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Numerical simulation of diffusion in the stratified flow

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Abstract

Simulations of atmospheric diffusion process under stable and unstable conditions were carried out using both numerical and experimental methods. Results from the previous study show that numerical simulation using 3-dimensional incompressible Navier-Stokes equation and density deviation are in good agreement with typical plume pattern. In this study, we use experimental data of temperature and wind profile obtained from a thermally stratified wind tunnel as initial conditions for numerical simulation and compare the results.

Keyword: *stratified flow, plume diffusion,*

1. Introduction

Atmospheric conditions change radically within hours due to the effect of solar radiation and the other complicated weather conditions. Miyashita et. al [1)] and Iwagawa et. al[2)] investigated the typical plume patterns of exhaust gas coming out of a stack that called 'fanning' and 'looping' in stable stratified condition and unstable condition respectively by numerical simulation. They used a uniform wind velocity and the temperature profile based on the rapes late of the atmosphere. In this paper we use actual experimental data from a wind tunnel for the numerical simulation and evaluate the results quantitatively. In this paper, we use actual experimental data from a wind tunnel for the numerical simulation and evaluate the results quantitatively.

2. Governing Equations

Three-dimensional incompressible Navier-Stokes equation considering the density variance is used to solve the velocity field. A time development equation for the density is used to solve the temperature field.

$$\frac{\partial \rho'}{\partial t} + (V \bullet \nabla)\rho' + w\frac{\partial \rho_B}{\partial z} = 0 \qquad (1)$$

where ρ_B is the sum of standard density and ρ' is the density deviation.

$$\rho(x,y,z,t) = \rho_B(z) + \rho'(x,y,z,t) \qquad (2)$$

The Navier-Stokes equation is solved with Fractional step method. In these equations, truncation errors are in the third order.

Virtual particles are generated from a source point and moved using local velocity to simulate the plume behavior.

3. Calculation Scheme

In this study, we use the experimental data obtained from the thermally stratified wind tunnel as the initial conditions for both the temperature and wind profile in the numerical simulation. The domains are 2m x 1.2m x 0.8m for the unstable condition, and 5m x 0.8m x0.008m for the stable condition that assume the actual wind tunnel scale. The number of computational grid point is 100 x 50 x 50. Non-uniform grid system is employed.

Here the air is assumed to be an ideal gas so that the basic density is:

$$\rho_B = \frac{p_0}{R(T_0 - \gamma z)}\left(\frac{T_0 - \gamma z}{T_0}\right)^{\frac{g}{R\gamma}} \qquad (3)$$

where p_0 is the pressure at the sea level (=101325 pa) and T_0 is the temperature corresponding to p_0 whereas R and γ are the gas constant ($287\,J/kg°C$) and the dry adiabatic lapse rate respectively. We select a large temperature gradient in order to satisfy the similarity theory in the wind tunnel and to make the value of γ changes with height. The γ values are -2000deg/m near the ground and -200deg/m higher in the stable condition, while the actual value in the atmosphere is -0.06deg/m.. The initial condition for pressure distribution is calculated with the following equation based on the floor level pressure p_0 and temperature T_0.

$$p(z) = p_0 - \rho_B g dz = p_0\left(1 - \frac{g \cdot dz}{R \cdot T(z)}\left(\frac{T(z)}{T_o}\right)^{\frac{g}{R\gamma}}\right) \qquad (4)$$

For the boundary conditions, it is assumed the $v = w = 0$, and $\rho_B = 0$, that the inlet flow is set to be the initial wind tunnel u profile. All parameters in the outlet flow and the upper part (ceiling) are the same as in the previous grid and non-slip condition ($u = v = w = 0$ and $\rho_B = 0$) is assumed at the floor level.

4. Results

The distribution of density deviations, which grows from the lower while the values in the initial condition are all zero. The density deviations change intensely with time in unstable condition, while it changes gradually in stable condition. A particle trace method is adopted to visualize the plume patterns. The particle path in the y-z plane is shown in Fig.1and Fig.2. Particles move with local velocity and the particle path change intensely with time. In unstable condition particles rise rapidly and disappear beyond the top of the calculation domain, and those are distributed in lateral direction. In stable condition particle path not much change is observed after a long period of time as same as wind profile change.

5. Conclusion

We use wind profile and the temperature distribution in the wind tunnel which is hundreds times larger than that in the real atmosphere as inlet conditions but the simulated flow patterns are in good agreement in both stable and unstable conditions.

In future, we will carry out quantitative evaluation of the plume spread with experimental data that is consistent with the atmospheric data.

References

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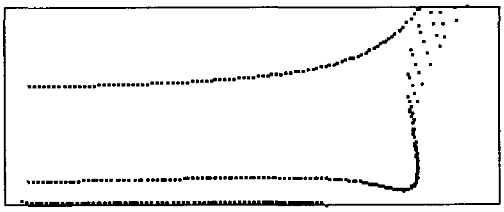

Fig.1 Particle pathes in Unstable condition

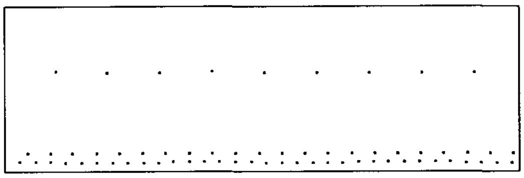

Fig.2 Particle pathes in Stable condition