Environment Protection Engineering

Vol. 34 2008 No. 4

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ANALYSIS OF DIFFUSION WITHIN CAVITY REGION OF POLLUTANTS FROM SHORT-POINT SOURCES – WIND TUNNEL EXPERIMENTAL INVESTIGATION

The diffusion of gases emitted from short-point sources within the recirculation cavity was tested and measured in a wind tunnel. A free-standing short chimney was situated beyond the building and the distance between the chimney and the building could be changed. The analysis of gas diffusion in the air stream was carried out based on the visualization technique with a camera detection and the measurements of the tracer gas concentration. The investigation proves the usefulness of this particular method as it best describes and establishes the limits of the recirculation cavity region beyond the obstacle.

1. INTRODUCTION

Buildings are responsible for the disturbances in the airflow. The horseshoe vortexes are then generated over the edges of the building windward side. At the lee side, the wake region and the cavity recirculation region are generated, with a reduced air change. According to [1] and [2], the cavity region can approach $z = (2 \div 2.5)\ H_B$ in the range of $x = 6\ H_B$, while the boundaries of the wake region can approach $z = 3\ H_B$ and $x = 16\ H_B$. ELTERMAN [3] describes the boundary of the wake as an isotach (a line connecting points of equal wind speed): $u = 0.95\ u_o$ (u_o is the velocity of undisturbed air stream) and the boundary of a cavity region as follows:

$$\int_0^{z_b} u dz = 0\,, \qquad (1)$$

where z_b is the height reached by the cavity boundary at the point whose distance from the building windward side is x.

The shapes of the curves representing the boundaries of the wake and the cavity regions do not depend on the value of speed u_o, but on the building configuration and

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its surroundings. However, the value of u_o has the crucial influence on the diffusion of the smoke emitted from the short chimney in the wake area:

$$\Delta p = 0.5 \cdot K(u_o^2 \rho), \qquad (2)$$

where:
K – the aerodynamic factor of the obstacle,
ρ – the density of gas.

Several studies of the flow field around an isolated building and a group of buildings in the wind tunnel were carried out (for example [4]–[7]). AHMAD et al. [8] describe the results of some research in the review paper. If the fume from short-point sources enters the wake region, especially the cavity region, then the space of the diffusion of pollutants is restricted. This refers especially to the so-called short-point sources of the second class, which fulfill the following conditions: $h_s < 1.1\ H_B$ and the emission plume rise $\Delta h \approx 0$.

The objective of this study was to analyse the diffusion of pollutants from the short chimney of the second class inside a total cavity region. The study was based on the author's investigations and the simulations carried out in the wind tunnel. The long building was the source of the flow disturbances, which restricts the analysis of the phenomenon to the 2D surface *ZX*. A free-standing short chimney was situated on the lee side of the building. The change of the distance from the building to the chimney, with other parameters constant, makes it possible to observe and analyse the phenomena of gaseous diffusion.

2. EXPERIMENTAL SET-UP AND PROGRAMME OF INVESTIGATION

The wind tunnel used for testing the diffusion of gaseous pollutants emitted from the short-point and line sources was constructed at the Institute of Environmental Engineering, Poznań University of Technology. A sketch of the experimental set-up is shown in figure 1. Its explanation can be found in other papers by the author [9], [10].

The analysis of the tracer gas diffusion in the air stream was carried out by means of visualization technique with camera detection and also by measuring the field concentration on the surface *ZX*. The smoke was produced in a smoke generator. In order to investigate the pollutant concentration, CO_2 from CO_2 cylinder was used as a tracer gas. CO_2 concentration in the chimney reached 100%. The gas for the analysis was collected by a sampling probe at the induction speed $w_z < 0.2$ m/s. The concentration of CO_2 was determined with the MSMR-4 analyzer equipped with INFRA-RED head, within the range of 0÷5.0% and the accuracy of 0.01% (for high concentration within the range of 0÷100.0%). The values of concentrations, taken simultaneously from three sampling probes, were registered every 6 s. The background value of CO_2 concentration in the airflow before the building was measured as well, within the range of 0÷0.5%.

