MODELING OF ATMOSPHERIC TRANSPORT AND FUMIGATION AT SHORELINE POWER PLANT SITES

Robert N. Meroney
Fluid Mechanics and Wind Engineering Program
Colorado State University

## INTRODUCTION

When air blows over a cold water surface, the lower layers of the atmosphere are cooled and an inversion develops to a depth of from 30 to 300 m. During an onshore wind this stable marine layer is heated from below after crossing the coastline, creating a superadiabatic lapse rate in the lower levels while retaining a stable condition above. With increased distance from the shoreline, the heated region, or mixed layer, grows vertically until the original stable layer is destroyed. If a tall stack associated with a power plant that is located near the shoreline discharges into the elevated stable layer, the plume initially disperses slowly as it moves downwind. At some point inland, the mixing layer extends upward to the plume level. At this point, material in the plume mixes rapidly downward to cause "fumigation" and high concentrations at ground level (1,5,6,7,8,3, and 12). The determination of the spatial extent of the diffusion transition zone becomes an important aspect of the environmental evaluation of industry, fossil-fuel power plants, and nuclear reactors located at coastlines.

## MODELING THE "ONSHORE WIND"

When vertical motion of plumes takes place in an atmosphere with thermal stratification, additional requirements must be met to achieve similarity of the atmospheric motion. These requirements have been discussed by Yamada and Meroney (1971), and SethuRaman and Cermak (1973). Similarity of the stably stratified flow approaching the power plant over a body of water can be achieved by requiring equality of the bulk Richardson number

$$Ri_B = g \frac{\Delta\theta}{T} \frac{\delta}{V_a^2} \qquad (1)$$

for the laboratory flow and the atmosphere. In this expression, $\Delta\theta$ is the difference between mean temperature (potential temperature for the atmosphere) at the surface and at the height $\Delta$, $T$ is the average temperature over the layer of depth $\delta$ and $g$ is the acceleration due to gravitational attraction.

The similarity between the flow-generating mechanisms of sea breezes and flow over "urban heat islands" suggest governing boundary parameters. Linear numerical analysis of Olfe and Lee (1971a,b) and experimental and numbercal studies by Yamada and Meroney (1971) suggest the intensity of heating by the land surface may be characterized by a heating ratio

$$HR = \frac{(T_{land} - T_{sea})_{z_1}}{(T_{z=L_z} - T_{z=z_1})_{over\ sea}} \cdot \frac{L_z}{L_x} . \qquad (2)$$

Since the vertical-to-horizontal modeling scale is undistorted, the parameter reduces to a single temperature ratio.

A survey was made of available meteorological data which typified "sea breeze fumigation" situations in the Great Lakes area (6,7,5, and 8). Only two of four experimental realizations appeared complete enough to estimate the required parameters $Ri_B$ and HR. It would appear that laboratory values to examine are:

1/ $Re = \frac{\rho_a V_a L_z}{\mu_a} > 11,000$

2/ $Fr = \frac{\rho_a V_a^2}{\Delta\gamma D_s}$; $(Fr)_m = (Fr)_p$

3/ $R = \frac{V_s}{V_a}$; $R_m = R_p$

4/ $(z_o)_m = (z_o)_p$

5/ Similar velocity and turbulence profiles upwind

6/ HR = 1.3 ~ 1.9

7/ $Ri_B$ = 1.25 ~ 1.5

It has been found that other turbulence scales such as intensities and spectral shapes will generally be reproduced satisfactorily if the fourth and fifth conditions are maintained over a sufficiently long fetch (5).

## WIND-TUNNEL EXPERIMENT AND INSTRUMENTATION

The meteorological wind tunnel (MWT) in the Fluid Dynamics and Diffusion Laboratory, Colorado State University was used for the study.

For this hypothetical power plant study, geometric similarity is satisfied by an undistorted model of length ratio 1:400. This scale was chosen to facilitate ease of measurements, provide a boundary-layer equivalent to 240-300 m for the atmosphere and minimize wind-tunnel blockage. The model consisted of the hypothetical power station, the stacks, and the auxiliary buildings constructed from aluminum to a linear scale of 1:400. Only two wind approach angles were examined for the fumigation study--onshore and 60 deg to the shoreline. A set of vortex generators were installed 0.6 m downwind of the entrance to give the simulated boundary and initial impulse of growth. Between 1.8 and 12 m downstream, a set of 12 roll-bond aluminum panels were placed on the tunnel floor. These panels were connected to the facility refrigeration system and cooled to approximately 0 deg C. From 12 m to the end of the test section, a permanently installed set of electric heaters was used to raise the aluminum floor temperature to a level prescribed by the heating ratio, HR. An array of ground-level sampling tubes permitted concentration measurements downwind to an equivalent field distance of 2400 m (see Figure 1).

