Gas Pressure Drop in Concurrent Flow With Pseudoplastic Films

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Although there are many industrially important flow situations in which concurrent flow of pseudoplastic liquid films and gas streams occur, the only existing experimental data on this flow situation are those of Skelland and Popadic (1975). Using the method of Dukler (1959), those authors have published the design equations for predicting both the velocity profile and thickness of liquid film as the function of liquid flow rate, gas velocity, and liquid rheological properties. But the design procedure is incomplete if one is not able to predict the gas pressure drop. Hence, the major motivation for the present work was the construction of an empirical correlation which can be used to predict gas pressure drop.

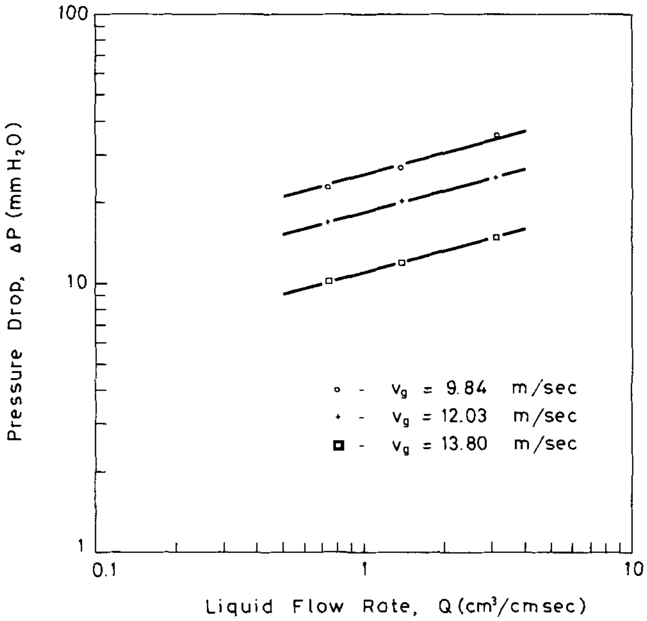

Figure 1. Air pressure drop dependence on liquid flow rate. Liquid: $n = 0.74$; $K = 1.444$ ($\Delta L = 121.92$ cm).

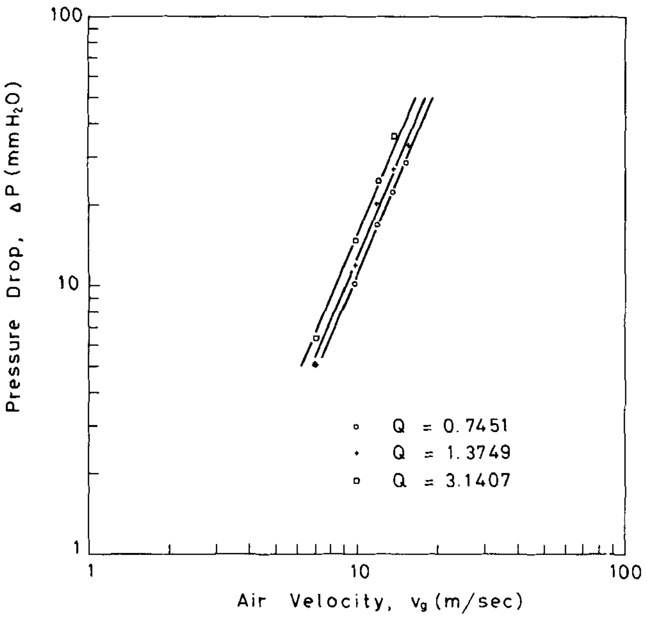

Figure 2. Air pressure drop dependence on air velocity. Liquid: $n = 0.74$; $K = 1.444$ ($\Delta L = 121.92$ cm).

The downward flow of gas in parallel with non-Newtonian liquid films is frequently used in wetted wall columns and reactors. Among non-Newtonian fluids, pseudoplastics are most representative in practical and industrial applications. In a viscometric flow, the constitutive equation of pseudoplastic liquids has the simple form:

$$\tau_{12} = K(\gamma)^n \tag{1}$$

The experimental data of Skelland and Popadic (1975) on the following liquids were used in this work:

Water	$n = 1$	
Liquid 1	$n = 0.930$	$K = 0.124 \dfrac{\text{dyne sec}^n}{\text{cm}^2}$
Liquid 2	$n = 0.740$	$K = 1.444 \dfrac{\text{dyne sec}^n}{\text{cm}^2}$
Liquid 3	$n = 0.417$	$K = 7.048 \dfrac{\text{dyne sec}^n}{\text{cm}^2}$

It should be noted that the liquids used by Skelland and Popadic (1975) were aqueous solutions of Carbopol 934, and the surface tension was practically independent of Carbopol concentration. The geometry of the flow situation was gas flow through a narrow rectangular channel, one large surface of which was provided by the concurrent pseudoplastic film and the other by a rigid, smooth wall. The gas velocities applied were between 4 and 16 m/s. Liquid flow rates measured were between 0.7451 and 3.1407 cm^3/cm s.

