone. The value of the turbulence intensity here is several times higher than in the inflow region. It is worth noting the experimental studies confirmed that this high level of velocity fluctuation is maintained at a small range of values of $z/H$. Obtained during the measurement data allowed estimation of backflow zone, which extends to a distance close to $x/0.5W = 9$. This fact is confirmed by, among others, visualization results [1, 5].

The evolution of the concentration profile of carbon dioxide in a hilly environment for different locations and height source emissions is shown on Fig. 4–6. As shown in the aforementioned diagram, courses differ on a particular drawing both qualitatively and quantitatively, but generally speaking, the presence of the terrain obstacle, which modifies the shape of emitted in environment trail of pollution in a relevant way could be ascertained.

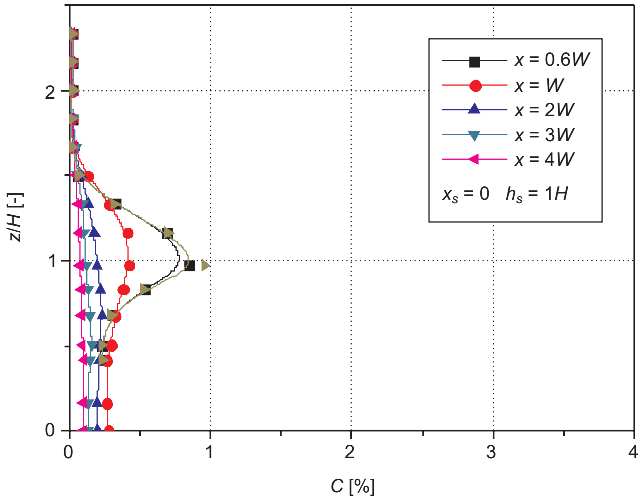


Fig. 4. Concentration profiles of carbon dioxide in surroundings of a hill for a source emission in a location (1)

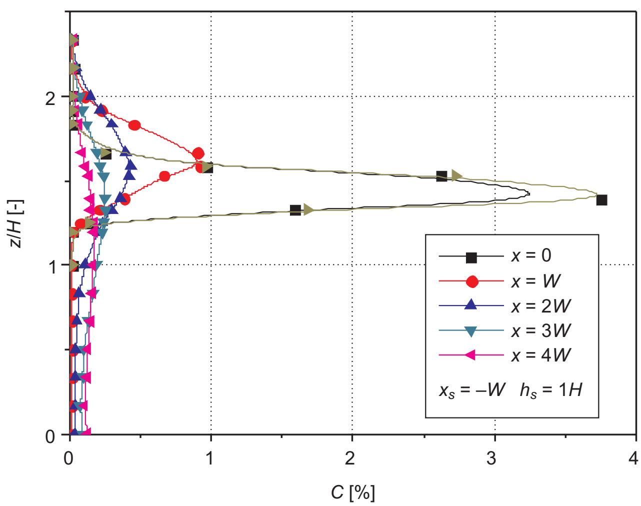


Fig. 5. Concentration profiles of carbon dioxide in surroundings of a hill from a source emission in a location (2)

This stands to features of velocity fields linked to an aerodynamic object in a fluid stream, but in a particularly closed environment in which recirculation zones rise from the zone of increased turbulence zone behind the hill.

For the dispersion process of substances emitted from the source responsible are both mass diffusion mechanism, caused by concentration gradients and advection, transported pollution in a flow direction with help of average air flow and a turbulent transport process in which their own part has own turbulent velocity fluctuations.

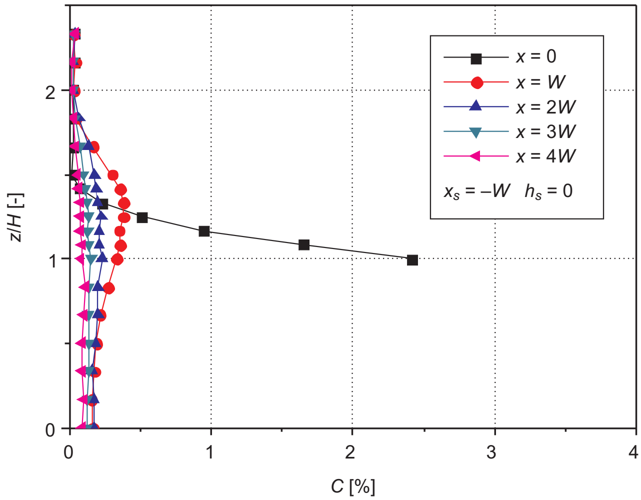


Fig. 6. Concentration profiles of carbon dioxide in surroundings of a hill for a source emission in a location (3)

This is confirmed by comparison the Concentration profiles of carbon dioxide measured on flat ground (without hills) – Fig. 7.

