Droplet prediction for annular flow in SPACE code

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1. Introduction

SPACE code is a system code using the two-fluid and three-field model. This study deals with entrainment and deposition of droplet field for annular flow. To assess the droplet prediction capability, two experiments are simulated: Cousins et al. (1965) and Mantilla (2008).

2. Entrainment and Deposition

Pan and Hanratty (2002) and McCoy and Hanratty (1977) were selected for entrainment and deposition, respectively, in annular flow. But several modifications have been made through various tests. The entrainment rate S_E is computed as follows:

$$S_E = \min[S_{E1}, 0.0012\rho_l] \text{ kg/m}^2\text{s}$$

$$S_{E1} = \min[k_a v_g^2 \sqrt{\rho_g \rho_l} \max[W_{lf}/P - \Gamma_c, 0]]$$

$$k_a = 3.5 \times 10^{-6} \text{ s}^2\text{/kg}$$

$$W_{lf} = \alpha_l \rho_l v_l A \text{ kg/s}$$

$$P = 4A/D_h \text{ m}$$

$$\Gamma_c = 0.046 \text{ kg/ms}$$

Here, A and D_h are the cross-sectional area and the hydraulic diameter of a flow channel, respectively. The value of the atomization rate k_a was taken from Bertodano et al. (1997), and the value of the minimum liquid flow rate for droplet entrainment Γ_c from Dykhno and Hanratty (1996). The deposition rate S_D is estimated as below.

$$S_D = k_D C \text{ kg/m}^2\text{s}$$

$$k_D = 20.7 u^* / \sqrt{\tau^+} \text{ m/s}$$

$$\tau^+ = d_d^2 u^{*2} \rho_g \rho_l / (18\mu_g^2)$$

$$u^* = \sqrt{0.5 f_i v_g^2} \text{ m/s}$$

$$f_i = 0.005(1 + 75\alpha_l)$$

$$C = \alpha_d \rho_d / (\alpha_g + \alpha_d) \text{ kg/m}^3$$

3. Simulation Conditions

Cousins et al. (1965) measured the droplet mass flow rate in vertical upward annular flow. The experiment was conducted with a 0.375" pipe under about 40 psia. A total of 21 data sets were selected among 52 data sets for simulation. The air injection flow rate is 40~70 lb/hr, and the water injection rate is 25~230 lb/hr.

Mantilla (2008) provides the experimental data for droplet mass flow rates in horizontal annular flow. In particular, the data includes the liquid film flow rates at four different points along the circumferential. The experiment pressure is about 2 bar. Since the droplet mass flow rates are very little in a 6" pipe, the experiment data sets for a 2" pipe are simulated.

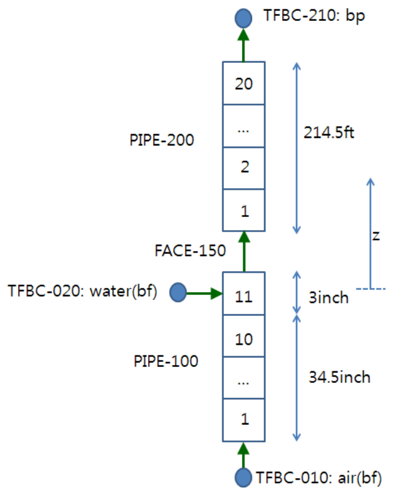

Fig. 1. SPACE code nodding diagram for Cousins et al. (1965)

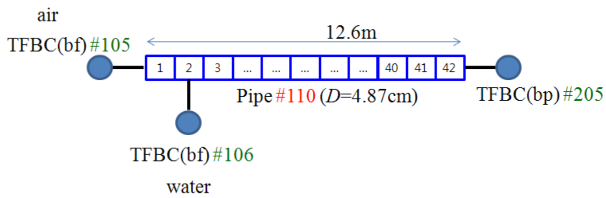

Fig. 2. SPACE code nodding diagram for Mantilla (2008)

3. Results

Figures 3 and 4 show a comparison of droplet mass flow rates with Cousins et al. (1965). As seen, the prediction agrees fairly well with experiment. As going downstream, the droplet mass flow rate increases, which is a typical behavior.

