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# THE ANALYSIS OF DISPERSION OF POLLUTANTS FROM SHORT POINT SOURCES – WIND TUNNEL EXPERIMENTAL INVESTIGATION

Dispersion of gases emitted from by short point sources was investigated in a wind tunnel. The street canyon was simulated by two buildings parallel to each other and perpendicular to the wind direction. In the upstream building, a short chimney was situated. The influence of the following technical factors of the source was investigated: gas emission velocity, the ratio between the heights of the upstream and downstream canyon buildings, and the location of the chimney in relation to the upstream building. The analysis of gas dispersion in the stream of the air was carried out using the visualization technique with a camera detection as well as the measurements of field concentration of the tracer gas. Smoke and $CO_2$ were used as the tracer gases.

Generally, in a street canyon area, one can expect gas concentration reaching approximately 1–2% of the concentration of the pollutants emitted from short point sources. However, when the short point source is situated at the wall of a building, on the side of the canyon, the concentration of the pollutant in the street canyon can sharply increase.

## 1. INTRODUCTION

Cubical buildings in an open terrain will produce aberrations in the wind flow. This obstruction changes the local wind speed and direction as well as the turbulence. Building effects may be mechanical or thermal in origin. The aberrations in the wind speed and direction extend upwind in a short distance, however downwind they are affected.

The plume with pollutants enters the turbulent region from small combustion and technological sources with chimneys, where the chimney height ($H_s$) is smaller than the doubled height of the building ($H_b$), i.e., $H_s < 2\ H_b$ (the height from the ground level to a chimney top). Such chimneys are defined as short stacks, according to data of Warren Spring Laboratory [1].

The flow of pollutants from small combustion sources, natural ventilation and exhaust fans are often characterized not only by small relative height $H_s$ = (0.7–1.4

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m)·$H_b$, but also by a low temperature of the stack gas and a low gas ejection velocity ($w$ < 1.5 m/s).

In these circumstances, the plume has a low capacity to rise due to its low buoyancy and exit speed. The aberrations in the wind flow because of the turbulence are responsible for a stochastic character of the distribution of pollutants along the building and in its wake. There are no analytical methods for solving this problem, even to a degree of accuracy approaching that available for high stacks.

There are numerous tests on the pollutant flow and dispersion within and over urban structures, for example, those in the wind tunnel carried out by JARŻA et al. [2], MERONEY et al. [3], OKE [4], GERDES and OLIVARI [5], LIU et al. [6]. In the papers of LIEN et al. [7] as well as CHANG CHENG-HSIN and MERONEY [8], [9], there are presented numerical models of such a flow and dispersion. Urban structures are most often single buildings, the set of buildings in a street or an urban street canyon. Pollutants are most often emitted from line or point sources at the ground level (for example, in a street canyon) with a very low ratio of the emission velocity to the wind velocity.

The objective of this paper was to analyse the influence of technical factors on the dispersion of pollutants from short stacks. The height of the stack approaches the height of the building, and the velocity of emission is similar to that of the wind. In this study, a wind tunnel is used to simulate a gas flow at low speed. Wind tunnel simulations offer the possibility of examining the effect of several parameters, individually and in combination, on the pollutant dispersion. Three technical factors are tested: gas emission velocity, the ratio between the heights of the upstream and downstream buildings and the stack location at the building.

## 2. EXPERIMENTAL SET-UP

### 2.1. THE WIND TUNNEL – APPARATUS AND PROCEDURE

The wind tunnel used for testing the dispersion of pollutant emitted from short stacks was made at the Institute of Environmental Engineering, Poznań University of Technology, by the author of the paper. The articles of MERONEY et al. [3] and GERDES et al. [5] were helpful in planning the experimental set-up.

The wind tunnel is 4.5 m long, with the test section of 1200 mm in length and a square cross-section of 400 mm × 400 mm. The stream of air is generated by a confusor of a bell shape (D 800 mm/400 × 400 mm) equipped with the set of tranquillization screens. The flow is encouraged by an axial fan with an infinitely variable speed control, placed at the end of the wind tunnel. Tranquillization bar and the screen are located between the test section and the axial fan. The experiments are performed in the test section of a stable profile of the speed. The wind velocity profile is shown in figure 1.

