8. A. A. Samarskii, Theory of Difference Schemes [in Russian], Nauka, Moscow (1977).
9. G. K. Filonenko, "Hydraulic drag of pipelines," Teploenergetika, No. 4, 40-44 (1964).
10. N. V. Golovanov, "On crisis situations in full-scale elements of steam generators," Modern Problems of the Theory of Heat Transfer and Physical Gasdynamics [in Russian], Inst. Thermophysics, Sib. Branch, USSR Acad. Sci. (1984), pp. 242-265.
11. D. E. Daney and P. R. Ludtke, "Friction factors for flow of near-critical helium in curved tubes," Cryogenics, 18, 345-348 (1978).

HYDRODYNAMIC CHARACTERISTICS AND EFFICIENCY OF CONTACT ELEMENTS OF WET-GAS-CLEANING EQUIPMENT

A. A. Andrizhievskii, A. A. Mikhalevich,
and A. G. Trifonov

UDC 532.55:66.074.51

Mathematical modeling, with the use of unidimensional equations, is employed as a basis for determining the relations between the hydrodynamic characteristics and the efficiency of wet-gas-cleaning in single-pass contact elements.

Single-pass gas—liquid units for removing impurity particles from gas by the wet method are a widely used type of modern industrial equipment [1, 2]. The inclusion of such equipment in thermally stressed power-generating systems tightens requirements in regard to their reliability and efficiency, while it is at the same time necessary to minimize energy expenditures for pumping the heat carrier being cleaned.

It was shown in several studies [1, 3] that the rate of interphase mass transfer of solid microscopic impurity particles in contact units (CU) can be described by relations of the type

$$\eta = A\Delta P^{n}, \quad (1)$$

where the coefficients A and n are functions only of the disperse composition of the impurities. This relation is unquestionably approximate in nature, but it adequately illustrates the above-mentioned relationship between the efficiency of a CU and the energy costs of its operation.

The presence of such a functional relation makes it possible to choose the total pressure drop as the determining parameter in the optimization of mass-transfer (connected with interphase transport of impurity particles), dynamic, and geometric characteristics of single-pass contact elements of CUs.

This optimization is done on the basis of a mathematical model of a vapor-drop flow with impurity particles in channels of variable diameter in regard to the process of cleaning of a gaseous dissociated heat carrier in contact with its condensate. The model was constructed on the basis of unidimensional equations of conservation of mass, thermal energy, and the momenta of the liquid, vapor, and solid inert phases with the use of distribution functions for the size of the drops and impurity particles [4]. The model is closed by integral relations for the interphase heat-transfer coefficient and friction coefficient.

The total pressure drop in a unidimensional approximation was determined in the form [4]

$$\frac{dP_{\Sigma}}{dz} = \frac{dP_{\text{fr. wa}}}{dz} + \frac{dP_{\text{fr.d}}}{dz} + \frac{dP_{\text{a}}}{dz} + \frac{dP_{g}}{dz}, \quad (2)$$

where

$$\frac{dP_{\text{fr.wa}}}{dz} = \xi_{\text{wa}} \frac{1}{d} \frac{\rho'' W''^{2}}{2}, \quad (3)$$

Institute of Nuclear Power Engineering, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 49, No. 5, pp. 733-737, November, 1985. Original article submitted October 4, 1984.

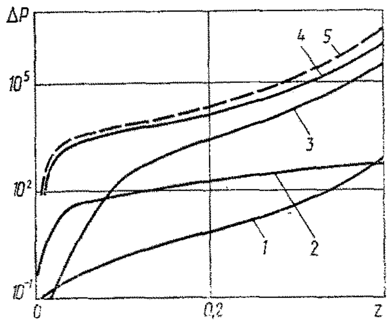

Fig. 1

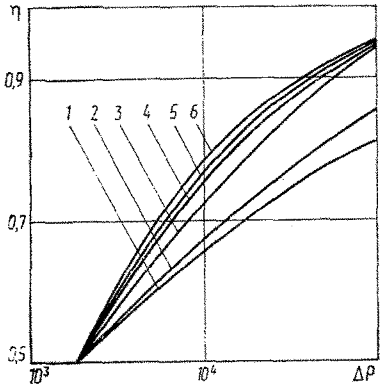

Fig. 2

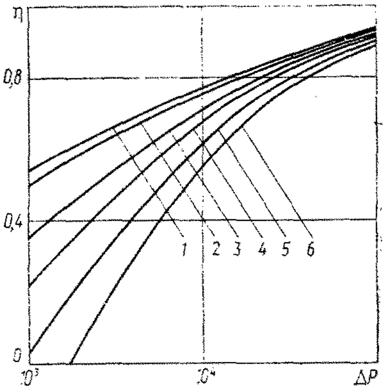

Fig. 3

Fig. 1. Profiles of the components of the pressure drop in a contact element: 1) friction against the channel wall; 2) gravitational component; 3) pressure losses due to acceleration of the gas—liquid flow; 4) interphase friction; 5) total pressure drop; $G_0'' = G_0' = 3$ kg/sec, P = 2 MPa, $\varphi_0 = 0.5$, $\beta = 0.2$ rad, $d_0 = 0.2$ m; ΔP, Pa; z, m.

