# PRESSURE DISTRIBUTION ALONG THE RADIUS OF EDDY CONTACT ELEMENTS OF MASS-TRANSFER EQUIPMENT

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The rotational motion of a gas produces an appreciable pressure gradient along the radius of rotation. Equations are derived that describe the pressure distribution in agreement with the experimental data.

One of the ways to increase the efficiency of mass transfer is to increase the multiplicity of dispersal of the liquid. At the instant of formation of the drops and at the time of their break up the mass transfer is several times larger than during filmy flow of the liquid or in the case of flying drops. In direct-flow eddy equipment with tangential vortex generators the liquid is subjected to multiple dispersal due to the interaction of the liquid particles among themselves and with the elements of the vortex generator. However, in spite of its good efficiency their extensive use is held up due to a lack of computation techniques.

The rotational motion of a gas in eddy contact elements produces appreciable pressure gradients. The existing techniques of computing the distribution of static pressure of twisted gas flows are based on the assumption that the pressure is equal to the pressure of the medium in which the flow occurs, at the stage when the tangential component of the velocity reaches its saturation value [1], or they are based on the change in the heat content in the computation of highly twisted diaphragmed flows [2]. However, experience shows that these premises are not valid for the eddy contact elements of mass-transfer instruments [3]. In the present work an attempt is made to obtain a computational formula for the distribution of static pressure along the radius of rotation of a single-phase flow in contact elements with tangential vortex generators.

Experiment shows [3] that the axial pressure gradients are small compared to the radial gradients; therefore, we shall consider a two-dimensional motion. In this case the Euler equation is written in the following form:

$$W_r \frac{dW_\varphi}{dr} + \frac{W_\varphi W_r}{r} = 0, \tag{1}$$

$$W_r \frac{dW_r}{dr} - \frac{W_\varphi^2}{r} = -\frac{1}{\rho} \frac{dP}{dr}. \tag{2}$$

We shall integrate Eq. (1) for the boundary conditions $r = r_{in}$, $W_\varphi = W_{\varphi in}$, and obtain the law of potential flow $W_\varphi r = W_{\varphi in} r_{in}$.

It is evident from this equation that the velocity of the gas near the axis of rotation must be infinitely large, which corresponds to absolute vacuum. In view of the physical impossibility of such a phenomenon, the azimuthal velocity of the twisted flow increases from radius $r_{in}$ to some radius $r_m$ and attains its maximum [1], i.e., the region of potential flow:

$$W_\varphi r = \text{const}; \quad r_m \leqslant r \leqslant r_{in}. \tag{3}$$

In the region adjacent to the axis the azimuthal velocity of the gas decreases to zero, i.e., the motion occurs in accordance with the law of motion of a solid body

$$\frac{W_\varphi}{r} = \text{const}; \quad 0 \leqslant r \leqslant r_m, \tag{4}$$

and $r_m$ depends on the coefficient of twisting [3,4].

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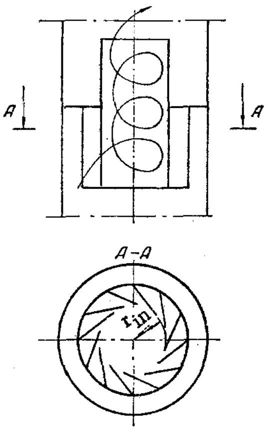


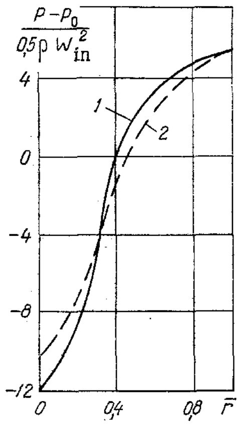


Fig. 1 Fig. 2

Fig. 1. Eddy contact element with tangential vortex generators.

Fig. 2. Pressure distribution along the radius of the eddy contact element with tangential vortex generators.

For contact elements with tangential vortex generators a semiempirical dependence is obtained in [3]; in our case this dependence can be written as

$$r_m = \frac{0.35 r_{in}}{\sqrt{A}},$$

where A is the coefficient of twisting of the flow.