A flap in the ceiling of the tunnel makes assembling the models of urban structure elements possible (the wooden blocks whose height ranges from ca. 0.1 to 0.2 of the height of the tunnel). It also enables investigating the tunnel in the *Z*- and *X*-axes in order to measure the profiles of the flow speed and the concentration of the tracer gas. The gas (pollutants) enters the flowing stream through a copper tube installed in "the building" or at its wall with the possibility of controlling a $H_s/H_b$ ratio. The gas may be heated up. A sketch of the experimental set-up is shown in figure 2.

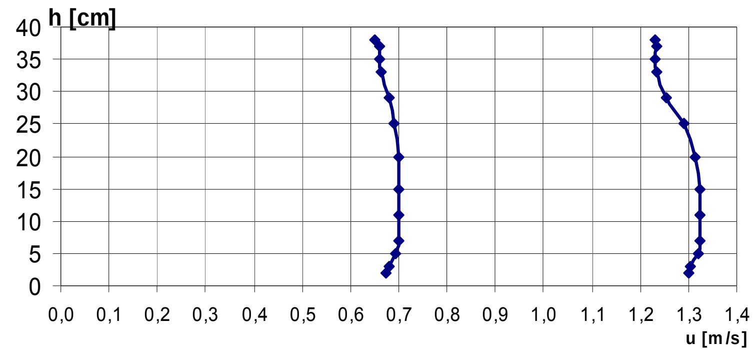


Fig. 1. Wind velocity profile in test section

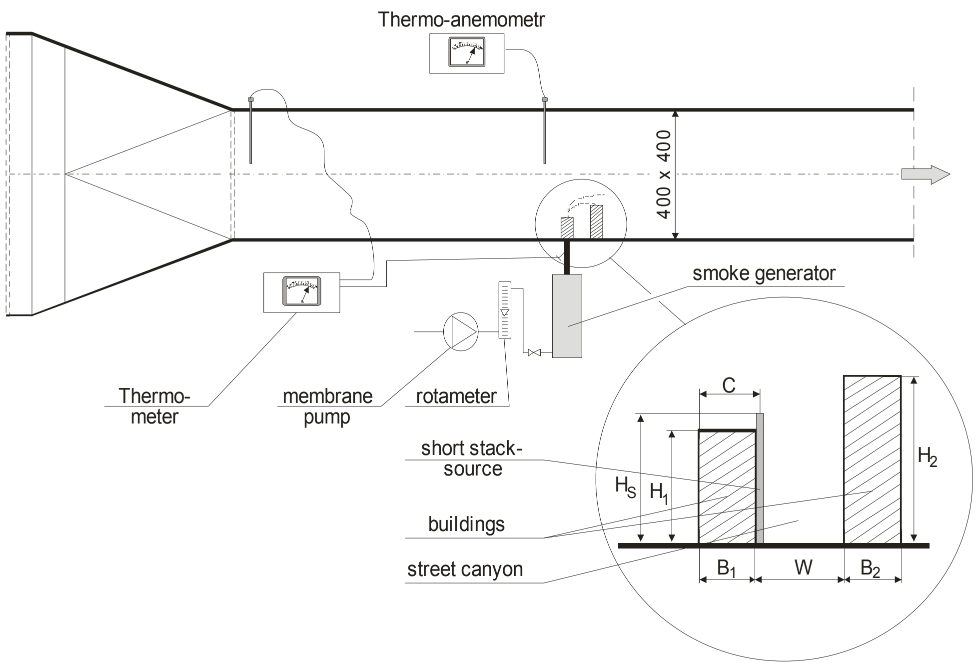


Fig. 2. A sketch of the wind tunnel with an experimental set-up

The analysis of pollutant dispersion in the air stream was carried out by means of visualization technique with camera detection as well as by measuring the field concentration on the surface *ZX*. For visualization the smoke was produced in a smoke generator, and its flow being encouraged by membrane pump. The flow rate of this smoke was controlled and measured by a rotameter. In order to investigate the pollutant concentration, we used $CO_2$ as the tracer gas from $CO_2$ cylinder with a pressure regulator and a rotameter. $CO_2$ concentration in the chimney reached 100%. The gas to be analysed was collected by a sampling probe at a speed of the induction $w_z < 0.3$ m/s. $CO_2$ concentration was determined with the analyzer MSMR-1 INFRA-RED of the measuring range of 0–5.0% and accuracy of 0.01% (figure 3).

