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ANALYSIS OF POLLUTANT DISPERSION IN FLOW AROUND THE ARRAY OF BUILDINGS

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Abstract: The problem of pollution dispersion throughout atmospheric boundary layer has grown in importance since human activity has become so intense that it started having considerable impact on natural environment. The level of concentration of pollutants has escalated, particularly in urban areas and it impacts on their inhabitants. The paper presents the results of the complex research program aimed at understanding a character of the flow field in neighborhood of bluff-bodies immersed in a boundary layer and characteristics of pollutants dispersion in that area. Analysis of gas pollutants dispersion process requires in-depth identification of the structure of flow around the buildings. The analysis has been performed for the 3D case of two in-line surface-mounted bluff bodies, arranged in tandem, which were placed with one face normal to the oncoming flow. The mean concentration profiles of tracer gas (CO_2) for various interobstacle gaps were measured in wind tunnel. Characteristic feature of flow field around groups of buildings in urban areas is high level the unsteady phenomena resulting from itself character of the wind or from the interference of the wake flow connected with a process of vortex shedding. This is the factor affecting process of the dispersion of pollutants in the built-up area acting more complex the mechanism of propagate of small parts explained on the basis of processes of advection and turbulent diffusion. The local characteristics of flow were obtained by the use of commercial CFD code (FLUENT).

Keywords: buildings arrays, pollutant dispersion, experimental and numerical modelling

The dispersion of pollutants in space around wind engineering structures, governed by convection and diffusion mechanism, depends strongly on the velocity field. To understand the phenomena related to the forming of concentration fields it is necessary to recognize the local features of the flow around the objects with the special emphasize for the mean velocity direction, random fluctuations, and periodical oscillations accompanying the vortex generation in bodies neighbourhood. The specific flow conditions generated around bluff bodies' arrangement make it possible to study the gas pollutant dispersion for the case of very complex velocity field typical for built environment. Curved streamlines, sharp velocity discontinuities, high level flow oscillations and non-homogenous turbulence disperse effluents in a complicated manner related to source configuration and object geometry [1, 2].

Ensuring adequate air quality requires proper aeration of these areas. Its efficiency depends mainly on wind direction, configuration of buildings and locations of emissions sources. The process of pollution dispersion is mainly influenced by mechanisms of mass diffusion, caused by concentration gradients and advection which transfers pollutants in flow direction through mean air movement. Important role is also played by turbulent transport processes [3]. Improvement in air quality on a local scale and limitation of effect of pollution on human health requires consideration of all the listed factors.

This paper presents the experimental test of the qualification of the relation between a structure of the flow field in complex urban terrain (in the built-up area) and

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characteristics of pollutants dispersion. The aim of this work was to determine the impact of objects configuration, their degree of "immersion" in the boundary layer and location of emission source for the spread of the tracer gas emitted in the vicinity of two rectangular blocks in tandem arrangement.

Methods of analysis

The program of this study consists of comparison of mean concentration profiles with aerodynamic characteristics for building-downwash effect (obtained respectively as a result of experiment and numerical simulation).

The mean concentration profiles of tracer gas (CO_2) were measured in an open-circuit wind tunnel at the Institute of Thermal Machinery of the Czestochowa University of Technology. The test section was 0.4 m x 0.4 m square and 4 m long. All the measurements were carried out for the Reynolds number $Re_D = 3.4\cdot10^4$ based on the free stream velocity $U_\infty = 13$ m/s and the cube width D = 0.04 m. The geometries of the analyzed cases of two obstacles and location of the source and the measurement probe in relation to the investigated arrangement of the objects as well as the assumed coordinate system are presented in Figure 1. CO_2 flow rate was maintained at constant level Q = 5 dm^3/min, which produced output speed of $U_{CO2} = 11.8$ m/s. In order to measure mean concentration of gas marker a "Guardian plus CO_2" analyser was used. The results of testing presented in this work relate to a fixed ratio of object height $H_1/H_2 = 0.6$ and their "immersion" in boundary layer $H_2/\delta = 0.6$.