We integrate Eq. (2) for the first region under the condition that $P = P_{in}$, $W_\varphi = W_{\varphi\,in}$, $W_r = W_{r\,in}$ for $r = r_{in}$:

$$-\frac{P}{\rho} = -\frac{P_{in}}{\rho} + \frac{W_r^2}{2} + \frac{W_{r\,in}^2}{2} + \frac{W_{\varphi\,in}^2}{2}\left(\frac{r_{in}^2}{r^2} - 1\right). \tag{5}$$

An integration of Eq. (2) for the second region in the general form gives

$$-\frac{P}{\rho} = \frac{W_r^2}{2} - \frac{W_{\varphi\,in}^2}{2}\,\frac{r_{in}^2}{r_m^4}\, r^2 + C. \tag{6}$$

The constant of integration C is determined from the condition of conjugacy of the regions of potential and quasisolid rotation:

$$C = \frac{P_{in}}{\rho} + \frac{W_{r\,in}^2}{2} - \frac{W_{\varphi\,in}^2}{2}\left(\frac{r_{in}^2}{r_m^2} - 1\right) - \frac{W_{\varphi\,in}^2}{2}\,\frac{r_{in}^2}{r_m^4};$$

for the second region we get

$$-\frac{P}{\rho} = -\frac{P_{in}}{\rho} + \frac{W_r^2}{2} + \frac{W_{r\,in}^2}{2} + \frac{W_{\varphi\,in}^2}{2}\left[\frac{r_{in}^2}{r_m^2}\left(2 - \frac{r^2}{r_m^2}\right) - 1\right]. \tag{7}$$

We take the distribution of the radial velocity along the radius as $W_r = -(\delta/r)$ in the first region and $W_r = -\lambda r$ in the second region [5]; here $\delta$ and $\lambda$ are constants.

We shall use the notation $r/r_{in} = \bar{r}$ and write Eqs. (5) and (7) in dimensionless form:

for the first region,

$$\frac{P - P_0}{0.5\rho W_{\varphi\,in}^2} = \frac{P_{in} - P_0}{0.5\rho W_{\varphi\,in}^2} - \frac{W_{r\,in}^2}{W_{\varphi\,in}^2}\left(1 - \frac{1}{r^2}\right) - \frac{1}{r^2} + 1, \tag{8}$$

for the second region,

$$\frac{P - P_0}{0.5\rho W_{\varphi\,in}^2} = \frac{P_{in} - P_0}{0.5\rho W_{\varphi\,in}^2} - \frac{W_{r\,in}^2}{W_{\varphi\,in}^2}\left(1 - \frac{\bar{r}^2}{r_m^2}\right) - \frac{1}{r_m^2}\left(2 - \frac{\bar{r}^2}{r_m^2}\right). \tag{9}$$

When the gas enters along the tangent to the cylindrical body of revolution (Fig. 1) $W_{r\,in}^2 \ll W_{\varphi\,in}^2$, i.e., the terms containing $W_{r\,in}^2/W_{in}^2$ can be neglected.

We take $W_{\varphi\,in} = W_{in}$ and for the first region we finally get

$$\frac{P-P_0}{0.5\rho W_{in}^2} = \frac{P_{in}-P_0}{0.5\rho W_{in}^2} - \frac{1}{\bar{r}^2} + 1, \tag{10}$$

and for the second region we have

$$\frac{P-P_0}{0.5\rho W_{in}^2} = \frac{P_{in}-P_0}{0.5\rho W_{in}^2} - \frac{1}{\bar{r}_m^2}\left(2 - \frac{\bar{r}^2}{\bar{r}_m 4}\right) + 1. \tag{11}$$

The curve for the dependence of the dimensionless pressure on the dimensionless radius, computed from Eqs. (10) and (11) for the conditions

$$\frac{P_{in}-P_0}{0.5\rho W_{in}^2} = 4.75, \quad A = 1.07,$$

is shown in Fig. 2 (curve 1). Curve 2 in this figure is the experimentally obtained curve [3] for the same conditions.

It is evident from this figure that the disagreement between the computed and experimental curves is small except in the region near the axis.

The experimental determination of the pressure distribution was carried out with a five-channel spherical probe. The disagreement in the region near the axis can apparently be explained by the difficulty encountered in measurements by the five-channel spherical probe in the region near the axis of rotation.

## NOTATION

$\rho$, gas density, kg/m$^3$; r, $\varphi$, z, cylindrical coordinates, m; $W_\varphi$, $W_r$, velocity vector projections on the coordinate axes, m/sec; $W_{in}$, gas velocity at the entrance to the eddy contact element, m/sec; $\tau$, time; sec; P, pressure, N/m$^2$; $r_{in}$, radius of the circle inscribed in the eddy contact element, m; $r_m$, radius of the circle on which the tangential component attains its maximum value, m; A, coefficient of twisting or the ratio of the area of the input loop to the area of the exit cross section of the contact element; $\delta$, $\lambda$, constants; $\bar{r} = r/r_{in}$, dimensionless radius.

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