4. COOLING POND FOG STUDIES

B. B. Hicks*

4.1 INTRODUCTION

During the colder parts of the year, the generation of steam fog above exposed water surfaces is relatively common. For obvious reasons, the situation is considerably more frequent when the water surfaces in question are artificially heated. In the case of cooling ponds, the matter might be much more than a mere curiosity, since at times the fog generated above industrial cooling ponds might give rise to thick stratus from which precipitation might occur. For the purposes of predicting the susceptibility of a given proposed installation to fog-related problems, a number of factors concerning the planned cooling pond need to be determined. Clearly, the prevailing meteorological conditions will play a crucial part, but so must the characteristics of the pond itself, especially its surface temperature. Estimated surface temperatures are routinely obtained in the early stages of the planning process, normally as an output of some numerical model. Then these must be coupled with meteorological data obtained in the region of interest in order to develop statistics regarding the formation of fog. The present intent is to look into the matter of fog prediction and to test the applicability of the Fog Excess Water Index (FEWI) presented earlier by Hicks.[1]

A number of field studies have addressed the problem of cooling pond fog generation. Notable among these is the study reported by Currier et al.[2] of fog over the Coffeen and Four Corners cooling ponds. Currier et al. suggest the adoption of a Fog Index Number (FIN) defined as $(T_0 - T_a)/(e_0 - e_a)$. This property is found to be a good empirical indicator of fog intensity. However, it has been shown recently that there is some benefit in following the lead of cloud physicists and consider the excess water vapor in air that is thoroughly mixed above the surface under consideration. The average vapor pressure of this mixed air is clearly

*Atmospheric Physics Section, Radiological and Environmental Research Division, Argonne National Laboratory, Argonne, Ill.

$(e_0 + e_a)/2$. The mixing process will result in an average temperature $(T_0 + T_a)/2$. It is hypothesized that fog will occur whenever the average vapor pressure exceeds the saturated vapor pressure at the average temperature. These simple considerations led to the definition of the FEWI (or the excess vapor pressure, e_{xs}) as

$$e_{xs} = [e_s(T_0) + e_a]/2 - e_s[(T_0 + T_a)/2] \ .$$

The present purpose is to examine the practicality of this new fog index and to test it by use of recent field observations. As has already been pointed out (e.g., by Hicks and Shannon[3]), the data presented in some considerable detail by Currier et al. tend to support the new index rather than the old. Figure 4.1 illustrates this by comparing the ability of the two fog indices to differentiate between conditions of no fog and occasions in which some fog was reported. By selecting a value of about 0.7 mb for the excess water index, the error margin resulting from the Currier et al. data set is less than 8%. This is substantially less than the minimum error margin (about 18%) derived from the application of the FIN method to the same data.

ORNL–DWG 78–8309

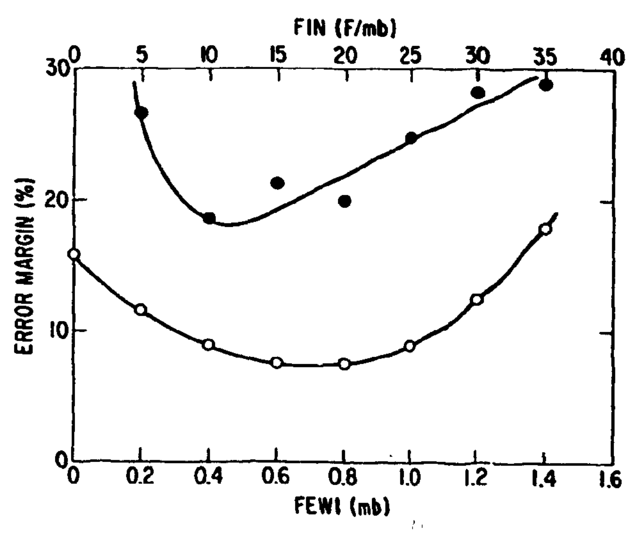

Fig. 4.1. A comparison of the Fog Index Number and the Fog Excess Water Index as indicators of the formation of steam fog. Data used are those of Currier et al.[2]

4.2 1974 "SIMULATOR" DATA

During 1974 and 1975, a pair of cooling pond simulators was operated at Argonne as part of a study of the efficiency of heat exchange from disturbed water surfaces. These simulators were each of about 10 m^2 area and were exposed in natural surroundings in a grassy field. The ponds were constructed of expanded polystyrene foam blocks of about 10 cm thickness so that conductive losses of heat through the sides were minimized. Each pond was lined with black polyethylene sheet in an attempt to simulate the radiative properties of deeper water and was filled with clean filtered water to a depth of about 10 cm. Electrical heater cables laid along the bottom of each pond generated heat at adjustable rates up to about 5 kW. The data reported here were obtained by the use of one simulator in which a series of sunken perforated pipes allowed air to be ejected in fine streams of bubbles along rows spaced about 20 cm apart. In the case of this particular pond, therefore, the subsurface thermal film that had been a problem in some previous studies was eliminated.

