Heat Transfer in Vertical Annular Two-Phase Flow

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Collier, Lacey, and Pulling (*1*) applied the Dukler-Hewitt (*2*) model to heat transfer data obtained with steam-water flow in a vertical annulus. The data which represent the annular and annular-mist flow regimes, were obtained under conditions in which nucleate boiling was suppressed. Although applicable, the theoretical model predicted heat transfer coefficients about 50% greater than the experimental coefficients.

Hughmark (*3*) presented a method for estimating heat transfer coefficients in horizontal annular gas-liquid flow. The method utilizes empirical gas-liquid–flow-holdup (*4*) and pressure-drop (*5*) correlations and the momentum–heat-transfer analogy. An average absolute deviations of 11.8% was obtained from comparison of calculated coefficients with the experimental heat transfer data of four investigators. The objective of this paper is to apply this method to vertical upward annular two-phase flow.

ANALYSIS OF THE DATA

The horizontal annular flow method was readily adapted to a vertical upward flow model by substitution of vertical upward for the horizontal flow pressure drop. An equivalent diameter for the annuli was used with the Collier et al. data. Nine of the twenty-four conditions reported in these data fell within the range of conditions covered by the empirical holdup and pressure-drop correlations. Steam quality ranged from 4.8 to 24.1 for these data. As experimental pressure-gradient data were reported for the runs, heat transfer coefficients could be calculated from either experimental or calculated pressure gradients.

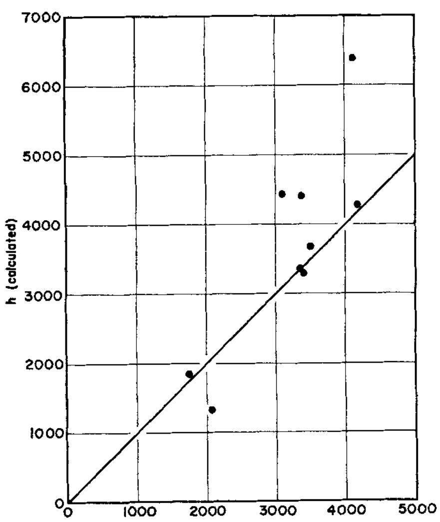

Fig. 1. Steam-water coefficients; experimental pressure gradient.

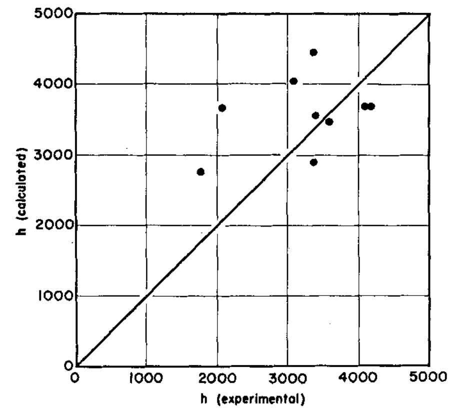

Fig. 2. Steam-water coefficients; calculated pressure gradient.

Figure 1 shows a comparison of the experimental and calculated coefficients in which the experimental pressure gradients were used to obtain the calculated coefficients. The contributions of static head and acceleration were subtracted from the experimental total gradient to obtain the gradient applicable to the heat-transfer–momentum analogy. The average absolute deviation between experimental and calculated coefficients is 20%. Figure 2 shows the calculated coefficients for which the vertical–upward-flow–pressure-drop correlation was used. This is comparable to the total pressure gradient minus the static head and acceleration. Here the average absolute deviation between experimental and calculated coefficients is 25%.

Groothuis and Hendel (*6*) published data for air and water and air and gas oil in vertical upward flow, part of which represent the annular flow regime. The momentum–heat-transfer model based upon vertical upflow pressure drop was used to calculate heat transfer coefficients for twelve air–gas-oil and ten representative air-water runs. Average absolute deviation between experimental and calculated coefficients was 12% for the air–gas-oil data and 10% for the air-water data. Figure 3 compares calculated and experimental heat transfer coefficients for the air-water system with a water flow 79.5 lb./(hr.)(sq. ft.). The calculated and experimental coefficients both show a maximum value at V_G/V_L ratio of about 100.

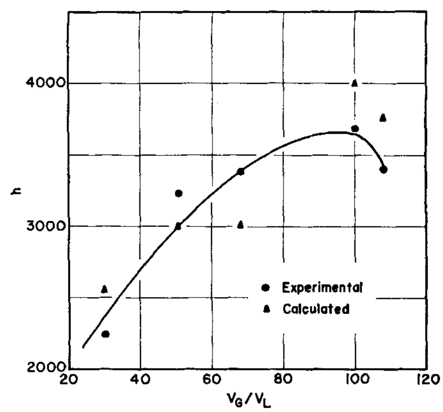

Fig. 3. Air-water experimental and calculated coefficients.

SUMMARY

A method utilizing empirical holdup and pressure-drop correlations and the momentum–heat-transfer analogy was applied to data for upward flow of vapor and liquid and gas and liquid in an annulus. An average absolute deviation of 25% was shown from comparison of calculated and experimental coefficients for steam and water in annuli. Deviations of 12 and 10% were obtained for air and gas oil and air and water in a 0.551-in. I.D. tube.

NOTATION

h = heat transfer coefficient, B.t.u./(hr.)(sq. ft./°F.)

V_G = volumetric gas flow rate, cu. ft./sec.

V_L = volumetric liquid flow rate, cu. ft./sec.

LITERATURE CITED

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