Journal of Engineering Physics and Thermophysics, Vol. 74, No. 4, 2001

MODELING OF HEAT AND AEROSOL DISCHARGES OF POWER COMPLEXES INTO THE SURROUNDING MEDIUM

A. A. Andrizhievskii, A. G. Lukashevich, and A. G. Trifonov

UDC 621.039+551.510.42

The sources of possible technogenic pollution of the atmosphere near power units are discussed. A procedure for evaluating the interaction of cooling-tower plumes with technogenic discharges of power units and with other pollutants of the atmosphere is presented. Results of a series of computational experiments as applied to an analysis of the action of the discharges of cooling towers on the aerosol discharges of ventilation systems of nuclear power plants (NPPs) are reported.

Along with harmful pollutants, a great amount of vapor-drop moisture is discharged into the atmosphere from many industrial sources of pollution of the air basin. In this connection, the problem of the influence of moisture discharged in great amounts from cooling towers, which are a part of the cooling systems of power complexes, is of special interest. Moreover, the use of cooling towers brings about a number of environmental problems. One of the most serious problems is interaction of the discharges of moisture with the discharges of impurities from nearby technogenic sources. As a result, the impurities undergo redistribution, and pollution of the near-ground layer considerably increases [1–3]. Therefore, in investigating the propagation of moisture from a source it is important to determine not only the condensation zone but also the microstructure of the formed cloud of drops in order to subsequently evaluate their influence on the propagation of the impurity from the source.

In the present work, we discuss methods of describing the dynamics of technogenic sources of heat and aerosol discharges from power complexes into the surrounding medium. The methods are constructed with the use of evolution models of ecological systems.

Basic Models. As the basis for modeling a transport flow and a transported dispersed impurity in the problem of description of the interaction of vapor-drop structures with technogenic discharges of power complexes, we used a system of nonstationary conservation equations for individual phases which is solved simultaneously with the equations that describe the processes of interphase transfer and the dynamics of interphase surfaces [4].

To model the dynamics of the transport flow in a longitudinal section, the following system of conservation equations is adopted:

$$\frac{\partial \rho W_i}{\partial x_i} = 0 \,, \tag{1}$$

$$\frac{\partial W_i}{\partial t} + W_j \frac{\partial W_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu_{\mathrm{e}} \frac{\partial W_i}{\partial x_j} - \overline{W_i' W_j'}\right) + g_i\,\delta_{ij} \,, \tag{2}$$

Institute for Problems of Power Engineering, National Academy of Sciences of Belarus, Minsk, Belarus; email: tral@sosny.bas-net.by. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 4, pp. 77–80, July–August, 2001. Original article submitted September 11, 2000.

$$\frac{\partial T}{\partial t} + W_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j}\left(a_{\mathrm{e}} \frac{\partial T}{\partial x_j}\right), \tag{3}$$

$$\frac{\partial N_{\mathrm{p},n}}{\partial t} + (W_{\mathrm{p},n})_j \frac{\partial N_{\mathrm{p},n}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D_{\mathrm{p},n} \frac{\partial N_{\mathrm{p},n}}{\partial x_j}\right) + J_{\mathrm{p},n}\,, \tag{4}$$

$$N_{\mathrm{p}} = \int\limits_{L_{\min}}^{L_{\max}} [\tilde{N}_{\mathrm{p}}\,(L_n)]\, N_{\mathrm{p},n}\, d\,(L_n)\,. \tag{5}$$

Convective-diffusive transfer of technogenic impurities in dissolved form (inside drops) is described by the equation

$$\frac{\partial N_{\mathrm{d}} C}{\partial t} + W_{\mathrm{d},j} \frac{\partial N_{\mathrm{d}} C}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D_{\mathrm{d}} \frac{\partial}{\partial x_j}\,(N_{\mathrm{d}} C)\right) - \lambda_{\mathrm{d}} N_{\mathrm{d}} C - (J)_{\mathrm{d}} \tag{6}$$

using the drop size-distribution function

$$\frac{d\,(N_{\mathrm{d}})}{d\,(d^*)} = 4\,(d^*)^2 \exp\left\{-2d^*\right\}. \tag{7}$$

To calculate the efficiency of deposition of particles in the case of a gas flow past a sphere, the following relations were suggested for the diffusion and inertia mechanisms, respectively [5]:

$$\eta_{\mathrm{D}} = 2\,\sqrt{2}/(\mathrm{Pe})^{1/2}\,, \quad \eta_{\mathrm{in}} = \left(\frac{\mathrm{Stc}}{\mathrm{Stc} + 0.35}\right)^2, \tag{8}$$

here the turbulent diffusion coefficient is taken to be equal to the coefficient of turbulent viscosity $D_{\mathrm{p}} = \nu_{\mathrm{e}}$.