Figure 4.2 shows that the fog observations made in conjunction with the simulator studies confirm the main points of the earlier arguments. However, it is clear that in this particular case the theoretically based criterion of zero for the excess vapor pressure is far more satisfactory than the empirical value of 0.7 mb derived from the Currier et al. data. This finding tends to support the theory that the subsurface thermal film controls this matter. It should be noted, in passing, that there is no evidence of a wind speed effect in Fig. 4.2, as indeed was the case in the earlier investigations of Coffeen and Four Corners data.

4.3 1976 DRESDEN OBSERVATIONS

Also shown in Fig. 4.2 are the results of a number of fog observations made at the Dresden cooling lake (near Morris, Ill.) of the Commonwealth Edison Company. The number of data points is quite small; this first winter of the ANL fog-observation program was exceedingly cold and a considerable number of logistic and technical difficulties arose

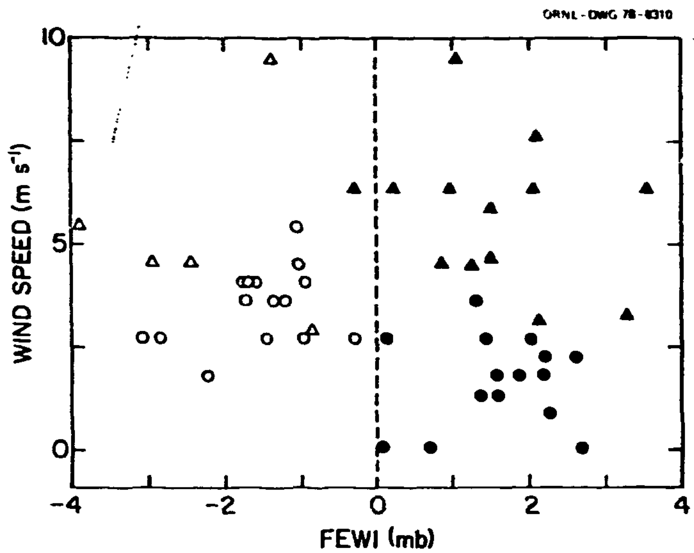

Fig. 4.2. Results of some recent tests of the ability of the Fog Excess Water Index to predict the formation of steam fog above heated water surfaces. Solid symbols indicate occasions in which fog was observed.

(q.v. Everett and Zerbe[4]). The plotted values are derived from water temperatures measured by an immersed thermometer and air temperatures and humidities measured upwind of the fog area by means of a hand-held psychrometer. This limited data set confirms the general picture developed so far, but it is not clear whether the observations support the theoretical 0-mb criterion or the empirical 0.7-mb one. Once again, there is no obvious influence of wind speed.

As a caustic test of the excess vapor pressure method, an attempt has been made to relate fog observations made at Dresden to ambient temperature and humidity data reported at the nearest meteorological observing station, some 60 km distant at Argonne National Laboratory. For this purpose, accurate surface temperatures of the cooling pond are critical, and hence it has been necessary to employ data recorded by an automatic system centrally located in the warmest subpond of the Dresden lake. Scrutiny of the data shows that the FEWI provides a good method for ordering the density of observed fog except in the early morning. The reason for difficulties to be encountered immediately following sunrise is not clear, but it is possible that at these times the tacit assumption of horizontal homogeneity over a distance of 60 km is quite wrong. Figure 4.3 illustrates the ability of the present methods to explain fog observations at Dresden in this manner, on the basis of meteorological data obtained at Argonne. Only observations made after 9 AM local time have been included. The data seem to support the use of the 0.7-mb criterion or even a slightly greater value.

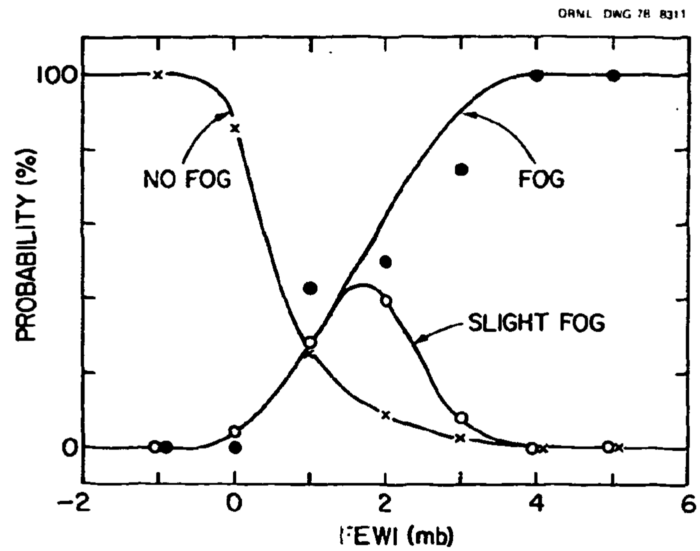

Fig. 4.3. The probability of finding fog, slight fog, or no fog above the Dresden, Illinois, cooling pond, based on meteorological data reported at Argonne.

