CHAPTER 2

LITERATURE REVIEW

To date, the advective transport and dispersion of air pollutants over a complicated terrain are understood only to a limited extent because the non-planar topography increase the complexity of flow and diffusion characteristics over the area. Consequently, many researchers have attempted to elucidate the flow structure and plume diffusion by adopting experimental and/or theoretical approaches and developing the good practical models for predicting the pollutant dispersion over a complex terrain.

2.1 Experimental Study

To gain better the understanding of the airflow and air pollutant dispersion characteristics over a complex terrain, many researchers, e.g. Brian Lamb et al.(1984) and Edward E. Hindman et al.(2002) etc., relied on field observations. However, the approach is quite laborious and expensive, so the wind-tunnel experiment is one of the alternative means because it is powerful tool for investigating airflow and pollutant diffusion over complex topography and is inexpensive costs. Hence, there are many experimental studies of airflow and pollutant diffusion over a complex terrain in the wind tunnel.

Brian Lamb, W. Ryan, and Elmer Robinson (1984) experimentally studied plume transport over and around an isolated hill in various atmospheric conditions in order to document plume characteristics of the source emissions. Twenty-one single and dual tracer tests were carried out at Steptoe Butte, a 300-meter-height hill located in eastern Washington, during May and June, 1981. In all of these tests, tracer plumes were allowed to form continuously for slightly more than an hour at various release heights approximately 2 km. upwind of Steptoe Butte. Four tests were carried out during various times of several days using tracer released from the surface of the hill. From the tracer experiment results, they found that plumes released upwind during daytime near-neutral conditions traveled up and over the hill have maximum concentrations in the same range as the calculated from a model for neutral flow over a hemisphere. Plumes released upwind during transitional day-to-night conditions exhibited maximum concentrations similar to the daytime releases, but the tracer isopleths indicated some plume bifurcation. The study results obtained for the night-time stable condition confirmed that plumes released above the dividing streamline height tend to travel up and over the hill while plumes released very near or below that height tend to impinge upon the hill.

R. Ohba et.al.(1990) investigated air flow and gas diffusion in neutrally and stably stratified flow over a complex terrain using wind tunnel experiments to compare with similar tracer experiments reported by B. Lamb et al.(1984). In order to compare wind tunnel results with reported field data, gas concentrations measured in the former were computationally superposed using probability distributions for the wind direction. Their superposition results provided good agreement with the field data.

K. Kitabayashi (1991) conducted wind tunnel experiments to simulate the behavior of airflow and air pollutant diffusion around a rather isolated hill. The topographical model was constructed in scale of 1/7500 and 1/5000 times Mt. Tsukuba for the horizontal and vertical direction, respectively. The effects of source height and atmospheric stability (i.e. adiabatic or neutral and stable conditions) on plume transport and diffusion were investigated. It was clear that the transport and diffusion in adiabatic and stable conditions were totally different. Under an adiabatic condition plume diffused to the lee side due to the wake formed there, whereas, the plume was blocked by the peak and divided in two regions around the peak under a stable condition. As for the interactive effect of source height and stability condition, it was found that for a source higher than the inversion layer, the plume trajectory under stable and adiabatic conditions was essentially in different. On the other hand, for a source lower than the inversion layer, the plume transport was separated by the peak and moved around the peak under a stable condition, but under an adiabatic condition the plume passed over the peak.

William H. Snyder et al.(1991) described and compared the results from the wind-tunnel experiments and a theoretical model concerning the flow structure and pollutant diffusion under the neutral atmospheric boundary layer over two-dimensional valleys of varying aspect ratio. Three valley models were used, having gentle, medium, and steep slopes. They found that the wind tunnel experiments provided a reasonable simulation of the flow structure and diffusion characteristics in the neutral condition. The wind tunnel experiment results reveal that in the valley with gentle slope, its flow characteristics were relatively smooth and well-behaved. On the other hand, the steeper slope the valley has, the more its flow structure separates intermittently, but not in the mean. Moreover, in the sharply steep valley, a recirculating flow was also formed within the valley. Pollutants released at the same relative locations within each of these valleys behave very differently from one another, and the resulting surface concentration patterns are dramatically different. The data from the above experiments were also compared with the results of a mathematical model for treating flow and dispersion over two-dimensional complex terrains. The model used the wind tunnel measurements to generate mean flow field and eddy diffusivities, and these were applied in the numerical solution of the diffusion equation. Measured concentration fields were predicted reasonably well by this model for the valley of gentle slope and somewhat less well for the valley with medium slope. Because of flow separation within the steepest valley, the model was not applicable in this case.

Edward E. Hindman and Bidur P. Upadhyay (2002) investigated if air pollution generated in the Himalayan foothills reached higher elevations. Surface air pollutant concentration measurements were made between October 1995 and May 1996. Measurements were made in the Kathmandu valley of the foothills, in the Dudh Kosi valley of the eastern Himalayas and at the base of Mt. Everest in Nepal and Tibet. The Kathmandu valley measurements revealed a semi-diurnal variation of the pollutant and moisture in the mountain-valley wind system and a reduction of both by strong afternoon convection. The air was polluted at all times in the valley. The Dudh Kosi measurements revealed a diurnal variation in the pollutant and moisture; both were drawn into the valley by the strong afternoon valley wind, and cleaner and drier air flowed into the valley with the nighttime mountain wind. The air was unpolluted in the mornings but frequently polluted in the afternoons and evenings; some of the evening pollution was from local sources. The pollutant concentrations in Tibet were smaller than in Nepal at the same elevation due to dilution in the late afternoon convective boundary layer in Tibet. The results for the Himalayas pollution transport showed that a 7-h pollution episode originating in Nepal was advected into Tibet and a 18-h episode originating in Tibet was advected into Nepal.