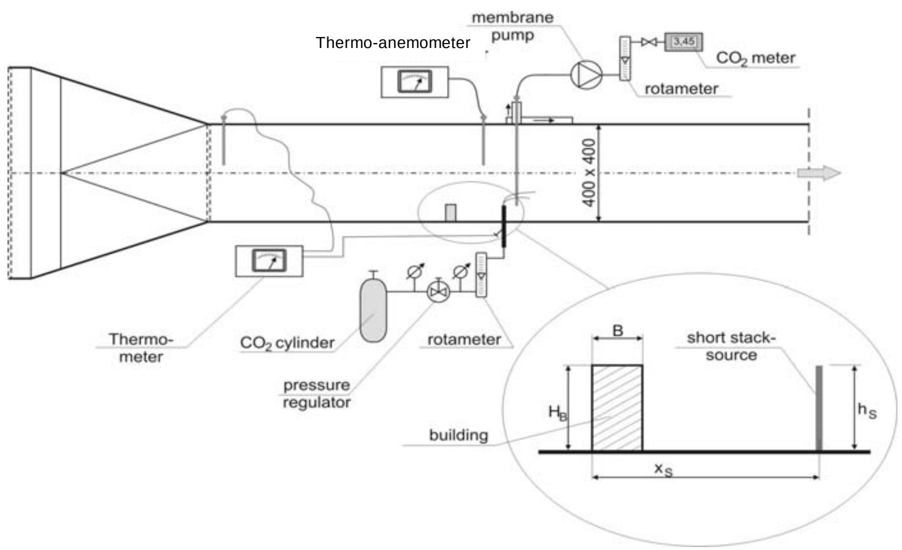

Fig. 1. A sketch of the wind tunnel and experimental set-up

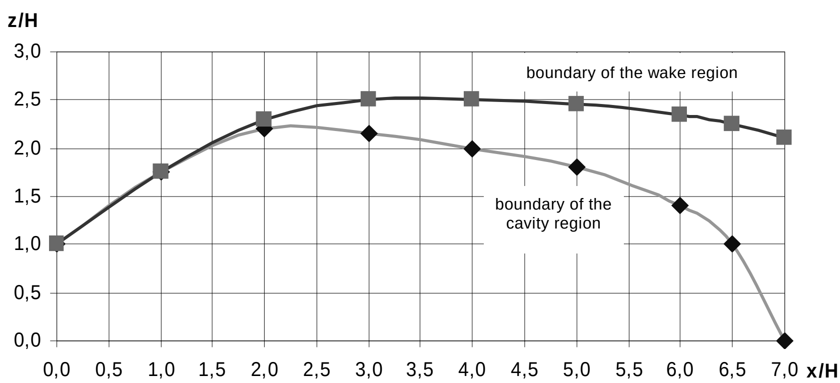

Fig. 2. Hypothetical boundaries of wake and cavity recirculation regions

The source of the airflow disturbances was a rectangular building with the following dimensions: H_B = 58 mm, B = 38 mm ($0.65H_B$), L_B = 400 mm (the width of the wind tunnel). Based on equations reported by ELTERMAN [3], the hypothetical boundary of the wake region and cavity recirculation region behind the building was determined (figure 2). During the research the distance between the free-standing chimney and the building was being changed in the full range of that cavity region.

The following values were assumed to be constant:

• the characteristics of the building,

• the characteristics of the chimney: the height $h_s = H_B$; the inside diameter $D = 8.0$ mm; the emission velocity $w = 0.5$ m/s; the isothermal conditions $T_s = T_o$.

The variable values were as follows:

• the wind velocity u_H (free stream velocity): $u_H = 1.0$ m/s ($Re = 3844$); $u_H = 2.0$ m/s ($Re = 7687$),

• the distance between the chimney and the windward side of the building x_s/H_B, in the range from $x_s = H_B$ to $x_s = 6H_B$.

3. ANALYSIS OF RESULTS

The results of the investigations were presented in the selected pictures of the smoke plumes and the selected profiles of tracer gas concentration in the plume from a short chimney. In figures 3 and 4, the pictures of undisturbed streamline plumes are presented. The corresponding profiles of the tracer gas concentration (the speed of $u_H = 1.0$ m/s)