4.4 STABILITY REGIMES ASSOCIATED WITH COOLING PONDS

The development of an improved method for predicting the formation of steam fog above cooling ponds presents only a partial answer to the more general problem of estimating the downwind visibility and riming effects. In the past, a number of attempts to apply the simple Gaussian-plume models favored by air pollution meteorologists have been made. However, a moment's thought will verify that the large instabilities that are characteristic of flow over heated surfaces of any kind will have a major effect on the dispersion of fog. The data set presented by Currier et al. is sufficiently complete that a comparison between micrometeorological stability parameters and the stability classification scheme common in numerical modeling circles is possible. Table 4.1 lists the average values (and standard errors) of the Obukhov scale lengths L deduced from the tabulated data and sorted according to stability classification. An infinite value of L would indicate neutrality; positive values indicate stability and negative instability. As expected, no stable occasions can be identified. The methods used in deriving L, described elsewhere,[5] require that the wind speed be above 1 m/s (since otherwise conditions are either too stable or too unstable to be accommodated by contemporary formulations). Consequently, the most unstable data are omitted from Table 4.1. Nevertheless, it is clear that the association of stability categories C, D, E, and F with most of the occasions is rather misleading, although they are possibly accurate indications of stability regimes surrounding the hot water surfaces. To address the net effect of strongly heated surfaces embedded in prevailingly stable (or at least near-neutral) flow requires the use of far more complex modeling methods, such as the second-order closure schemes presented by Yamada.[6]

Table 4.1. Average values of the Obukhov scale length L corresponding to the Currier et al.[2] stability classes[a,b]

Stability class	L (m)	Number of values
A		0
B	−0.29 ± 87%	3
C	−0.32 ± 21%	18
D	−1.27 ± 23%	41
E	−0.33 ± 31%	7
F	−0.14 ± 14%	11

[a]Currier et al. identified these stability classes as appropriate for their Coffeen and Four Corners cooling-pond data.

[b]Only data associated with reported wind speeds greater than 1 m/s have been analyzed; the remaining occasions are all highly unstable (i.e., L is exceedingly small and negative).

No matter what scheme is adopted for investigation of the dispersion of fog emanating from a cooling pond, it is critical that the stability parameter employed take the buoyancy of water vapor into account. It seems grossly illogical to omit this factor when the main aim is to study the dispersion of the water itself.

4.5 CONCLUSIONS

The FEWI method of fog prediction has been verified by the use of data obtained at the Dresden cooling pond during 1976 and 1977 and by a reanalysis of observations made in conjunction with a study of cooling pond simulators during 1974. For applications in which the method is applied to measurements or estimates of bulk water temperature, a critical value of about 0.7 mb appears to be most appropriate. The present analyses confirm the earlier finding that wind speed plays little part in determining the susceptibility for fog generation.

The extension of the philosophies that enter into the derivation of the FEWI to the case of downwind fog dispersion and riming is a matter that remains to be investigated. Field investigations planned for the coming winter will start to address this problem.

4.6 NOMENCLATURE

e_a	ambient vapor pressure (mb)
e_0	surface vapor pressure (mb)
$e_s(T)$	saturated vapor pressure at temperature T (mb)
e_{xs}	excess vapor pressure (mb)
FEWI	Fog Excess Water Index (mb)
FIN	Fog Index Number (°C mb^{-1})
L	Obukhov scale length (m)
T_a	ambient temperature (°C)
T_0	surface temperature (°C)

4.7 ACKNOWLEDGMENTS

J. D. Shannon, R. G. Everett, and G. A. Zerbe of Argonne National Laboratory made most of the observations reported here. W. P. Pogliano made the visual fog observations at Dresden.

References

1. B. B. Hicks, "The Prediction of Fog over Cooling Ponds," *J. Air Pollut. Control Assoc.* 27, 140–42 (1977).
2. E. L. Currier, J. B. Knox, and T. V. Crawford, "Cooling Pond Steam Fog," *J. Air Pollut. Control Assoc.* 24, 860–64 (1974).
3. B. B. Hicks and J. D. Shannon, "A New Cooling Pond Fog Index," *Argonne National Laboratory Radiological and Environmental Research Division Annual Report, January–December 1976*, ANL-76-88, Part IV, pp. 104–107 (1977).
4. R. G. Everett and G. A. Zerbe, "Winter Field Program at the Dresden Cooling Ponds," *Argonne National Laboratory Radiological and Environmental Research Division Annual Report, January–December 1976*, ANL-76-88, Part IV, pp. 108–113 (1977).
5. B. B. Hicks, M. L. Wesely, and C. M. Sheih, "A Study of Heat Transfer Processes above a Cooling Pond," *Water Resources Res.*, in press (1977).
6. T. Yamada, "A Preliminary Result of a Three-Dimension Numerical Simulation of Cloud Formation over a Cooling Pond," *Proceedings, 2nd AIAA/ASME Thermophysics and Heat Transfer Conference, Palo Alto, California, May 24–26, 1978.*