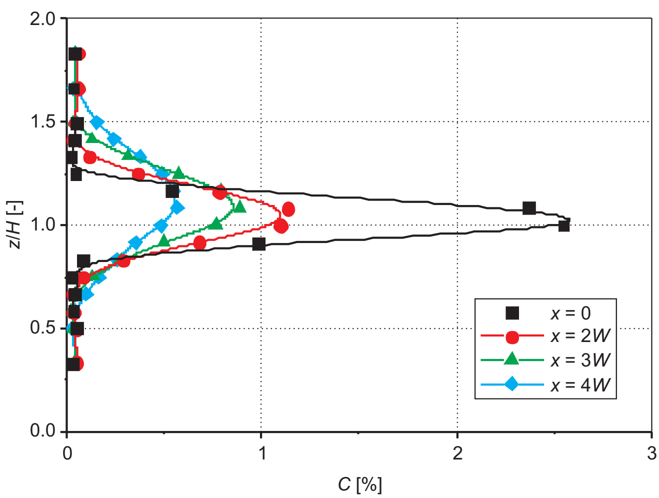


Fig. 7. Concentration profiles of carbon dioxide on flat ground for a source emission in a location (1)

The characteristic of analyzed concentration fields is the different localization of gaseous tab concentrations. The local maxima of the curve of concentrations move with the surrounding flow around an object according to the curves shown in Fig. 8 for two different locations of source emission.

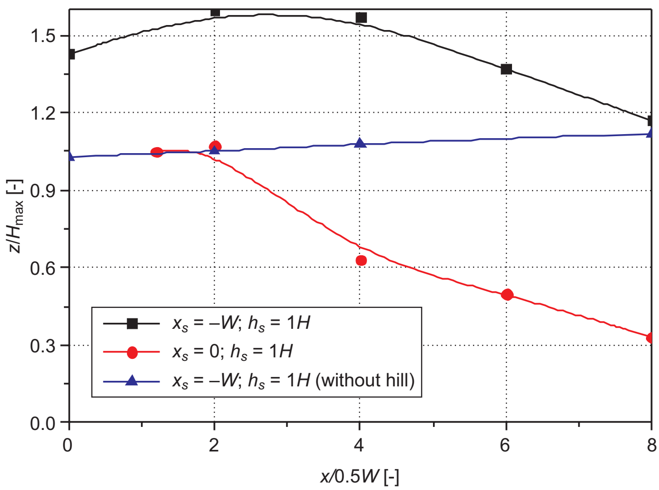


Fig. 8. The changes in concentration of $CO_2$ to ground along with wandering from the hill for different situated source emissions

For comparison, the drawing also contains data concerning the evolution of an axis of the tracer's plume's location floating in an undisturbed zone which is not affected by the obstacle presence. Appropriate maximum concentration values of carbon dioxide ($C_{max}$) shown on a Fig. 9a. As is shown, the holding on the plume axis in every considered case varies. As the maximal values of distributions show qualitative similarity, they decreased with the distance from the source emission in every case, as long as the plume axis locations depend on a location at a predetermined distance from source location.

As an effect of deflection of the stream which is emitted from a source in a location, ($p2$) ($x_s$ = 0, $h_s$ = 1$H$) an increased value of $CO_2$ concentration at ground level is obtained ($C_g$), this is shown in drawing draw Fig. 9b. In that case of the location of source the stream of carbon dioxide is provided almost directly into a recirculation zone behind the hill, where dilution and dispersion appears.

The effect of that is mainly movement at ground level. In the case where the source was located on a height $h_s = 1H$ it was found in a distance W in front of the hill, then the dominant transport mechanism of emitted gas is advection, which causes the maxima of concentration to rise above the recirculation zone. At the same time the concentration of $CO_2$ is measured at ground level is practically equal to normal atmospheric values at close distances behind the hill. At long distances the influence of the situated source in terms of tab gas concentration at ground level disappears.

The last considered case is when a source which is located at the foot of a hill ($x_s$ = –$W$, $h_s$ = 0). In that case the location of source of emission, the flow $CO_2$ is directed upwards along the surface of the hill (maximal concentration profile measured on a top of a hill exists near hill surface), it then gets into the intensive mixing zone behind the hill, which effects are very flat concentration profiles measures in a forwards distances and big concentration values at ground level.