Fig. 3. Free streamline from free-standing chimney; $u_H = 1.0$ m/s

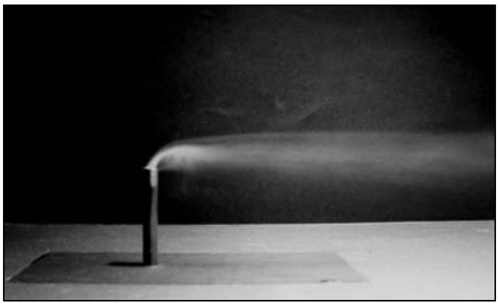

Fig. 4. Free streamline from free-standing chimney; $u_H = 2.0$ m/s

Fig. 5. Flow field around isolated long building; $u_H = 1.0$ m/s

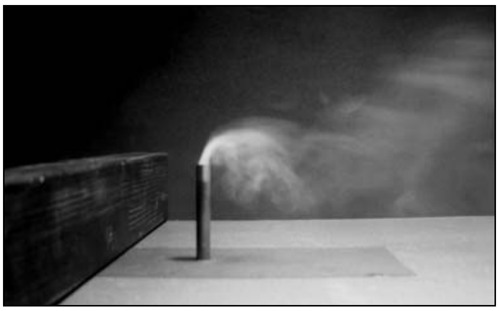

Fig. 6. Disturbed fume flow; $u_H = 1.0$ m/s; $x_s = 1.6\ H_B$

are shown in figure 11. The diffusion of the pollutants in an undisturbed plume takes place along the streamline axis, at the height of h_s. A slight depression in the path-line (figure 11) results from the tracer gas density. The flow around an isolated long building at the wind velocity u_H = 1.0 m/s is shown in figure 5. It can be observed that the cavity recirculation region is determined by the shape and the route of the smoke stream.

The selected pictures of the disturbed fume emitted from a short chimney of the second class, in the cavity recirculation region, at different wind velocities u_H and different distances between the chimney and the building x_s/H_B are shown in figures 6 –10.

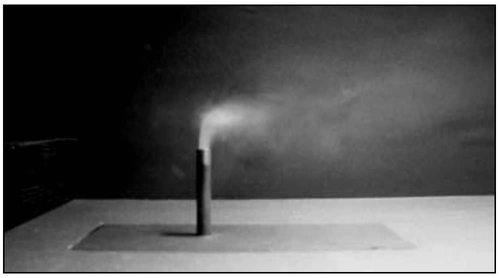

Fig. 7. Disturbed fume flow;
u_H = 2.0 m/s; x_s = 3 H_B

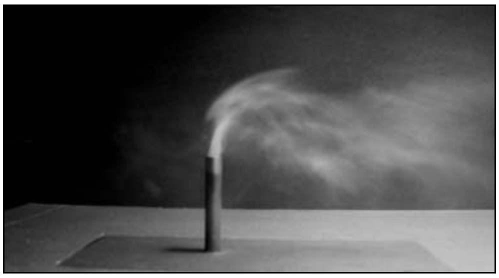

Fig. 8. Disturbed fume flow;
u_H = 1.0 m/s; x_s = 4 H_B

Fig. 9. Disturbed fume flow;
u_H = 1.0 m/s; x_s = 6 H_B

Fig. 10. Disturbed fume flow;
u_H = 1.0 m/s; x_s = 9.5 H_B

For a chimney of the height $h_s = H_B$ and for the distances from x_s = 1.6 H_B to x_s = 6 H_B, shown in the pictures, the smoke outflow takes place inside the cavity region and up to x_s = 10 H_B – inside the wake region. The character of this diffusion totally differs from that in the undisturbed plume. Intensive turbulences in the stream of the gas in the range up to x_s = 6 H_B are responsible for high concentrations of the pollutant in the ground zone.

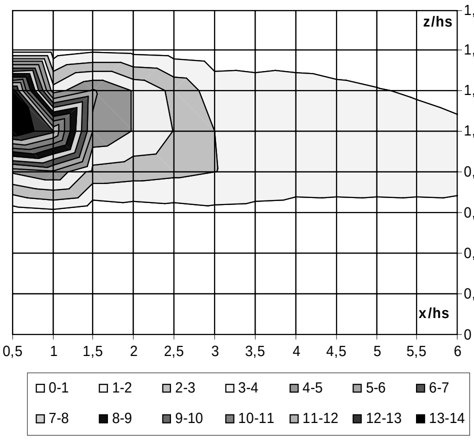

Fig. 11. Profiles of gas concentration [%] for free plume; $w = 0.5$ m/s; $u_H = 1.0$ m/s

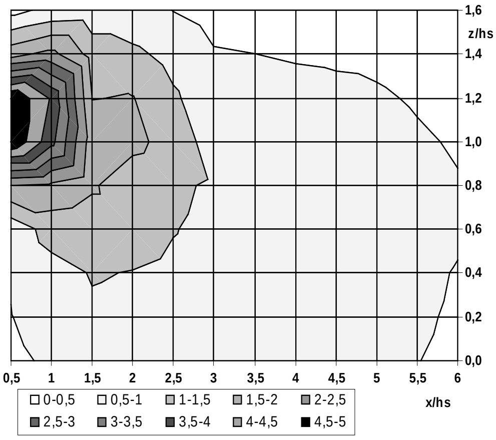

Fig. 12. Profiles of gas concentration [%] for disturbed plume; $u_H = 1.0$ m/s; $x_s = H_B$