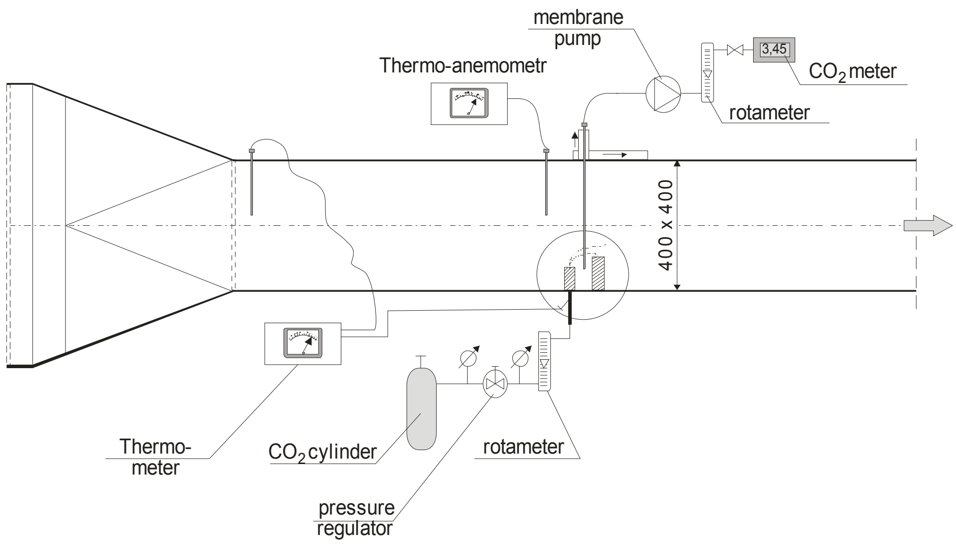


Fig. 3. A sketch of set-up for the emission of $CO_2$ and measurement of its concentration

### 2.2. THE PROGRAM OF THE INVESTIGATION

The pollutant dispersion was investigated in a street canyon (figure 2) of the width $W$ and the heights of the buildings $H_1$ and $H_2$. In the measuring series presented, the following values were assumed to be constant: the dimensions of an upstream canyon building $H_1$ = 58 mm, $B_1$ = 38 mm; a relative height of the chimney $H_s/H_1$ = 1.1, the diameter $D_s$ of the chimney, the gas temperature $T_s = T_t$ = 293 K (the isothermal mixing of streams), and the spacing between the canyon walls $W = H_1$. The variable values are as follows: the emission velocity $w$, the height of the building $H_2$, the position of the chimney in relation to the width of the building ($C/B_1$). A constant wind velocity $u_{100}$ = 1.0 m/s and a constant wind temperature $T_t$ = 293 K were accepted, which means that the Reynolds number $Re_t$ = 3850.

## 3. RESULTS AND THEIR ANALYSIS

The results of the investigations were presented in the form of selected and processed digital photos of pollutant distribution in the canyon and selected horizontal profiles of $CO_2$ concentration in the space between the buildings.

The following dependencies were analyzed:

**Series I:** The influence of the emission velocity *w* on the pollutant dispersion:

$H_1 = H_2 \rightarrow$ canyon configuration: 6–6–6($H_1$–$W$–$H_2$), $C = 0.5\ B_1$, $w = 0.53$ m/s, $w = 1.1$ m/s, $w = 1.5$ m/s.

The results are shown in figures 4, 5, 6 and 10, 11.