Fig. 2. Dependence of η on ΔP for different angles of inclination of the generatrix of the cone of the contact element: 1) $\beta = 0$; 2) 0.1 rad; 3) 0.2; 4) 0.4; 5) 0.8; 6) 1. The parameters of the two-phase flow in the contact element are the same as in Fig. 1.

Fig. 3. Effect of initial vapor content on the relation between η and ΔP: 1) $\varphi_0 = 0.2$; 2) 0.3; 3) 0.5; 4) 0.7; 5) 0.9; 6) 0.95. The parameters of the two-phase flow in the contact element are the same as in Fig. 1.

$$\frac{dF_{\mathrm{fr.d}}}{dz} = \int\limits_0^{(d_\mathrm{d})_\mathrm{m}} \xi_\mathrm{d} \frac{\pi d_\mathrm{d}^2}{4} N \frac{\rho'' (W'' - W_\mathrm{d}')^2}{2} F(z,\ d_\mathrm{d})\, d(d_\mathrm{d}); \tag{4}$$

$$\frac{dP_\mathrm{a}}{dz} = \varphi \frac{d(\rho'' W''^2)}{dz} + (1-\varphi) \frac{d(\rho' W'^2)}{dz}; \tag{5}$$

$$\frac{dP_g}{dz} = (1-\varphi)(\rho' - \rho'')\, g; \tag{6}$$

$F(z,\ d_\mathrm{d})$ is the drop-size distribution function normalized with respect to $(d_\mathrm{d})_\mathrm{m}$.

Figure 1 shows the characteristic relation linking the components of $(\Delta P)_\Sigma$, which is regarded in the present case as the analog of the energy costs for operation of the CU. It follows from the figure that most of $(\Delta P)_\Sigma$ is accounted for by the energy consumed by friction

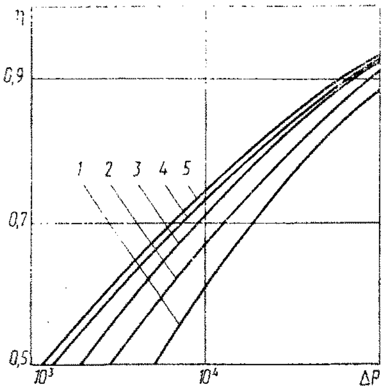

Fig. 4. Dependence of η on ΔP for different rates of flow of the liquid for spraying the contact element: 1) $G_0' = 0.75$ kg/sec; 2) 1.5; 3) 3; 4) 4.5; 5) 6; $G_0'' = 3$ kg/sec, P = 2 MPa, $\varphi_0 = 0.5$, $\beta = 0.2$ rad, $d_0 = 0.2$ m.

against the drops. This friction in turn depends heavily on the bulk density and disperse composition of the drop moisture.

The relation $\eta = f(\beta, (\Delta P)_\Sigma)$ (Fig. 2) shows that with a given $(\Delta P)_\Sigma$, cleaning efficiency increases with an increase in the conicity (the angle β) of the contact element. This effect is achieved by accelerating the gas—liquid flow in the outlet sections of the contact element and correspondingly increasing the volumetric concentration and dispersion of the drop liquid [5].

At the same time, at angles of inclination of the generatrix of the cone of the contact element greater than 0.2-0.4 rad, the relation $\eta = f(\beta, (\Delta P)_\Sigma)$ becomes $\eta = f((\Delta P)_\Sigma)$, and when a certain value of $(\Delta P)_\Sigma$ is reached, an increase in the angle does not lead to an appreciable increase in the coefficient of impurity-particle removal. It should also be noted that an increase in the angle β is connected with a decrease in the volume of the contact element and a corresponding increase in the number of such elements within a CU of a given capacity. All this makes it possible to recommend the above values of the angle β as optimum for the conditions being examined.

A similar effect of an increase in the efficiency of impurity-particle removal in a CU is seen (Fig. 3) with acceleration of the gas—liquid flow in the inlet sections of the contact element due to a reduction in its initial vapor content φ_0 (the cross section of the perforated plate). In this case as well we can distinguish optimum values of the quantity $\varphi_0 \cong 0.2$-0.3, which in the region of reduced pressure drops (adjusted velocities of the gas being cleaned) is characterized by a marked increase in the efficiency of the CU. With an increase in $(\Delta P)_\Sigma$, the relation $\eta = f(\varphi_0, (\Delta P)_\Sigma)$ degenerates into $\eta = f((\Delta P)_\Sigma)$, and the method of intensifying the cleaning process by changing φ_0 becomes ineffective. Also, an excessive reduction in φ_0 in the region of high gas-flow rates leads to an appreciable increase in pressure loss directly in the perforated plate.

