Wind Tunnel Study on Effect of Thermal Stratification on Contamination Diffusion in Urban Area

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1. Introduction

Some extensive investigations dealing with the specific subject of contamination diffusion in urban areas under neutral or stable and / or unstable stratified boundary layer are discussed by Ogawa et al. (1980), Maroney et al. (1996), Gerdes et al. (1996). These studies have discussed a number of parameters as the thermal stratification, plume buoyancy, building geometry, street dimension, vegetation or landscape and surface roughness.

The aim of the present work is to study the contamination diffusion in thermal stratified boundary layer wind tunnel using a tracer gas emitted from a point source. Diffusion fields are simulated in a turbulent boundary layer wind tunnel using the Hamamatsucho city model in the center of Tokyo. In this study, the general non-dimensional concentration coefficient $K$ is defined as the ratio of the actual concentration $C$ at any point in the field and wind tunnel experiments to a reference concentration: $K = CH'U_0/Q$, where $U_0$ is the reference velocity at reference height, $H$ and $Q$ the contaminate release rate.

2. Thermal stratified wind tunnel

Experiments are performed in a thermal stratified wind tunnel at the Institute Industrial Science, University of Tokyo. For more details of wind tunnel, approaching flow and conditions, refer to Yassin at el. (2002). The test section is surrounded by thermal insulation walls on both sides to avoid a secondary flow. The model of Hamamatsucho area within 500 m radius is of an urban area at the centre of Tokyo, and is constructed at a geometric scale 1:600. A photograph of Hamamatsucho model in wind tunnel is shown in Fig. 1.

Three different types of thermal stratification: stable, neutral and unstable within the atmospheric boundary layer are created in the test section by controlling the wind tunnel airflow temperature and wind tunnel floor temperature. Heating the airflow and cooling the wind tunnel floor produced a stable stratified layer. The airflow temperature ($T_h$) and wind tunnel floor temperature ($T_b$) are set at 36.5 °C and 28.5 °C respectively, where the Bulk Richardson number ($R_i = gHATTbU_{1/2}$, where $AT = T_h-T_b$) and Reynolds number ($R_e$) are set at 0.14 & 7144 respectively. While, cooling the airflow and heating the wind tunnel floor produced an unstable stratified layer. The wind temperature and wind tunnel floor temperature are 14.0 and 16.9 °C respectively, where $R_i$ & $R_e$ are at -0.05 & 7694 respectively. In neutral stratified layer, $R_i$ & $R_e$ are 0.0 & 7831 respectively.

3. Instrumentations

Mean velocity and turbulence intensity profiles are measured using 3-D LDV. Mean velocity at sampling points are measured using Multi-Channel Anemometer. The airflow and floor temperatures are measured using thermocouple with copper-constantan thermocouples. Ethylene, C$_2$H$_4$, is used as a tracer gas and released from a point source as stack that has a diameter and height of 6 & 3 mm. A hydrocarbon analyzer detector (FID) is used to measure the C$_2$H$_4$ concentration. Mean concentration is obtained by collecting samples through pipeline that is attached from below model outside tunnel using Scanivalve with Quick-Kapura.

4. Results

4.1 Simulated boundary layer

A simulated atmospheric boundary layer is obtained by using a combination of spires and roughness elements on the floor of the tunnel. Fig. 2 shows the simulated turbulent boundary layer in the wind tunnel under atmospheric stability conditions: stable, neutral and unstable at $X=0.0$. Typical temperature profiles in the vertical direction on stable and unstable stratified boundary layer at $X=0.0$, $Y=0.0$ and $X=1200$ mm and $Y=500$ mm are shown in Fig. 3.

4.2 Flow characteristics

The measurements of mean velocity are made at 83 sampling points for neutral stratified boundary layer with wind direction NW. Mean velocity are normalized by the reference velocity $U_{ref}$ at height of 19.33 mm in the undisturbed boundary layer. Mean velocity is measured in the turbulent boundary layer starting at 5 mm above the floor of the Hamamatsucho model. Fig. 4 presents mean velocity at some sampling points. In this figure, the maximum velocity is reached up to 0.96 at sampling point 32 and a minimum velocity is decreased up to 0.32 at sampling point 7. The higher velocity is

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4.3 Diffusion characteristics

Diffusion experiments are carried out in the thermal stratified boundary layers: **stable**, **neutral** and **unstable** with wind direction **NW**. The measurements are made with model stack's height of 5 mm. The ground level concentration is measured starting at 2.5 mm above the floor of the Hamamtsucho model. The ground level concentration data are non-dimensionalized $K$ by the reference velocity $U_{ref}$ at height of 19.33 mm, $H_{ref}$. Fig. 5 illustrates the non-dimensionalized under **stable**, **neutral** and **unstable** stratified boundary layers at some sampling points. Under **neutral** condition, there is no buoyancy acting on the air parcel in the vertical direction. This is due to there is not enough energy to pass the parcel. Due to the weak diffusion ability for pollutants in stable atmospheres, the pollutant transport and diffusion in **stable** atmospheres has drawn much more attention in air pollution studies. The maximum concentration for **stable** condition is higher than that for **neutral** and **unstable** conditions. This is due to the buoyancy force, which have effect on the mean velocity. Therefore, the plume are dispersed with very little vertical diffusion due to the limitation of buoyancy in vertical direction, they can be expanded largely in horizontal direction. Under small wind conditions, the air parcels have too low kinematics energy to overcome the buoyancy, and so they cannot pass over the buildings, but only flow around the buildings. The most minimum concentration is found in **unstable** condition. In addition, it is smaller than that in **stable** and **neutral** conditions. On the

5. Conclusions

The diffusion experimental in thermal stratified wind tunnel results is described above can be summarized as follows:

a) The higher velocity is found near to the gas source,
b) The maximum concentration for stable condition is higher than that for neutral and unstable conditions, and
c) the most minimum concentration is found in unstable condition and is smaller to that in stable and neutral conditions

Reference

4) M.F. Yassin et al, Wind Tunnel Study on the PollutantDispersion over an Urban Area, Tenth Int. Conf. on Mod., Mon. & Man. of Air Pollution, Segovia, Spain, 1-3 July, 2002, pp. 625-634.