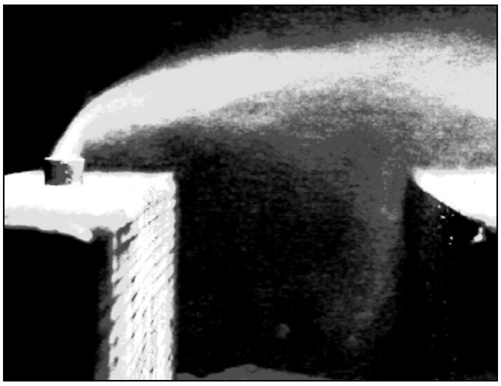

Fig. 4. Path of the plume; *w* = 1.1 m/s, canyon configuration: 6–6–6; *C* = 0.5 *B*

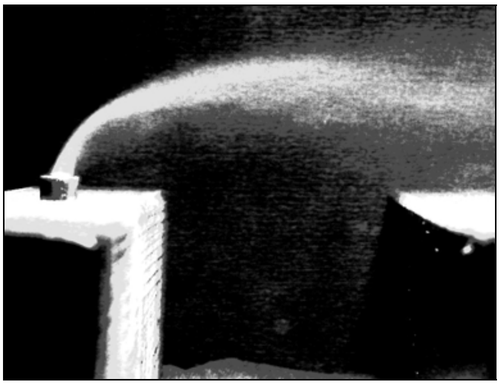

Fig. 5. Path of the plume; *w* = 1.5 m/s, canyon configuration: 6–6–6; *C* = 0.5 *B*

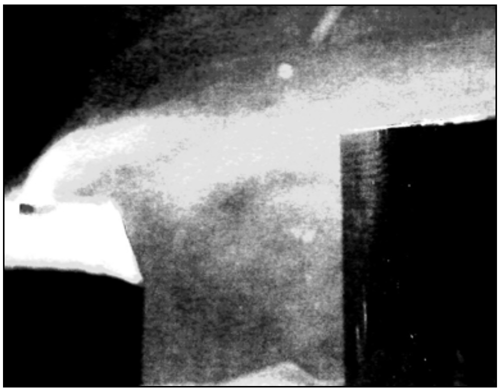

Fig. 6. Path of the plume; *w* = 0.53 m/s, canyon configuration: 6–6–8; *C* = 0.5 *B*

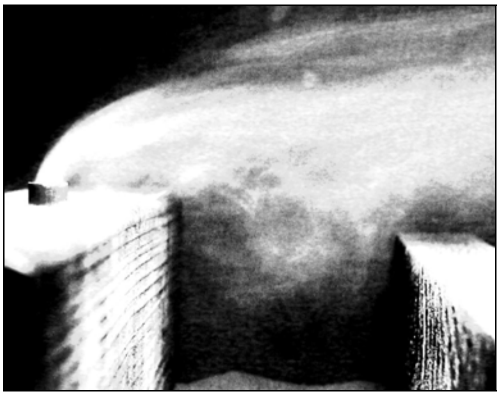

Fig. 7. Path of the plume; *w* = 0.53 m/s, canyon configuration: 6–6–4; *C* = 0.5 *B*

