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Comparison between field measurement and wind tunnel experiments of gas dispersion in an urban area and verification of similarity law

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SUMMARY: (10 pt)
This study aims to validate prediction of pollutant dispersion in urban area based on wind tunnel experiment. For this purpose, wind tunnel experiments and filed measurements of tracer gas dispersion were conducted in the campus of Tokyo Polytechnic University (TPU), and their results were compared. In addition, wind tunnel experiment was carried out under various conditions of experimental model scale, wind speed, and pollutant emission rates to confirm similarity law. The normalized concentration obtained by the wind tunnel experiments agreed well with the field measurement data. It was also confirmed that the normalized concentration was nearly independent of experimental model scale, wind speed, and gas emission rate.

Keywords: field measurement, wind tunnel experiment, similarity law

1. INTRODUCTION

Few studies have compared actual urban pollutant concentration obtained from wind tunnel experiments and field measurements. Therefore, the accuracy of the concentration prediction in actual urban areas by wind tunnel experiments has not been sufficiently verified. Thus, we conducted field measurements and wind tunnel experiments of gas dispersion at the campus of TPU, and we compared the results. Additionally, we confirmed similarity laws in wind tunnel experiments by varying the experimental model scale, wind speed, and tracer gas emission rate.

2. OUTLINE OF FIELD MESUREMENT

2.1. Measurement of reference wind speed and wind direction

The field measurement of gas dispersion was conducted at TPU on February 25th and 26th, 2014. The weather on the two days were clear with no precipitation, and wind direction was mostly 180 degrees (south). Using an ultrasonic anemometer, we measured the reference wind speed U_H and wind direction at the reference point as shown in Fig. 1(GIS maps). The anemometer was mounted at a height of 14m above the roof of the building. The reference height H was 41m from the ground.

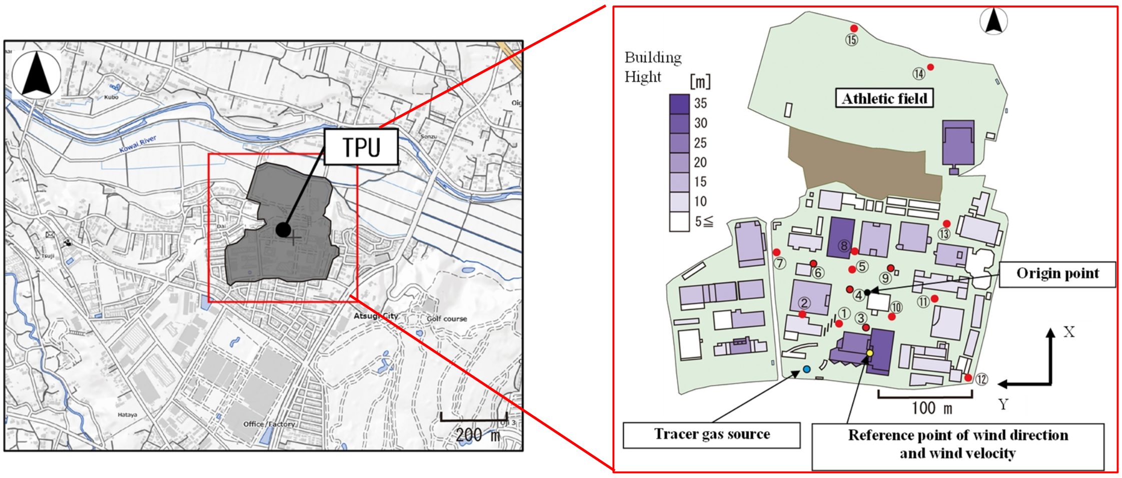


Figure 1. View of the campus and measurement points.

2.2. Measurement of gas concentration

In this study, Perfluoro methylcyclohexane (PMCH, C_7F_{14}) was used as the tracer gas. The tracer gas was continuously emitted from a height of 1.5 m above the ground. The tracer gas concentration was 200 ppm, and the flow rate was 5 L/min (blowing speed was approximately 0.003 m/s) during the measurement. The measurement points were located at 15 positions as shown in Fig. 1. The measurement hight was 3m above the ground. Each measurement was conducted for a period of 30 minutes, and a total of 18 measurements were performed in two days. From these results, 7 measurement data were selected in which the wind direction was primarily south, and the atmospheric stability was neutral. The normalized concentration (non-dimensional concentration) C^* was calculated by Eq. (1) where C is the concentration [m^3/ m^3], U_H is the reference wind speed [m/s], q is the emission rate of tracer gas [m^3/s]