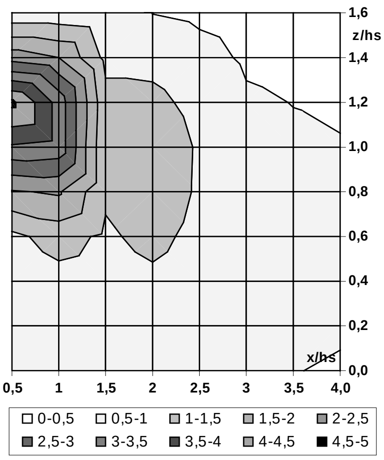

Fig. 13. Profiles of gas concentration [%] for disturbed plume; $u_H = 1.0$ m/s; $x_s = 2\ H_B$

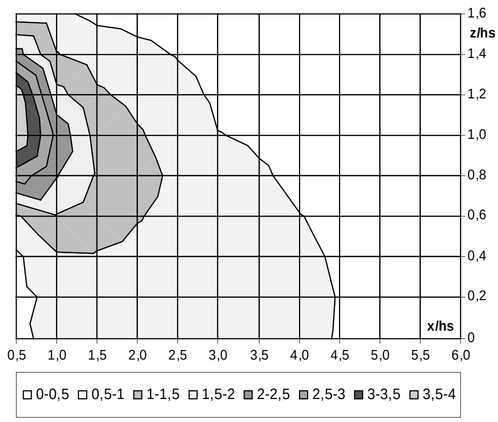

Fig. 14. Profiles of gas concentration [%] for disturbed plume; $u_H = 1.0$ m/s; $x_s = 6\ H_B$

The concentration profiles of the tracer gas in the cavity recirculation region, at the wind velocity $u_H = 1.0$ m/s and different values of x_s/H_B, are shown in figures 12, 13 and 14. The ranges of the concentrations measured, presented in these figures, included:

- the height: from $z = 0$ to $z = 1.6\ H_B$,
- the distance: from $x = 0.5\ h_s$ to $x = 6\ h_s$, which means the range up to $x = 12\ H_B$. This was the full range of the cavity region.

The profiles of the gas concentrations combined with the visualization of the phenomenon show that:

• the smoke plumes are characterized by a large turbulence in the whole range of the cavity region,

• the plume explicitly deflects downwards, which results in the high values of concentrations in the cavity region, not only as the episodes, but also as a mean value.

Based on the gas concentration profiles, it is possible to assess the range of the cavity region. The compatibility of the hypothetical boundary of the cavity recirculation region (figure 2) with the concentration line $C = 0.5\%$ (figures 12, 13 and 14) is visible.

4. CONCLUSIONS

Short-point sources of the second class present a considerable threat to the air quality. Therefore, it is very important to determine the boundary of the wake and cavity recirculation areas where the chimney outlet is situated. Based on the model testing presented in this paper it can be concluded that the visualization technique and the determining of the profiles of the tracer gas concentration enable researchers to determine the range of the cavity recirculation region for a definite obstacle. The results of the research have also verified the hypothetical boundaries of the cavity region, determined from the Elterman equation.

It is important to note that even at the distance of 9 H_B from the building's windward site, the flow disturbance produced by the building strongly influences the plume outflow from the short-point chimney and increases the pollutant concentrations in the ground zone.

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ANALIZA DYFUZJI GAZU EMITOWANEGO Z NISKIEGO ŹRÓDŁA PUNKTOWEGO W STREFIE CIENIA AERODYNAMICZNEGO – BADANIA MODELOWE

Dokonano analizy warunków dyfuzji, w pełnym zakresie cienia aerodynamicznego, gazu wypływającego z niskiego emitora punktowego. Analizę oparto na własnych badaniach modelowych prowadzonych w tunelu aerodynamicznym. Wolno stojący emitor punktowy był umieszczony za budynkiem. Badania prowadzono dla kilku odległości między budynkiem a emitorem. Zjawiska oceniano, wykorzystując metodę wizualizacji oraz pomiarowe wyznaczenie profili stężeń gazu wskaźnikowego. Z przeprowadzonych badań wynika, że przyjęta metodyka umożliwia wyznaczenie granicy strefy cienia aerodynamicznego za wybraną przeszkodą.