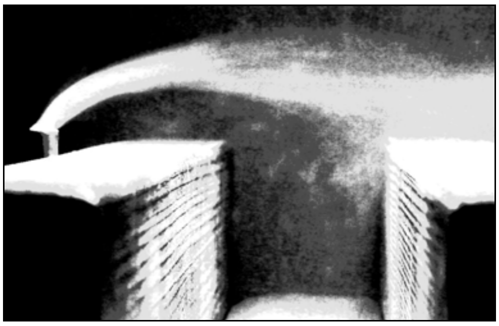

Fig. 8. Path of the plume; $w = 0.53$ m/s, canyon configuration: 6–6–6; $C = 0$

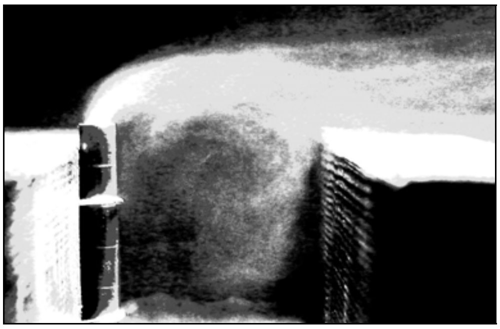

Fig. 9. Path of the plume; $w = 0.53$ m/s, canyon configuration: 6–6–6; $C = B$

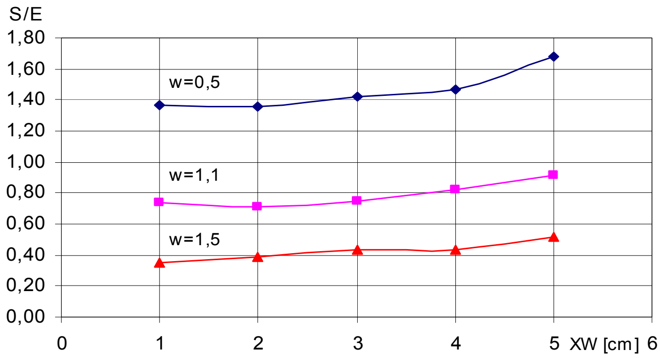


Fig. 10. Horizontal profiles of a relative concentration at the height of 4 cm; $w = 0.53$; 1.1 and 1.5 m/s; canyon configuration: 6–6–6; $C = 0.5\ B$
$XW = 0$ – wall of the building 1 (with stack); $XW = 6$ – wall of the building 2

At a constant $CO_2$ concentration in the chimney the gas velocity increases two times, and gas emission also increases two times. Therefore in figures 10 and 11 the horizontal profiles of relative concentration $S/E$ are shown, where $S$ is $CO_2$ concentration in the canyon, and $E$ is a relative $CO_2$ emission from chimney, $E = 1$ at the emission velocity $w = 0.53$ m/s.

**Series II:** The influence of the ratio between the heights of the upstream and downstream canyon buildings on the pollutant dispersion:

$w = 0.53$ m/s; $C = 0.5\ B_1$,

$H_1/H_2 = 1$ → canyon configuration: 6–6–6,

$H_1/H_2 = 0.72$ → canyon configuration: 6–6–8,

$H_1/H_2 = 1.32$ → canyon configuration: 6–6–4.

The results are shown in figures 6, 7 and 11, 12.

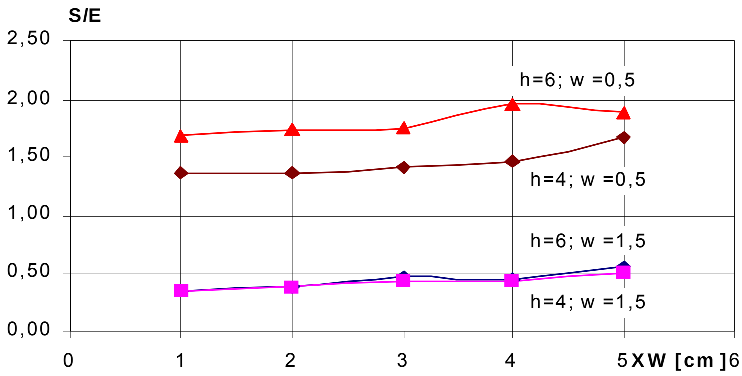


Fig. 11. Horizontal profiles of relative concentration at the heights of 4 cm and 6 cm;
$w$ = 0.53 and 1.5 m/s; canyon configuration: 6–6–6; $C$ = 0.5 $B$
$XW$ = 0 – wall of the building 1 (with stack); $XW$ = 6 – wall of the building 2

**Series III:** The influence of the position of the chimney in relation to the width of the building ($C/B_1$) on the pollutant dispersion:

$H_{B1} = H_{B2}$ → canyon configuration: 6–6–6; $w$ = 0.53 m/s = const,

$C = 0$; $C = 0.5\ B_1$; $C = B_1$.

The results are shown in figures 8, 9 and 13.

Visualizations of pollutant distribution in the canyon are given in figures 4–9, and horizontal concentration profiles of $CO_2$, in figures 10–13.