As shown by Zhivaikin and Volgin (1963), there are three major regions of the dependence of gas pressure drop on gas velocity. In the first region of so-called separated two phase flow, related to lowest gas velocities, gas pressure drop proved to be practically independent of liquid rheological properties (Zhivaikin and Volgin, 1963). The third region, related to the highest gas ve-

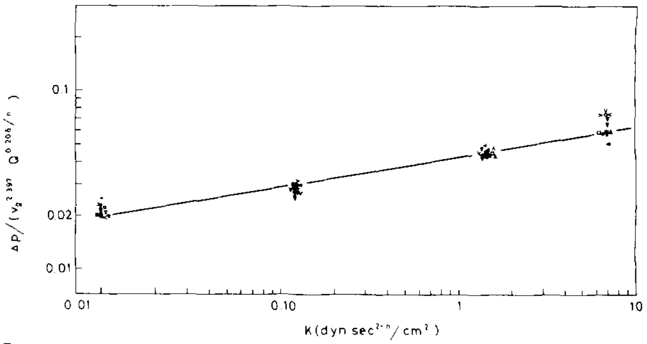

Figure 3. Dependence $\Delta P / v_g^{2.397}\, Q^{0.206/n}$ on K ($\Delta L = 121.92$ cm).

locities and practically the most interesting, belongs to pressure drops dependent on gas velocity, liquid flow rate, and liquid shear properties. For this region, it was intended in the present work to construct the design correlation for gas pressure drop.

In Figures 1 and 2, the experimental data on gas pressure drop dependence on gas velocity and liquid flow rate were shown, respectively.

In Figure 3, it is shown that the gas pressure drop in the two phase flow of pseudoplastic films and gas streams highly depends on liquid rheological properties.

Consequently, the following design correlation has been constructed:

$$\Delta P = 0.0438\, v_g^{2.397}\, Q^{0.206/n}\, K^{0.172} \qquad (2)$$

Comparison of Equation (2) with experimental data shows the following standard deviations:

Water	7.11%
Liquid 1	7.80%
Liquid 2	4.92%
Liquid 3	12.62%

Of course, an extensive experimental work for gas velocities from 0 to 40 m/s should be conducted to study all the regions of gas pressure drops. In any case, this work presents the correlation which covers practically the most important region of gas pressure drop in concurrent or pseudoplastic liquid films and gas streams.

NOTATION

K = consistency factor, dyne sec^n/cm^2
L = length of plate, cm
n = flow behavior index
Q = liquid volume flow rate per unit width of the plate, cm^3/cm s
v_g = gas velocity, cm/s
γ = rate of shear, s^{-1}
τ = shear stress, dyne/cm^2
P = pressure drop, mm water

LITERATURE CITED

Dukler, A. E., "Dynamics of Vertical Falling Film Systems," *Chem. Eng. Progr.*, **55**, 62 (1959).

Skelland, A. H. P., and V. O. Popadic, "Pseudoplastic Falling Films with Concurrent Gas Streams," *AIChE J.*, **21**, 861 (1975).

Zhivaikin, L. Ya., and B. P. Volgin, "Gidraulicheskoe soprotivlenie pri nishodyashem dvuhfaznom potoke v plenochnikh apparatakh," *Khim. Prom. (USSR)*, No. 6, 45 (1963).

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Critical Reynolds Numbers for Newtonian Flow in Concentric Annuli

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A number of years ago, a transition parameter was developed to compute critical Reynolds numbers of transition from laminar to nonlaminar flow in straight-walled ducts of arbitrary cross-section (Hanks 1963). This parameter is practical and useful for engineering design purposes, because with it, Re_c can be accurately predicted, regardless of duct geometry or fluid rheology.

Originally, Hanks (1963) applied this parameter to the case of Newtonian flow in concentric annuli. A curve of Re_c is presented, based on a special equivalent diameter defined by Lohrenz and Kurata (1960), as a function of annular aspect ratio ($\sigma = R_i/R_o$). In a more detailed study of transitional flow phenomena in concentric annuli Hanks and Bonner (1971) analyze the annular flow field in terms of two separate regions: 1) an inner or core region defined by $\sigma \leq \xi \leq \lambda$; and 2) an outer or wall region defined by $\lambda \leq \xi \leq 1$, where $\xi = r/R_o$ and $\xi = \lambda$ where the velocity is a maximum. By developing these separate velocity profile expressions and applying the transition parameter to each region separately, Hanks and Bonner showed that a second critical Re, different from the one originally calculated by Hanks (1963) could be predicted. They also showed that Hanks' original calculations corresponded to their results for the outer or wall region of the flow.

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This note will show that division of the annular flow into two regions for transitional flow analysis is artificial, and that upon more careful analysis, Hanks' original theory can be shown to predict both of the Re_c values found by Hanks and Bonner in 1971.

THEORETICAL ANALYSIS

The transition parameter (Hanks 1963) for this problem takes the form

$$K = \frac{\rho\, |\nabla(\tfrac{1}{2}v^2)|}{|\mathbf{f} - \nabla p|} \qquad (1)$$

where $\mathbf{f}$ is the body force, p is the pressure and $v^2 = \mathbf{v}\cdot\mathbf{v}$. For Newtonian flow in a concentric annulus the velocity distribution is well-known (Bird et al. 1960) to be

$$v(\xi) = \frac{R_o^2}{4\mu}\left(\frac{-dp}{dz}\right)[1 - \xi^2 + 2\lambda^2 \ln\xi] \qquad (2)$$

where $\xi = r/R_o$ and $\lambda^2 = (\sigma^2 - 1)/\ln\sigma^2$. Lohrenz and Kurata (1960) define an equivalent diameter $D_e = 2R_o\sqrt{\phi(\sigma)}$ with $\phi(\sigma) = 1 + \sigma^2 - 2\lambda^2$. When one uses D_e in defining the Fanning friction factor, $f = D_e(-dp/dz)/2\rho\langle v\rangle^2$, and $Re = D_e\langle v\rangle\rho/\mu$, these variables will satisfy the simple relation $f = 16/Re$.

By combining the above results, it is simple to express Equation (1) in the form