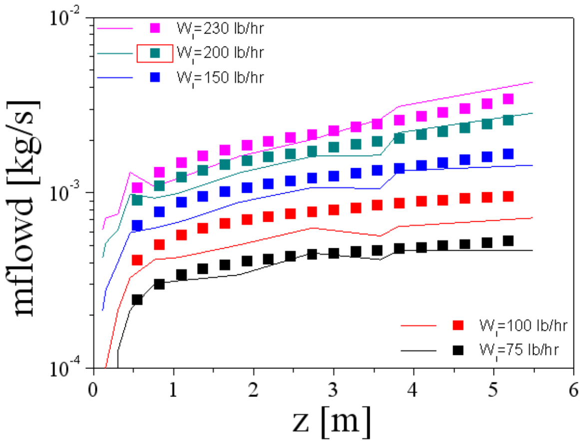

Fig. 3. Comparison with Cousins data (Wg=40 lb/hr)

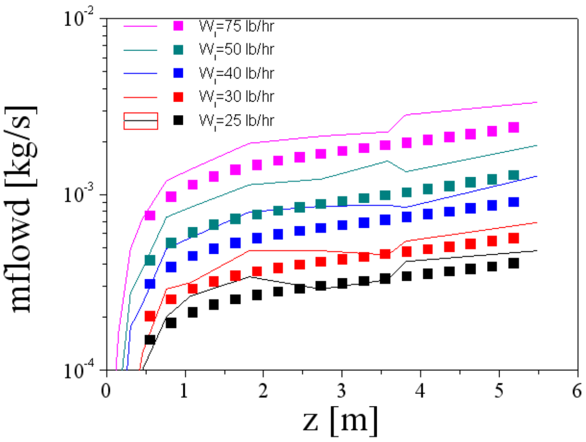

Fig. 4. Comparison with Cousins data (Wg=70 lb/hr)

Figures 5 and 6 show the liquid film thickness δ and the entrainment fraction $e=W_d/(W_d+W_{lf})$ at the outlet. The subscripts d and lf stand for droplet and liquid film, respectively. In Fig. 5, the angles 0° and 180° indicate the bottom and top of the channel, respectively. The large uncertainty of the droplet correlation considered, the predictions are excellent though the droplet entrainment is slightly over-estimated on the whole. It is found in Fig. 6 that no droplet entrainment occur for cases 1~5. But for such cases, due to very low water injection rates, the measured droplet mass flow rates are so small that the measured values may be within the measurement uncertainty.

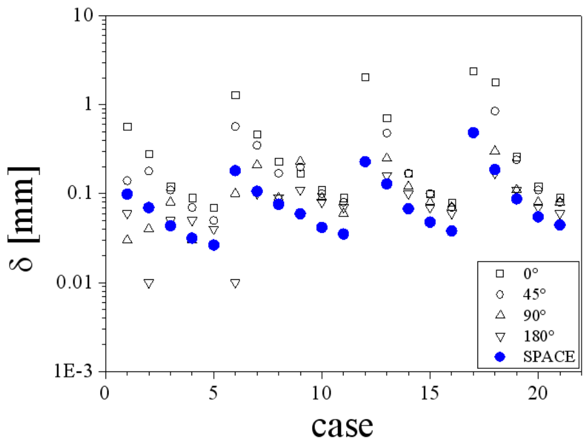

Fig. 5. Comparison of the liquid film thickness δ

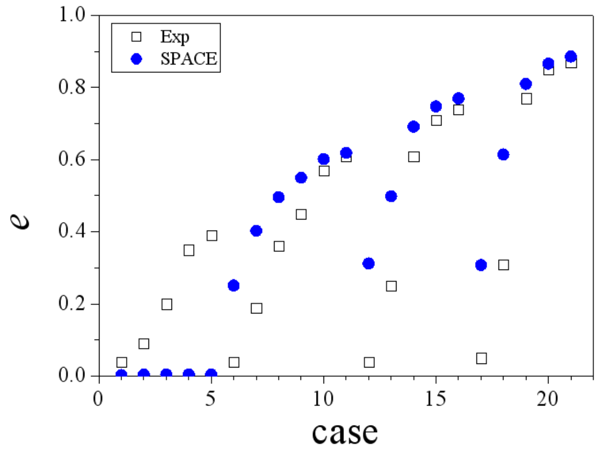

Fig. 6. Comparison of entrainment fraction *e*

Good agreements with experiment imply that the magnitudes and entrainment and deposition rate are appropriate in annular flow.

3. Conclusions

The prediction capability of SPACE code for droplet entrainment and deposition in annular flow has been tested. The results showed a good agreement with Cousins et al. (1965) and Mantilla (2008) which were performed at low pressures (2~3 bar).

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