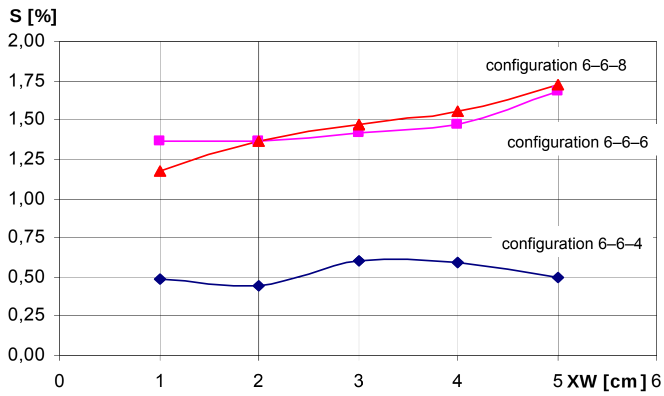


Fig. 12. Horizontal concentration profiles at the height of 4 cm;
$w$ = 0.53 m/s; canyon configurations: 6-6-4; 6-6-6; 6-6-8; $C$ = 0.5 $B$
$XW$ = 0 – wall of the building 1 (with stack); $XW$ = 6 – wall of the building 2

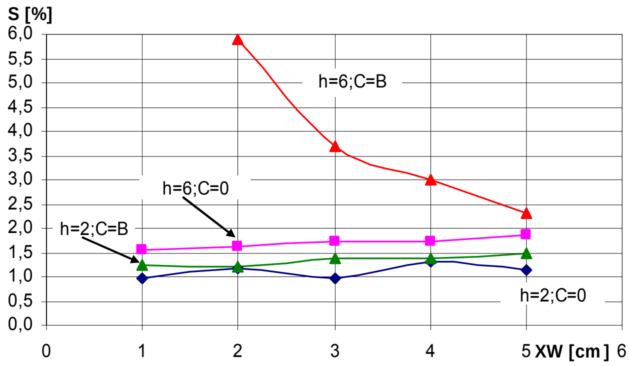


Fig. 13. Horizontal concentration profiles at the height of 2 and 6 cm;
*w* = 0.53 m/s; canyon configurations: 6–6–6; *C* = 0 and *C* = *B*
*XW* = 0 – wall of the building 1 (with stack); *XW* = 6 – wall of the building 2

## 4. CONCLUSIONS

Such technical factors of the pollutant source as gas emission velocity, the ratio between the heights of the upstream and downstream buildings in canyon and the location of the chimney in relation to the building width affect greatly the pollutant dispersion, especially when they are emitted from short sources in urban areas. The concentration of the pollutant in the area of street canyon is high, especially at low gas ejection velocity. The difference in the height of the upstream and downstream canyon buildings is of a paramount importance for the concentration field. In general, it can be expected that in the areas of street canyon, the concentration of gases emitted from chimney reaches approximately 1–2% of its concentration at the outlet from chimney. When the short point sources are situated at the walls of a building, from the side of the canyon, the concentration of pollutant in a street canyon can sharply increase.

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## DYSPERSJA ZANIECZYSZCZEŃ POWIETRZA EMITOWANYCH Z NISKICH ŹRÓDEŁ PUNKTOWYCH – BADANIA MODELOWE W TUNELU AERODYNAMICZNYM

Badano dyspersję zanieczyszczeń powietrza emitowanych z niskich źródeł punktowych. Model miejskiego kanionu ulicznego stanowiły dwa budynki równoległe względem siebie, a prostopadłe do przepływu wiatru. W budynku od strony nawietrznej był umieszczony komin. Badania obejmowały wpływ następujących warunków technicznych źródła emisji: prędkości emitowanego gazu, stosunku między wysokościami budynków po stronie nawietrznej i zawietrznej kanionu oraz lokalizacji komina w strukturze budynku na dyspersję zanieczyszczeń. Do badania dyspersji gazu w strumieniu powietrza wykorzystano technikę wizualizacji z rejestracją fotograficzną oraz pomiary koncentracji gazu wskaźnikowego. Jako gaz wskaźnikowy zastosowano dym oraz $CO_2$.

W obszarze kanionu ulicznego można się spodziewać wartości stężeń zanieczyszczeń na poziomie 1–2% stężenia wylotowego z niskiego emitora punktowego. Znacznie wyższe wartości stężeń mogą wystąpić, gdy niski emitor jest usytuowany przy ścianie budynku od strony kanionu ulicznego.