$$C^* = \frac{C U_H H^2}{q} \tag{1}$$

3. OUTLINE OF WIND TUNNEL EXPERIMENT

3.1. Experimental model and approach flow

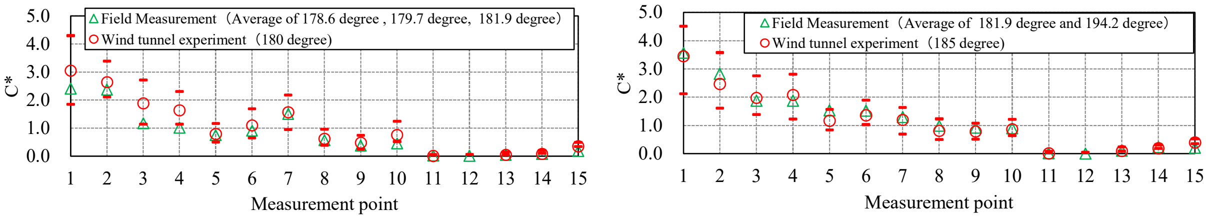
The wind tunnel experiment was conducted at TPU. The wind tunnel test section is 1.0 m high and 1.2 m wide. The experimental model was made using 3D printer and it replicated the buildings and topography of the area with a radius of 300 m. The experimental model scale was 1/600. The approach flow was generated using roughness and spire, with a power exponent of 0.27. The reference wind speed was set to U_H=4.12 m/s. The experimental wind directions were 180 degrees and 185 degrees.

3.2. Measurement methods of concentration

Concentration was measured using High-speed-total-hydrocarbon-analyzer. Ethylene (C_2H_4) at 100% concentration was used as tracer gas. It was ejected from an outlet with a diameter of 6 mm at a flow rate of 150 cc/min (discharge speed of 0.088 m/s). The sampling frequency was set to 1000 Hz. The measurement time was 240 s. The measuring points of the experiment were same as those of the field measurement (Fig. 1).

4. COMPARISON BETWEEN FILED MEASURMENT AND EXPERIMENT

Fig. 2 shows the normalized mean concentration of the field measurement and the wind tunnel experiment at each measurement point. According to (Schatzmann et al, 2010) the 30-minute average normalized mean concentration obtained from field measurements had large variations. To account for this, the time history obtained in wind tunnel experiment results was divided into 30-minute real-time equivalents, and the minimum and maximum values of the mean normalized concentration for each are plotted in Fig. 2. At a wind direction of 185 degrees, the agreement between the field measurements and the wind tunnel experiment is very good at any measurement points. At a wind direction of 180 degrees, the field measurement is almost within the range of the maximum and minimum mean values of the wind tunnel experiment, but the wind tunnel experiment results are somewhat larger than the field measurement at points 1 to 4.



(a) wind direction 180 degrees (b) wind direction 185 degrees

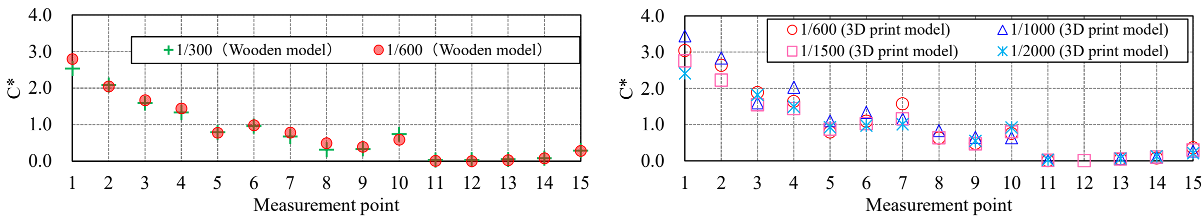
Figure 2. Comparison of normalized mean concentration from field measurements and wind tunnel experiments.