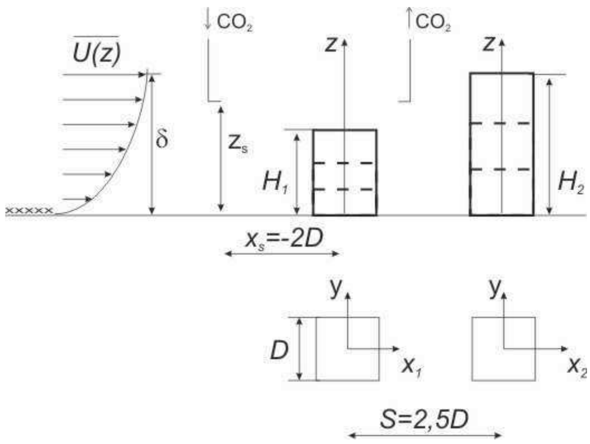


Fig. 1. Scheme of considered flow around two tandem arrangement objects

Rys. 1. Schemat rozpatrywanej konfiguracji obiektów w układzie tandem

Measurements of concentration CO_2 were taken in the gap between the elements in measurement cross-sections x/D = 0.5; 0.625; 0.75; 0.875; 1; 1.25 both in system axis and along the edges of external objects, for two different positions of emission source $z_S = 0$ and $z_S = H_1$ situated at the distance of 1.5 D in front of the windward object. In order to visualize the flow-modifying impact of the leeward object, some measurements of concentration CO_2 profiles were also taken for a single object.

Three-dimensional RANS simulations have been carried out using a commercial CFD code, FLUENT v.6.2, with the k-ε turbulence model in realizable version. According to the literature [4, 5] this model is widely used for flows in a build environment. For the considered configuration an identification of the structure of flow by means of surface oil visualization was performed too.

Discussion of the results

Analysis of gas pollutants dispersion process requires in-depth identification of the structure of flow around the buildings. The flow structure around three-dimensional bluff-body located on the surface with formed boundary layer is characterized by a high level of complexity.

The flow around a single object is composed of some characteristic areas: area of the horseshoe vortex forming in front of the object upper flow, close and farther wake zones [6]. Object impact zone, ie area where velocity field is strongly disturbed by the presence of the obstacle, changes considerably if another object is placed in the aerodynamic wake. This situation is presented in Figure 2, which shows the wall shear stresses distribution on the ground and the result of surface oil visualization for tandem arrangement of two cuboids. Disturbing impact of the second object is visible here.

The case under consideration in this work concerns tandem arrangement which is characterized by $H_1/H_2 = 0.6$ parameter, which is conducive to occurrence of downwash effect. This effect consists in washing of front side of the leeward object with large air masses, which results in strong air circulation in the area between objects, which determines flow structure between them. The level of modification of flow around the analysed arrangement of objects of tandem type depends on many factors (distance between elements, change in height of the objects, immersion parameter in boundary layer).

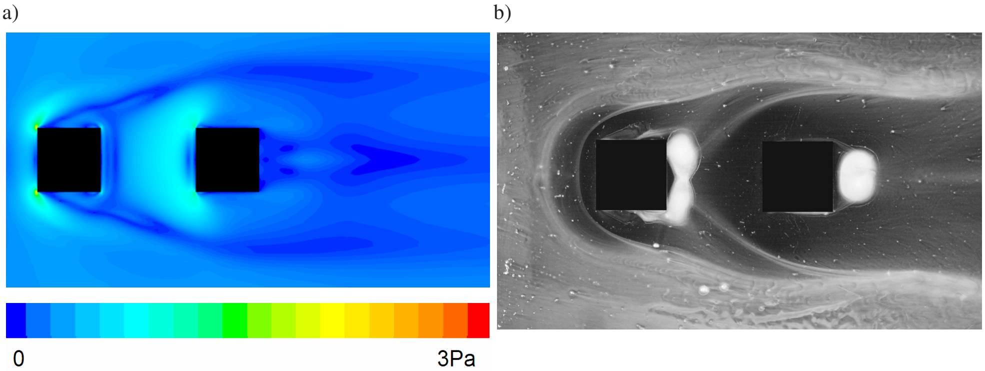


Fig. 2. The wall shear stresses distribution on the ground (a) and surface flow patterns obtained with oil-film technique (b) for tandem arrangement $S/D = 2.5$ $H_1/H_2 = 0.6$ $H_2/\delta = 0.6$

Rys. 2. Rozkłady naprężeń stycznych na poziomie gruntu (a) i wynik powierzchniowej wizualizacji olejowej (b) dla układu tandem $S/D = 2.5$ $H_1/H_2 = 0.6$ $H_2/\delta = 0.6$

The wall shear stress distributions (Fig. 2a) is clearly shown a qualitative relationship between the experimental oil visualization and numerical calculations in the area between the buildings and in the wake the arrangement. As results from Figure 2, the biggest changes in flow field are observed in the area between objects.