For a complete description of migration processes in conjugate regions (source–transport flow, transport flow–external region, transport flow–earth surface), the basic model mentioned above must be supplemented with: (a) the description of volume heat and mass sources; (b) the corresponding initial and boundary conditions.

Modeling of Possible Sources of Technological Discharges (Test Examples). A procedure for evaluating the possible interaction of technological discharges of power units and other pollutants of the atmosphere is constructed on the basis of the RELEASE program package and its constituting models describing the dynamics of the near-surface migrations of technogenic impurities in the atmosphere.

The computational package RELEASE is implemented on personal computers with the use of the integrated medium of the developer FORTRAN POWER STATION 4.0 for the Windows-95 and Windows-NT operating systems.

For a complete description of the migration processes of technogenic impurities in conjugate regions (source–transport flow, transport flow–external region, transport flow–underlying surface), the RELEASE program package is supplemented with the description of the volume heat and mass sources of technogenic discharges and with the corresponding initial and boundary conditions, including: (a) a set of geometric characteristics of a modeled device; (b) a set of flow-rate parameters at the inlet; (c) the characteristics and location of the sources of the dispersed phase; (d) the initial and boundary thermodynamic parameters.

As a test for modeling of industrial discharges, we employed a dry cooling tower (heat discharge) and a containment (aerosol discharge).

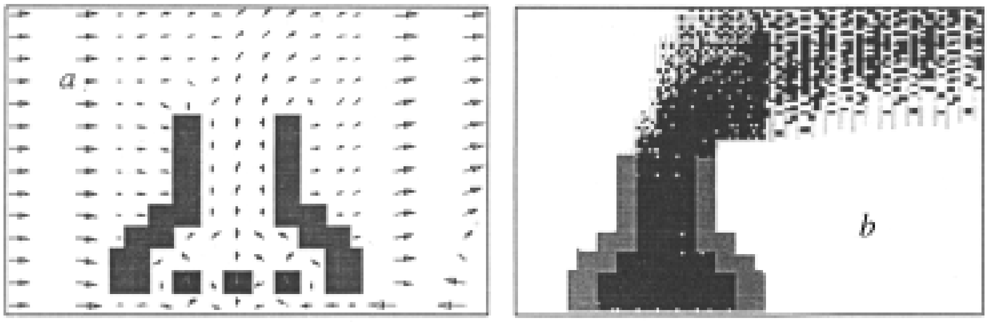

Fig. 1. Heat discharge of a dry cooling tower: a) velocity field; b) temperature field.

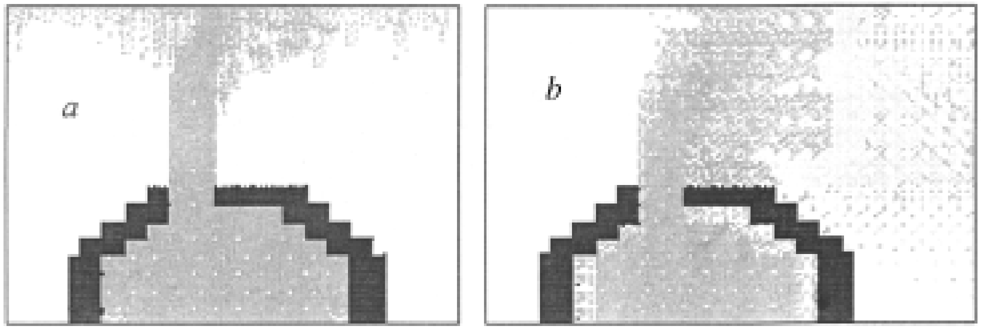

Fig. 2. Aerosol discharge from under the containment casing: a) initial stage of the discharge; b) stage of reaching the quasistationary parameters.

Dry cooling tower and its parameters:
- velocity in the outward flow, 30 m/sec,
- discharge temperature, 50^oC,
- discharge height, 160 m,
- base diameter of the cooling tower, 200 m,
- outlet diameter of the cooling tower, 120 m,
- velocity of the external wind flow, 3 m/sec.

Containment and its parameters:
- range of the size distribution of ejected drops, 1–10 μm,
- discharge temperature, 200^oC,
- containment diameter, 60 m,
- velocity of the external wind flow, 3 m/sec.