2.2 Modeling Study

Since mathematical modeling and simulation are a handy and effective tool, the prediction of air pollutant concentration and better understanding in the atmospheric dispersion processes and airflow structures in a complex terrain with the use of mathematical models are of great interest for many applications (e.g. the environmental impact assessment of continuous and/or accidental releases). At present, the air quality models are divided into 2 main branches: deterministic and stochastic models. The former is based on fundamental mathematical descriptions of atmospheric processes, in which effects are deterministically generated by causes. The latter is based upon semiempirical statistical relations among available data and measurements. One of the deterministic models, the CFD approach, conventionally applied by numerous researchers (e.g. David D. Apsley (1997) and Jan Burman (1998)). The Langrangian dispersion models based on the random walk process, e.g. RADM, ARCO, and SPRAY, etc., are also widely used. The RADM model developed by EPA is applicable to both point and area sources. The ARCO and SPRAY models were capably tested by D. Anfossi et al. (1998).

Leif Enger and Darko Koracin (1995) applied a three-dimensional higher-order closure dispersion model to simulate dispersion from an elevated point source in an area with complex terrain in the Colorado River Valley (southwestern U.S.). The wind, temperature and turbulence fields predicted by the fluid dynamics model were used as inputs to the dispersion model. Equations of the second-order closure dispersion model were solved in a horizontal polar coordinate system with its origin at the source in order to obtain a grid that was denser, closer to the source than further downstream. As for the modeling study, it consists of 2 significant parts. First, the simulated SO_2 concentrations were compared with surface and aircraft data collected on 16 and 26 June 1986.They found that the simulated SO_2 concentrations agree reasonably well with both the measured surface and aircraft data. Second, the dispersion model revealed the highly complex structure affected the evolution of the plume in this type of topographic forcing. It was shown that the plume quite frequently divided into two separate parts because the wind field diverged over this complex terrain.

David D. Apsley and Ian P. Castro (1997) used a SWIFT (Stratified Wind Flow over Topography) model, a finite-volume, incompressible, Navier-Stokes solver, using cartesian velocity decomposition on a staggered grid and a pressure-correction method to satisfy the continuity equation, for the prediction of flow and dispersion over hills. In order to yield satisfactory wind speed profiles (wind power) and terrain-amplification factors (dispersion applications), suitably-modified k-ε turbulence models were adopted. Furthermore, the sensitivity of ground-level concentration to wind direction was studied and found to be extremely strong.

Jan Burman (1998) used a CFD model to study how different structures at the side of the road influence concentration levels using three different scenarios: solid fence, hedge and road-valley. He found that a solid fence gave the strongest effect on the concentration level because it forced the mean flow to move vertically which promoted mixing in the wake behind the fence, so it decreased the concentration level. A hedge reduced the level of turbulence and the level of concentration becomes higher due to less turbulent dispersion. A road-valley generated turbulence in an intermediate regime and captured a part of the plume in the valley which gave high concentration locally. As for atmospheric stability, it increased the concentration level at a distance from the topographical disturbance. A heavy gas plume encountering the solid fence was broadened in front of the fence depending on the height of the fence and internal stability in the plume. The interactions between these parameters, the wind speed and the source rate also affected the level of concentration downwind the fence.

Yukimasa Takemoto et al.(1998) simulated dispersion of SO_2 over Yokkaichi area (non-planar topographical area) using a CFD model based on generalized coordinates and the finite difference technique. In order to enhance the precision of modeling they transformed a general coordinate system adapted to the topography (curvilinear coordinates) to the rectangular coordinate system and also calculated the wind velocity field and unsteady pollutant diffusion by means of a high-precision finite difference scheme using a 3D generalized coordinate along the topography of the ground. They found the trend of computational results to agree well with the observed data (in 1973) in their year-averaged concentration analysis of sulphur dioxide.

D. Anfossi et al. (1998) tested the efficiency of two 3D Langrangian particle models (ARCO and SPRAY) by comparing their simulation results with data collected from a tracer experiment carried out in the Alpine region located in the Ticino river valley (Southern Switzerland) during October 1989. The topography of the site consists of two narrow deep valleys departing from the tracer release point, one in direction north (Blenio Valley) and one in direction northwest (Leventina Valley), and surrounded by various tall mountains. They found that the Lagrangian particle models were not able to describe the whole complexity of phenomena observed from the experiment, due to the simplicity of the mass-consistent models, the limited number of meteorological and turbulence measurements and the rather steep and complicated topography. However, keeping in mind these limitations, they were able to describe the overall structure of the dispersion phenomena in a reasonable way and the models can be applicable for practical purposes.

Hyun Sun Oh and Young Sung Ghim (2001) investigated diurnal variations of wind field and pollutant dispersion in a complex terrain with a shoreline under the insolation conditions of summer and winter. The area is located in the south of the Korean Peninsula and includes a large petrochemical industrial complex. The Region Atmospheric Modeling System (RAMS) was used in the simulation study. Initial horizontal homogeneous wind fields were assumed on the basis of sounding data at the nearby upper-air station for those days with morning wind speeds below 2 m/s. The predicted pollutant concentrations were high almost all over the area in the morning both in the summer and winter. In the afternoon, pollutant concentration was not significant mainly because of the development of a mixing layer, which also greatly alleviates the terrain effects.