Comparison of Field Observation and Water Tank Experiment on Air Pollution Concentration in Katmandu Valley.

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Background

• Air pollution concentration in the winter season of Katmandu valley is high compared with the summer season.
  These causes were reported to be the pollutant emission from brick manufacturing and the accumulation of the pollutant because of the inversion layer.
• We measured NOx and TSP concentration for one week on February 2001.
  NOx concentration increased to the morning from the sunset and showed the peak value at 9 a.m.
The aim is to analyze the mechanism of the high air pollution concentration in Katmandu valley through the water tank experiment and the numerical model.
Averaged diurnal variation of NOx concentration

NOx gas in the air sucked by the pump was absorbed by TEA (Tetra Ethanol amine Acetone) filters. NOx concentration was analyzed by Photo Spectrometer.
We measured the temperature at the height of 400m and 60m from the ground level at Raniban Mountain.
In Katmandu valley, the air at 8 a.m. is the most stable state. After that, the air quickly changes to the unstable state.
The temperature of the top water tank is kept a constant temperature of 42 deg. The middle water tank corresponds to the atmosphere of Katmandu valley. The temperature of the bottom water tank is changed with 12 minutes period and a constant amplitude. (correspond to the ground surface temperature)
Experimental procedure

1. The water temperature of the top water tank is kept a constant temperature of 42 degree.
2. Simultaneously, the water temperature of the bottom water tank is kept a constant temperature of 37 degree.
3. The thermal stratification with a constant thermal gradient (1 degree/1cm) is formed in the middle water tank.
4. After that, the water temperature of the bottom water tank changes with 12 minutes period and a constant amplitude.
5. The flow and the temperature in the middle water tank are measured.
This temperature variation is used as the bottom boundary condition of the numerical simulation.
1. Firing styrene broken finely, which density is approximately same as the water density, was mixed in the middle water tank before the experiment.

2. After the start of the experiment, the flow in the middle water tank was visualized by firing styrene.

3. The video images were taken.

4. The velocity vectors were calculated from the movement of firing styrene of the visualized images.

Measurement method of flow
Measurement method of vertical temperature

1. The temperature at the height 5, 10, 15, 20, 40 and 60 mm from the bottom of the middle water tank was measured by thermocouples.
Measurement method of the whole of temperature

1. The thermal liquid crystal sheet was put into the middle water tank.
2. After the start of the experiment, the video images were taken.
3. The temperature was calculated from the color of the sheet of the visualized images.
## Similarity law

### Relations between the experiment and the field

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal length</td>
<td>1 mm</td>
<td>90 m</td>
</tr>
<tr>
<td>Vertical length</td>
<td>1 mm</td>
<td>56 m</td>
</tr>
<tr>
<td>Wind speed</td>
<td>1 mm/s</td>
<td>4.4 m/s</td>
</tr>
</tbody>
</table>
Numerical model

Coordinate transformation to $z^*$ coordinate

$x$-$z$ coordinate $\rightarrow$ $x$-$z^*$ coordinate

\[
\begin{align*}
z^* &= s \frac{z - z_G}{s - z_G} \\
G_1 &= \frac{\partial z^*}{\partial z} = \frac{s}{s - z_G} \\
G_2 &= \frac{\partial z^*}{\partial x} = \frac{z^* - s}{s - z_G} \frac{\partial z_G}{\partial x}
\end{align*}
\]
Numerical model

Momentum equation

\[
\frac{du}{dt} = -\frac{1}{\rho} \left( \frac{\partial p'}{\partial x} + G_2 \frac{\partial p'}{\partial z^*} \right) + \frac{\partial}{\partial x} \left( \nu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial x} \left( \nu G_2 \frac{\partial u}{\partial z^*} \right) + G_2 \frac{\partial}{\partial z^*} \left( \nu G_2 \frac{\partial u}{\partial z^*} \right) + G_1 \frac{\partial}{\partial z^*} \left( \nu G_1 \frac{\partial u}{\partial z^*} \right)
\]

\[
\frac{dw}{dt} = -\frac{1}{\rho} \frac{\partial p'}{\partial z^*} + \frac{<\rho> - \rho}{<\rho>} g + \frac{\partial}{\partial x} \left( \nu \frac{\partial w}{\partial x} \right) + \frac{\partial}{\partial x} \left( \nu G_2 \frac{\partial w}{\partial z^*} \right) + G_2 \frac{\partial}{\partial z^*} \left( \nu G_2 \frac{\partial w}{\partial z^*} \right) + G_1 \frac{\partial}{\partial z^*} \left( \nu G_1 \frac{\partial w}{\partial z^*} \right)
\]
Numerical model

Continuity equation

\[
\frac{\partial u}{\partial x} + G_2 \frac{\partial u}{\partial z^*} + G_1 \frac{\partial w}{\partial z^*} = 0
\]

Conversation equation of heat

\[
\frac{dT}{dt} = + \frac{\partial}{\partial x} \left( \alpha \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial x} \left( \alpha G_2 \frac{\partial T}{\partial z^*} \right) + G_2 \frac{\partial}{\partial z^*} \left( \alpha \frac{\partial T}{\partial x} \right) \\
+ G_2 \frac{\partial}{\partial z^*} \left( \alpha G_2 \frac{\partial T}{\partial z^*} \right) + G_1 \frac{\partial}{\partial z^*} \left( \alpha G_1 \frac{\partial T}{\partial z^*} \right)
\]
Flow fields by experiment and model

model

experiment

1mm/s 1 min/12 min.

Benard convection 3 min/12 min.
Flow fields by experiment and model

model

experiment

1mm/s

5 min/12min.

valley wind

1mm/s

7 min/12min.
Flow fields by experiment and model

<table>
<thead>
<tr>
<th>Model</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm/s</td>
<td>1 mm/s</td>
</tr>
<tr>
<td>9 min/12min.</td>
<td>11 min/12min.</td>
</tr>
</tbody>
</table>

mountain wind
Vertical temperature distribution by experiment and model

1 min. | 3 min. | 5 min.
---|---|---

unstable
Vertical temperature distribution by experiment and model.
Temperature fields by experiment and model

model

experiment

2 min.

4 min.
Temperature fields by experiment and model

6 min.

model

8 min.

experiment
Temperature fields by experiment and model

model

10 min.

12 min.

experiment
Conclusions

1. We performed the water tank experiment and the numerical simulation to analyze the mechanism of the high air pollution concentration in Katmandu valley.
2. The flow and temperature in the water tank experiment were reproduced by the numerical simulation.
3. It is the next object that the real simulation of Katmandu valley will be carried out.