Figure 1 illustrates application of the computational package RELEASE to modeling of heat discharge from the tank of the dry cooling tower, while Fig. 2 shows its application to modeling of aerosol discharge from under the containment casing. The more intense color in Figs. 1 and 2 depicts higher values of the temperature, concentration, and velocity.

As far as the modeling of the heat discharge from the dry cooling tower is concerned, in this case the mechanism of thermoconvective heat transfer in the outer medium prevails. In modeling of the aerosol discharge from under the containment casing it is necessary to distinguish two stages of this process:

(a) with the prevailing effect due to the initial pressure difference (about 4 atm) under the containment casing and the outer medium at the moment of its failure (dynamic discharge, Fig. 2a);

(b) with the prevailing thermoconvective mechanism of discharge (reaching the quasistationary parameters, Fig. 2b).

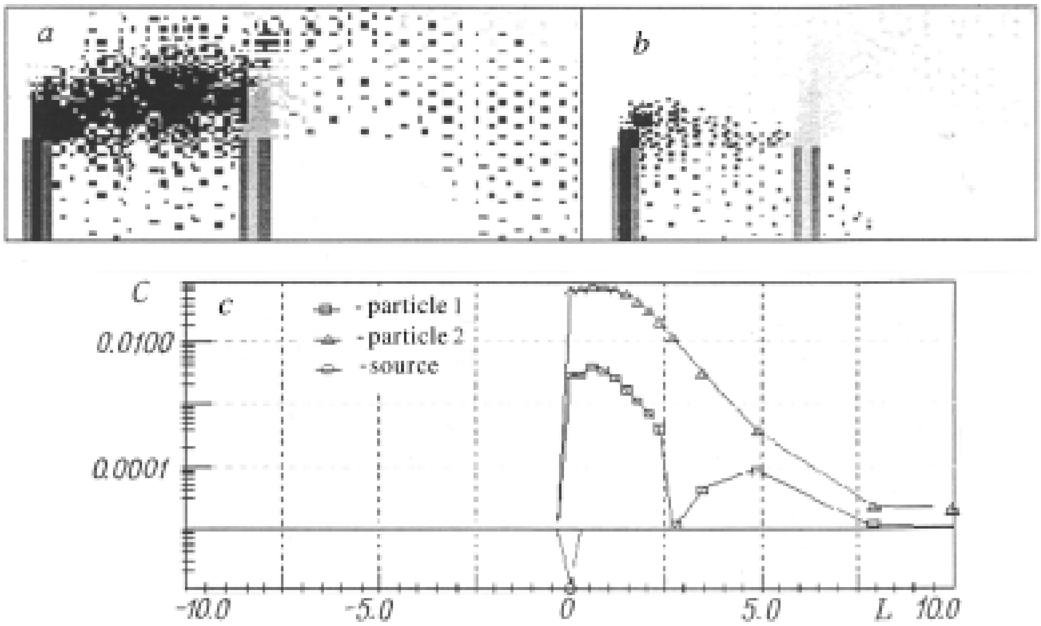

Fig. 3. Interaction (in the direction of wind flow) of cooling-tower plumes with the technogenic discharges of power plants (fragments a, b, and c are described in the text): *C*, concentration (dimensionless) of aerosol particles (particles 1 and 2) and of drops (a source).

It should be noted that Figs. 1 and 2 reflect the influence of the external wind action to a lesser degree as compared to the initial input parameters.

Computational Experiment on Description of the Interaction of Cooling-Tower Plumes with Ventilation Discharges of NPPs. The series of computational experiments presented below was conducted as applied to the standard conditions of the dynamic interaction and discharges of evaporative cooling towers and technological discharges from the ventilation systems of NPPs (under design operating conditions).

The relative position of the sources of the drop structure and of technogenic discharges relative to the direction of wind action was adopted in conformity with the conditions of the maximum action of the discharges of cooling towers on the discharges from ventilation systems (the conditions of maximum deposition of the particles of the drop structure onto the underlying surface).

In conducting the computational experiments, we adopted the following technological parameters.

Evaporative cooling tower:

- dispersed composition of discharges, 50–500 μm,
- mean (mass) velocity of the drop structure on the level of discharge, 7 m/sec,
- mean (mass) temperature of discharges, 30^{o}C,
- level of discharge, 120 m.

Ventilation system:

- dispersed composition of discharges, 5–50 μm,
- mean (mass) velocity of discharges, 15 m/sec,
- mean (mass) temperature of discharges, 50^{o}C,
- level of discharge, 100 m.