Scope and manner of interaction of objects in their environment wind changes as a function of distance from the ground. This phenomenon is clearly visible on the distributions of the longitudinal component of average speed for the example configuration S/D = 2.5 and $H_1/H_2 = 0.6$. Closer to the ground, the amount corresponding to the level of pedestrian (z/D = 0.01), one can observe the differential image velocity field with the strong gradient. The affected area the objects on the flow narrow (decrease in width and length of recirculation zone and extension of the area taken by vortices) as the distance from the ground increases.

a) b)

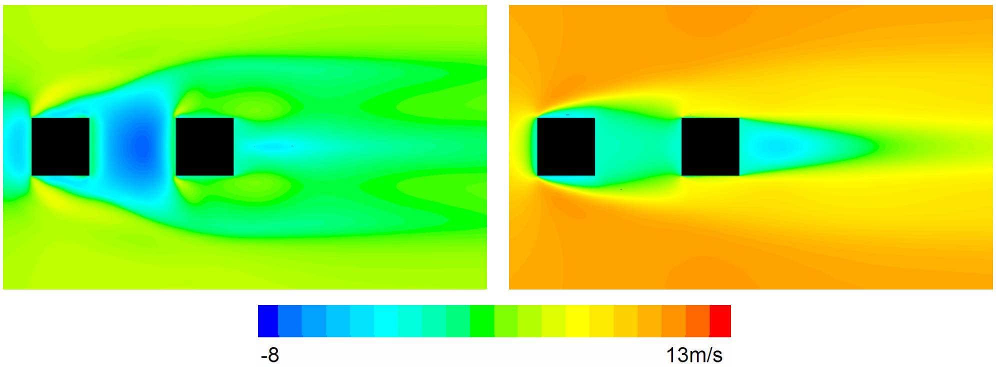


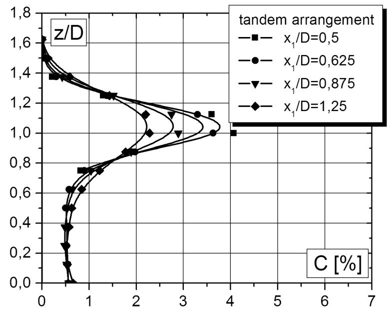
Fig. 3. Distribution of longitudinal component of average velocity as a function of distance from the ground: a) z/D = 0.01 and b) z/D = 0.25

Rys. 3. Rozkłady składowej wzdłużnej prędkości średniej w funkcji odległości od podłoża: a) z/D = 0.01 b) z/D = 0.25

The observed modifying impact of interaction between the objects in tandem arrangement is reflected in the results of measurements of concentration of the gas marker emitted in their environment. Impact of the location of emission source on the dispersion of marker gas in the environment of object arrangement of tandem type was analysed for two source heights, $z_S = 0$ and $z_S = H_1$. Figure 4 presents distribution of concentration in the gap between elements for the source located at the height of the windward object. The measurements were taken in the arrangement axis and also along the outside edges of its elements. The results obtained for emission source located on the base are presented in Figure 5.

For different heights of emission sources a diametrically opposite concentration CO_2 distribution was obtained. In the case of source located at the height of windward object, a dominating contribution to the transport of gas marker is from upper flow while for $z_S = 0$ value marker gas is moved mainly through surface vortex structures. In the case of emission source being located at the height of windward object, gas marker is moved mainly through upper flow, which is reflected in distribution of its concentration shown in Figure 4. Lower kinetic energy and, in consequence, lower flow rate, results in higher concentration of gas marker in the zone above the windward object.

a)



b)

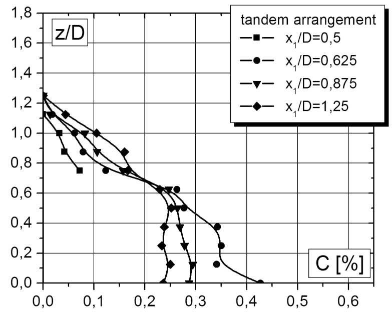
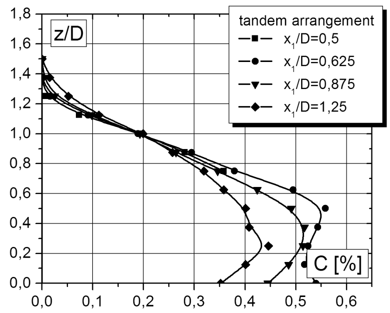


Fig. 4. Tracer gas concentration in the gap between objects in tandem configuration and single windward object for parameters $H_2/\delta = 0.6$; $z_S = H_1$; a) y/D = 0, b) y/D = 0.5