It follows from Fig. 4 that an increase in G_0' (analogously, G_0'') helps achieve maximum cleaning efficiency at minimum energy costs due to an increase in drop concentration per unit volume of the contact element. However, a substantial increase in G_0' (G_0'') is not accompanied by a significant increase in η for fixed values of $(\Delta P)_\Sigma$, which has to do with a change in the structure of the two-phase flow.

In connection with this, within the framework of the present study we determined the disperse composition of the drop liquid that (with specified thermodynamic parameters of the contact element) corresponds to maximum efficiency in the removal of impurity particles in the micron size range ($d_s \leqq 20$ μm). Here, the drop-size distribution function

$$F(z, d_d) = A\,\frac{4(d_d')^2}{(d_d)_v^3}\,\exp\{-2d_d'/(d_d)_v\}$$

is constructed from $(d_d)_v$, which is determined from the relation [4]:

$$(\mathrm{We})_v = \frac{\rho''(W''-W_d')^2(d_d)_v}{\sigma} = 7{,}5.$$

It was found that for typical thermodynamic operating conditions in a CU, the optimum values of mean drop diameter $\bar{d}_d$ lie within the range $(0.2$-$0.6)\cdot 10^{-3}$ m. With a substantial increase in $\bar{d}_d$, there is a sharp reduction in the Stokes number and a corresponding reduction in the coefficient of impurity-particle removal $\omega_{c.s.}$. When $\bar{d}_d$ decreases, there is a similar reduction in $\omega_{c.s.}$ due to a decrease in the difference in velocities between the drops and the gas being cleaned. This conclusion is consistent with the findings in [1, 2].

In conclusion, we should note that the above-described effects are manifest to a greater degree in the co-current movement of the gas and drops in the direction opposite to that of gravity.

NOTATION

η, cleaning efficiency; P, (ΔP), pressure, pressure drop; z, longitudinal coordinate; ξ, friction coefficient; d, diameter; W, velocity; ρ, density; σ, surface tension; φ, volumetric vapor content; N, number of drops per unit volume; β, angle of inclination of generatrix of cone; G, flow rate; ω, removal coefficient; g, gravitational acceleration; We, Weber criterional number. Indices: ", ', gas, liquid; Σ, total value; d, s, drop, solid particle; m, maximum value; fr, friction; wa, wall; a, acceleration; g, weight component; 0, quantity referred to the inlet section; n, most probable value.

LITERATURE CITED

1. V. N. Uzhov, A. Yu. Val'dberg, B. I. Myagkov, and I. K. Reshidov, Removing Dust from Industrial Gases [in Russian], Khimiya, Moscow (1981).
2. V. Strauss, Industrial Gas Cleaning [Russian translation], Khimiya, Moscow (1981).
3. L. I. Chesnokov and S. I. Priemov, "Comparative cleaning efficiency of wet-type dust catchers," Promyshlennaya i Sanitarnaya Ochistka Gazov, No. 6, 5-6 (1978).
4. A. A. Andrizhievskii, A. A. Mikhalevich, V. B. Nesterenko, and A. G. Trifonov, "Modeling heat and mass transfer processes in adiabatic vapor-drop flows," Vestsi Akad. Navuk BSSR Ser. Fiz.-Energ. Navuk, No. 2, 63-69 (1983).
5. A. A. Andrizhievskii and A. G. Trifonov, "Numerical investigation of characteristics of the process of removal of solid particles by drops," Vestsi Akad. Navuk BSSR Ser. Fiz.-Energ. Navuk, No. 3, 119-123 (1984).

ELECTRODIFFUSIVE DIAGNOSIS OF THE VISCOELASTIC PROPERTIES OF POLYMER SOLUTIONS ON A ROTATING SPHERICAL ELECTRODE

Z. P. Shul'man, N. A. Pokryvailo, O. Vain,
and I. I. Gol'bina

UDC 532.135:53.082.75

This article examines the feasibility of measuring normal stresses from data from electrochemical diagnosis over the surface of a rotating sphere.

The rotation of a sphere in a liquid causes a secondary meridional flow as well as the main circular flow. Such flow is centrifugal for Newtonian fluids, with flow toward a pole and flow back to the region of the equator. In rotational shear flow of viscoelastic liquids, nonisotropic normal stresses are created. These stresses either lower the rate of the centrifugal flow or convert it into centripetal flow. In the last case, the liquid flows over the sphere in the equator region and flows back from the pole region. These effects were first examined by Giesekus [1]. Quantitative calculations of the flow of a viscoelastic second-order fluid about a rotating sphere [1, 2] make it possible to determine the normal stresses on the basis of study of the kinematics of the secondary meridional flows. Such experiments are usually performed by visualization of the flow about a rotating sphere [3]. Since the intensity of the meridional flow decreases very rapidly with increasing distance

---

Institute of Heat and Mass Transfer, Academy of Sciences, Belorussian SSR, Minsk. Institute of Theoretical Foundations of Chemical Processes, Czechoslovak Academy of Sciences. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 49, No. 5, pp. 738-745, November, 1985. Original article submitted November 29, 1984.

0022-0841/85/4905-1270$09.50