5. CONFIRMATION OF SIMILARITY LAW IN WIND TUNNEL EXPERIMENTS

5.1. Effect of experimental model scale on normalized concentration

Wind tunnel experiments were conducted using five experimental models with scales of 1/300, 1/600, 1/1000, 1/1500, and 1/2000 to investigate the effect of the experimental model scale on the normalized concentration. The model scales of 1/1000, 1/1500, and 1/2000 were 3D printer model. The model scale of 1/300 was a wooden model. The model scale of 1/600 was tested with two types of models, a wooden model, and a 3D printer model. For all models, the experimental wind direction was set to 180 degrees (south), the reference wind speed was approximately 4 m/s, the diameter of the tracer gas source was 6 mm, and the tracer gas emission rate was 150 cc/min. The measurement points were same as described in section 3.2.

Fig. 3 (a), (b) shows the normalized mean concentration for each measurement point by the wooden models (1/300, 1/600) and the 3D printer models (1/600, 1/1000, 1/1500, 1/2000). The normalized mean concentration for the 1/300 and 1/600 scale wooden models agrees very well, even though the two scale model experiments were conducted in different wind tunnels. The normalized mean concentration of the 3D printer models with scales of 1/600, 1/1000, 1/1500, 1/2000 were similar regardless of the model scale.



(a) Wooden models (b) 3D printer model

Figure 3. Comparison of normalized mean concentration when changing the scale of the model.

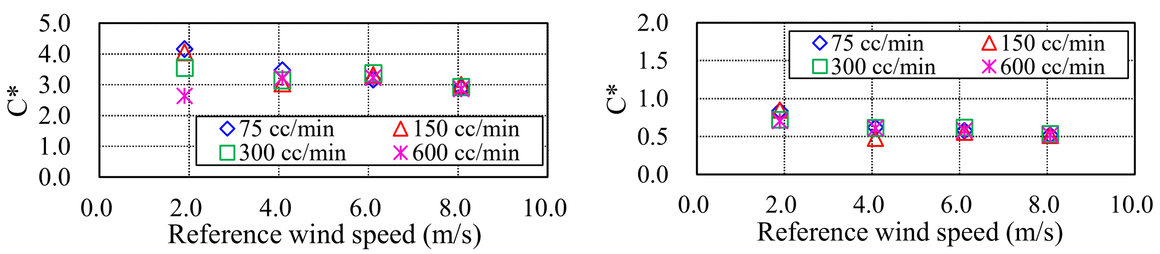
5.2. Effect of reference wind speed and gas emission rate on normalized concentration

As shown in Table 1, a total of 16 cases of wind tunnel experiments were conducted using model scale of 1/600 at four different reference wind speeds and four different tracer gas emission rates to investigate their effects on the normalized concentration. Fig. 4 shows the experimental results of representative points 1 and 9.

The normalized mean concentration at points 1 and 9 were almost constant at reference wind speed of 4.1 m/s or higher, even when the emission rate varied. However, the normalized concentration at the reference wind speed of 1.9 m/s were higher than those at other wind speeds, except for the gas emission rate of 600 cc/min at point 1. This was because high upward discharge speed caused the tracer gas to diffuse upward, making it difficult for the gas to reach the measurement point 1, which is the closest to the tracer gas source. In the range of reference wind speeds from 4.1 m/s to 8.1 m/s, the normalized concentration was generally constant regardless of the reference wind speed and tracer gas emission rate were changed. It indicates that the effect of wind speed and tracer gas emission rate on normalized concentration was small.

Table 1. Measurement cases for confirmation of similarity law.

Reference Wind (m/s)	1.9				4.1				6.1				8.1			
emission rate (cc/min)	75	150	300	600	75	150	300	600	75	150	300	600	75	150	300	600
Dicharge (m/s)	0.84	0.85	0.72	0.70	0.04	0.09	0.18	0.35	0.04	0.09	0.18	0.35	0.04	0.09	0.18	0.35
Discharge speed ratio	0.441	0.447	0.381	0.370	0.011	0.022	0.043	0.087	0.007	0.014	0.029	0.058	0.005	0.011	0.022	0.044



(a) Point 1 (b) Point 9

Figure 4. Effect of reference wind speed and gas emission rate on normalized mean concentration.

6. CONCLUSIONS

In this study, wind tunnel experiments and filed measurements of gas dispersion were conducted in the campus of TPU, and their results were compared. Furthermore, wind tunnel experiment was carried out under various conditions of experimental model scale, wind speed, and gas emission rates to investigate similarity law. The results of the wind tunnel experiments were found to be in good agreement with field measurement results. It was also confirmed that the normalized concentration (non-dimensional concentration) was nearly independent of experimental model scale, wind speed, and gas emission rate.

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