Rys. 4. Profile koncentracji znacznika gazowego w luce między obiektami konfiguracji typu tandem oraz w przypadku pojedynczego - nawietrznego obiektu dla $H_2/\delta = 0.6$; $z_S = H_1$; a) y/D = 0, b) y/D = 0.5

a)



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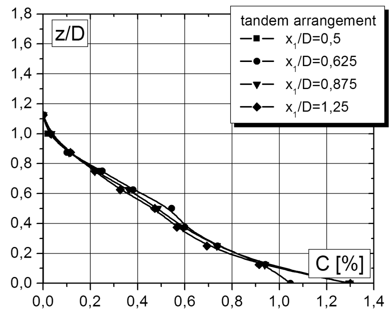

Fig. 5. Tracer gas concentration in the gap between objects in tandem configuration and single windward object for parameters $H_2/\delta = 0.6$; $z_S = 0$; a) y/D = 0, b) y/D = 0.5

Rys. 5. Profile koncentracji znacznika gazowego w luce między obiektami konfiguracji typu tandem oraz w przypadku pojedynczego - nawietrznego obiektu dla $H_2/\delta = 0.6$; $z_S = 0$; a) y/D = 0, b) y/D = 0.5

The differences appear practically for each location of the source and each measuring traverse. The highest values of marker gas in tandem arrangement axis (y/D = 0) are observed for $z_S = H_1$ in the area above the height of windward building, while for the source located on the base, along almost the whole height of the first element. For $z_S = H_1$ the values of gas marker concentration are almost ten times bigger for y/D = 0 than y/D = 0.5 while for $z_S = 0$ the situation is opposite (twice the difference). In the case of the measurements along the outside edges (y/D = 0.5), maximal C_{CO2} values appear in the base.

Conclusions

In present experimental study of CO_2 concentration fields around bluff-bodies in tandem arrangement have been observed with the special emphasize for the mean velocity direction and periodical oscillations accompanying the vortex generation in bodies neighborhood. The main attention of this paper was to determine the impact of objects configuration, their degree of "immersion" in the boundary layer and location of emissions sources for the spread of the tracer gas emitted in the vicinity of two rectangular cubes in tandem arrangement.

The presented results show how important for ensuring adequate air quality, proper formation of wind-related environment of ground objects is.

Acknowledgements

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Abstrakt: Problem rozprzestrzeniania się zanieczyszczeń w przyziemnej warstwie atmosfery nabrał znaczenia, gdy działalność człowieka stała się na tyle intensywna, że zaczęła wywierać istotny wpływ na stan środowiska naturalnego. Poziom koncentracji zanieczyszczeń nasilony jest zwłaszcza w obszarach zurbanizowanych, oddziałując na jego mieszkańców. W pracy przedstawiono wyniki modelowych badań dotyczących procesu dyspersji zanieczyszczeń gazowych w strefie zabudowanej. Ich celem było określenie wpływu konfiguracji obiektów, stopnia ich „zanurzenia” w warstwie przyziemnej, a także położenia źródła emisji na rozprzestrzenianie się znacznika gazowego (CO_2) emitowanego w ich otoczeniu ze źródła skupionego. Analiza procesu dyspersji zanieczyszczeń gazowych wymaga dokładnego rozpoznania struktury przepływu wokół elementów zabudowy. Badany układ typu tandem stanowiły dwa trójwymiarowe modele budynków o różnych wysokościach ustawione w jednej linii. Profile koncentracji gazu znacznikowego (CO_2) dla różnych konfiguracji obiektów zmierzono w tunelu aerodynamicznym. Cechą szczególną pól prędkości w otoczeniu grupy opływanych budynków jest wysoki poziom niestacjonarności wynikający zarówno z samego charakteru wiatru, jak i z faktu generowania przez obiekty zjawisk periodycznych związanych z procesem schodzenia wirów. Jest to czynnik, który oddziałuje na proces dyspersji zanieczyszczeń w obszarze zabudowanym, czyniąc jeszcze bardziej złożonym mechanizm rozprzestrzeniania się cząstek, tłumaczony na podstawie procesów adwekcji i turbulentnej dyfuzji. Wykorzystywane w pracy charakterystyki aerodynamiczne opływu budynków uzyskane zostały z wykorzystaniem programu FLUENT.

Słowa kluczowe: dyspersja zanieczyszczeń, układ budynków, modelowanie eksperymentalne i numeryczne