## RESULTS AND DISCUSSION

### Test Results: Characteristics of Flow

Turbulence was essentially absent upwind over the sea surface as evidenced by the behavior of smoke plumes released over the cooled model lake surface. The profiles are conditioned by the heated land surface and the presence of the building complex. Turbulent well-mixed surface flow grows beneath the

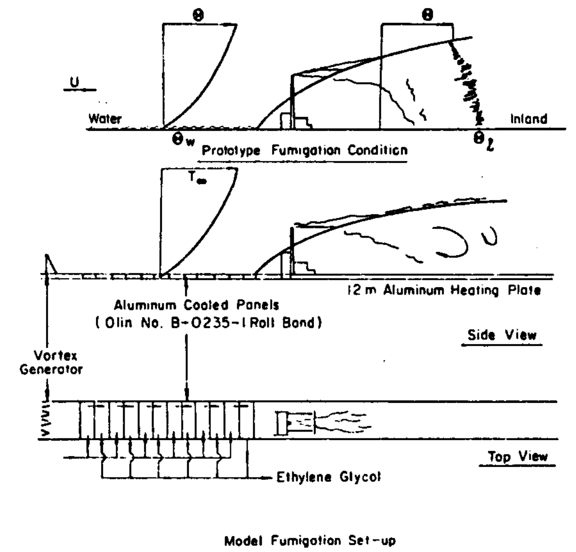


Fig. 1 Schematic diagram of model study of fumigation dispersion

capping stable lake air. Figure 2 displays the eroding effect of unstable air. The small thermistor temperature measuring device had a short time constant; thus the temperature fluctuations displayed are an indicator of the intensity of turbulence.

## Test Results: Concentration Measurements

Twenty-five ground level sampling locations were placed at distances equivalent to 300 to 2400 m downwind. Measurements of Krypton-85 activity at these locations have been converted to equivalent $\chi V_a/Q(m^{-2})$. Typical results for various sources, loads, wind angles, wind velocities, and surface heating rates are presented in Figures 3 and 4.

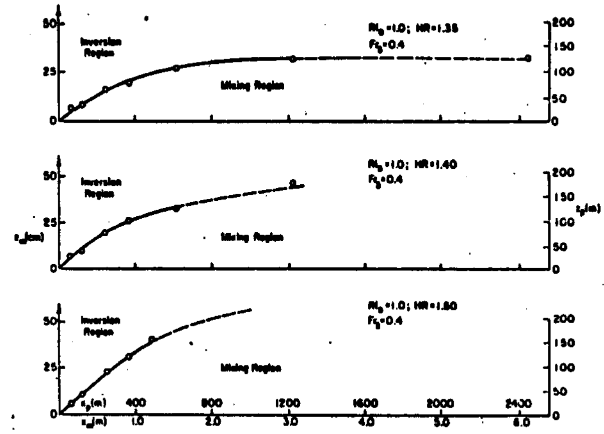


Fig. 3 Growth of the mixing layer at various floor temperatures

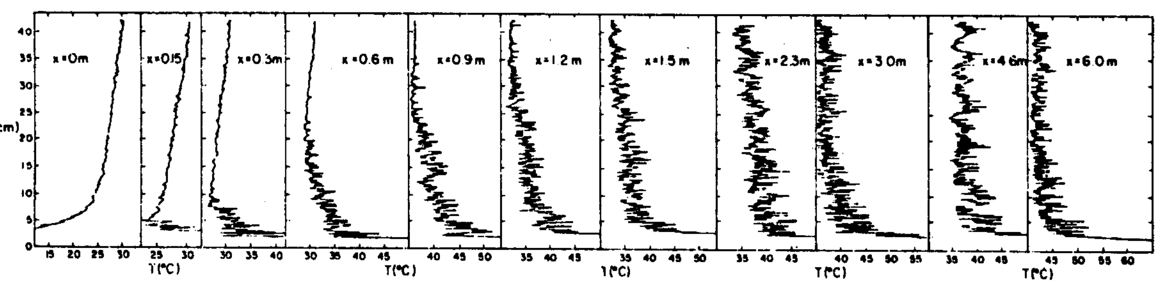


Fig. 2 Temperature profiles growing over simulated lake and level surfaces, $V_m = 0.6\ ms^{-1}$, $T_a = 43°C$, $T_w$ upwind = 0°C, $T_w$ downstream = 127°C

Figure 3 displays the boundary-layer growth for the three surface heating intensities studied. Initially the region grows at a rate proportional to downwind distance to the 0.8 power. Subsequently beyond about 300 to 600 scaled metres, the growth rate is proportional to downwind distance to the 0.5 power. The behavior of the initial region corresponds to previous experience over slightly roughened surfaces. The later growth rate corresponds to behavior noted by Prophet (1961) for sea- and lake-breeze systems and by Deardorff et al. (1969) for a laboratory study with penetrative convection of buoyant elements.

## Test Results: Visualization

The test results consist of photographs and movie sequences showing the nature of the air flow and diffusion in the vicinity of the power station. The more intense heating (HR - 1.5) accelerates the mixed layer growth and the entrainment of the plume. A decrease in hypothetical load from full to one-third has the same effect on the initial plume as does an increase in wind speed; however, the character of the surface mixed layer remains the same.

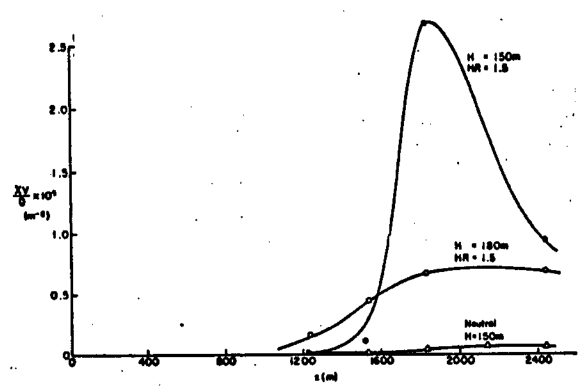


Fig. 4 Ground level concentrations Unit 2, Full load, Angle = -30°, Neutral vs. Model Sea Breeze, $V_a = 6.7\ ms^{-1}$

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