The characteristic results of the computational experiments on evaluation of a possible interaction of the plumes of cooling towers with ventilation discharges of NPPs are presented in Fig. 3.

The graphic fragments (see Fig. 3) illustrate, respectively: a, b, qualitative representation of the concentration fields with allowance for the interaction of drop discharges from evaporative cooling towers (dark background, drop size: fragment a, 100 μm and fragment b, 250 μm) and of aerosol discharges from ventilation systems (light background, size of aerosol particles is 10 μm); c, quantitative representation of the concentrations of aerosol particles in the near-surface zone.

As the analysis of the results of the computational experiments reveals, the drop structure tends to increase its influence on the discharges from ventilation systems when the sources of the discharges approach each other in the direction of a wind flow and in strengthening of the latter. These conclusions are completely consistent with the results of experimental studies [2].

The efficiency of the interaction of cooling-tower plumes with technogenic discharges of power units essentially depends on the intensity of thermoconvective processes in the proximity of a source of aerosol particles (the right-hand source on fragments a and b in Fig. 3).

It is pertinent to note that the main part of the interaction falls on the drops of minimum size and on the particles of moderate and maximum size. However, if we take into consideration the dependence of the coefficient of capture of aerosol particles by drops on the local concentrations of the drop structure, we can draw the conclusion of a relatively weak influence of the discharges of cooling towers on the technogenic discharges of ventilation systems under real operating conditions.

By and large, the testing of the RELEASE program package has shown its functional effectiveness and the internal consistency of the logic structure.

The results of the computational experiments conducted illustrate rather fully the capabilities of the basic computational algorithm and, correspondingly, of the suggested procedure of evaluation of the interaction of cooling-tower plumes with the ventilation discharges of NPPs.

NOTATION

a, thermal diffusivity; C, concentration of technologic impurities in dissolved form (inside drops); $D_{\mathrm{p},n}$, diffusion coefficient of the particles with size L_n; $d^* = 2L_{\mathrm{d}}/L_{\mathrm{d,pr}}$, dimensionless drop diameter; J, volume source; L, governing linear parameter; $L_{\mathrm{d,pr}}$, most probable drop size; g, gravitational acceleration; K, turbulent kinetic energy according to the k–ε model of turbulence; $N_{\mathrm{p},n}$, volume concentration of the particles with size L_n; $[\tilde{N}_{\mathrm{p}}(L_n)]$, particle distribution function with respect to size L_n; P, pressure; T, temperature; W, velocity; η, coefficient of capture; λ, disintegration constant; v, coefficient of kinematic viscosity; ρ, density; $\overline{W_i'W_j'} = -\nu_{\mathrm{e}}\left(\frac{\partial W_i}{\partial x_j} + \frac{\partial W_j}{\partial x_j}\right) - \frac{2}{3}\delta_{ij}K$; $\mathrm{Pe} = \frac{|W_{\mathrm{p}} - W_{\mathrm{d}}|L_{\mathrm{d}}}{D_{\mathrm{p}}}$, Péclet number; $\mathrm{Stc} = \frac{L_{\mathrm{p}}^2|W_{\mathrm{p}} - W_{\mathrm{d}}|\rho_{\mathrm{p}}}{18\nu_{\mathrm{g,e}}\rho_{\mathrm{g}}L_{\mathrm{d}}}$, Stokes number. Subscripts: d, drop; D, diffusion process; e, effective value of the coefficient according to the k–ε turbulence model; i, j, numbers of space coordinates; in, inertia; g, gaseous phase; n, fraction number for particles; p, solid particle; pr, most probable value.

REFERENCES

1. M. E. Berlyand and V. V. Kiselev, *Meteorologiya Gidrologiya*, No. 4, 3–15 (1975).
2. L. P. Bykova, *Meteorologiya Gidrologiya*, No. 8, 69–76 (1985).
3. V. A. Grigor'ev and V. M. Zorin (eds.), *Thermal and Nuclear Power Plants*, *Handbook* [in Russian], Moscow (1982).
4. A. A. Andrizhievskii, A. A. Mikhalevich, and A. G. Trifonov, *Inzh.-Fiz. Zh.*, **69**, No. 6, 965–968 (1996).
5. V. N. Uzhov, A. Yu. Val'dberg, B. I. Myagkov, and I. K. Reshidov, *Cleaning of Industrial Gases of Dust* [in Russian], Moscow (1981).