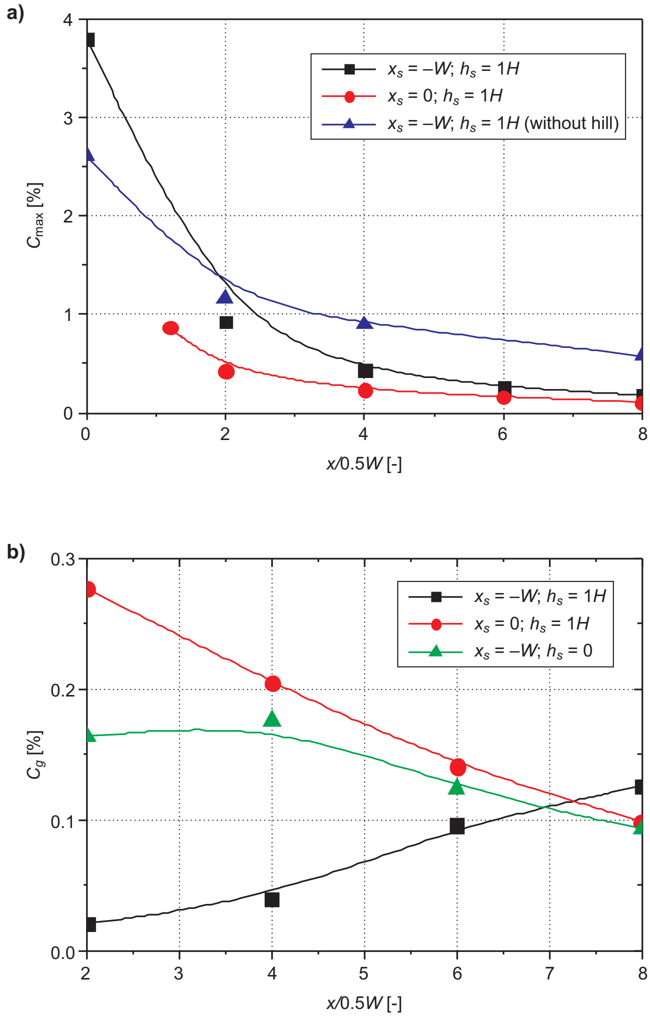


Fig. 9. a) Maximum concentration values above flat medium in a presence of a hill (source of emission in locations (1) and (2); b) Concentration values in a plume axis emitted over a flat medium and in a presence of the hill

## Summary and conclusions

The dispersion of the $CO_2$ emitted from point sources located in a flow flush on element of oscillating flow and on its top performs in the different flow conditions, which are responsible for different character of $CO_2$ concentration in modeled wind field. The source location in relation to the recirculation zone and the area of increased fluctuated turbulence velocity flow level is critical.

In the article, the initial results of researcher which suggest the significant influence of oscillation component of the velocity on pollution dispersion is shown. It is also acknowledged here that this theme still requires further research.

## Acknowledgements

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## ANALIZA ROZPRZESTRZENIANIA SIĘ ZANIECZYSZCZEŃ GAZOWYCH NA TERENIE PAGÓRKOWATYM

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**Abstrakt:** Proces rozprzestrzeniania się zanieczyszczeń zachodzi w warunkach przepływowych kształtowanych obecnością i rozmieszczeniem różnorodnych obiektów naziemnych. W warunkach rzeczywistych procesy te występują w otoczeniu złożonych układów przeszkód terenowych, jednak przedmiotem zainteresowania wielu naukowców jest przepływ i dyspersja zanieczyszczeń w otoczeniu pojedynczych elementów. Badania tego typu służą lepszemu zrozumieniu przepływu i rozprzestrzeniania zanieczyszczeń w terenach o złożonej topografii. W niniejszej pracy analizowano wpływ złożonego charakteru pola prędkości, w tym składowej okresowej (wygenerowanej w wyniku niestacjonarnych podmuchów wiatrowych) oraz struktur wirowych generowanych w otoczeniu wzgórza na rozprzestrzenianie się zanieczyszczeń o charakterze gazowym. Na koncentrację znacznika gazowego emitowanego ze źródła usytuowanego w strefie napływu na faliste podłoże ma wpływ przede wszystkim położenie źródła względem strefy recyrkulacji oraz obszaru o podwyższonym poziomie turbulentnych fluktuacji przepływu.

**Słowa kluczowe:** rozprzestrzenianie się zanieczyszczeń, zanieczyszczenia gazowe, eksperymentalne i numeryczne metody modelowania, teren pagórkowaty