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TABLE I

Smoothed air holdup values for air-water and air-water-glass bead systems as a function of superficial air velocity and temperature

U_g	Solids conc. = 0 wt.%				Solids conc. = 5-20 wt% (d_p = 143.3 µm)			Solids conc. = 5 wt.% (d_p [illegible] µm)			Solids conc. = 5 wt.% (d_p = 50 µm)		
(m/s)	297K	313K	323K	343K	297K	323K	343K	297K	323K	343K	297K	323K	343K
0.02	0.050	0.052	0.042	0.043	0.058	0.035	0.040	0.031	0.029	0.029	0.065	---	---
0.03	0.080	0.086	0.055	0.053	0.088	0.045	0.060	0.051	0.042	0.042	0.084	0.050	0.058
0.05	0.170	0.125	0.100	0.083	0.150	0.078	0.095	0.085	0.069	0.069	0.115	0.082	0.082
0.07	0.245	0.172	0.121	0.102	0.210	0.100	0.120	0.110	0.098	0.098	0.138	0.110	0.110
0.10	0.370	0.202	0.155	0.153	0.270	0.133	0.152	0.140	0.129	0.129	0.170	0.148	0.150
0.15	0.321	0.264	0.182	0.180	0.270	0.170	0.180	0.185	0.175	0.175	0.210	0.190	0.200
0.20	0.322	0.322	0.236	0.234	0.278	0.212	0.245	0.220	0.205	0.205	0.248	0.228	0.238
0.22	0.336	0.336	0.240	0.240	0.290	0.222	0.260	0.235	0.221	0.221	0.262	0.244	0.250
0.24	0.345	0.350	0.256	0.256	0.310	0.290	0.270	0.231	0.241	0.241	---	0.258	0.262
0.26	0.350	---	0.372	0.372	---	---	0.280	---	---	---	---	---	0.276

TABLE II

Smoothed heat transfer coefficient (kW/m^2K) values for air-water and air-water-glass bead systems as a function of superficial air velocity and temperature

U_g	Solids conc. = 0 wt.%			Solids conc. = 5-20 wt% (d_p = 143.3 μm)			Solids conc. = 5 wt.% (d_p = 90 μm)			Solids conc. = 5 wt.% (d_p = 50 μm)		
(m/s)	297K	323K	343K	297K	323K	343K	297K	323K	343K	297K	323K	343K
0.02	4.60	5.90	8.01	3.17	5.50	7.80	4.65	5.70	---	4.39	6.80	8.61
0.03	5.15	6.40	8.95	3.95	6.40	8.80	5.28	6.35	8.38	4.73	7.11	9.12
0.05	5.50	7.30	9.70	4.90	7.34	9.92	6.05	7.05	9.41	5.50	7.61	9.80
0.07	5.70	7.82	10.25	5.41	7.92	10.35	6.57	7.49	10.05	5.90	8.00	10.29
0.10	5.92	8.25	11.00	5.88	8.30	10.70	7.05	7.91	10.63	6.30	8.36	10.80
0.15	6.10	8.70	11.30	6.14	8.70	11.28	7.49	8.29	11.13	6.81	8.69	11.48
0.20	6.30	9.02	11.45	6.48	8.92	11.52	7.70	8.45	11.48	7.00	8.85	11.70
0.22	6.41	9.15	11.60	6.56	---	---	7.75	8.49	11.58	7.05	8.90	11.75
0.24	---	9.30	11.62	---	9.10	11.65	---	8.49	11.67	---	8.90	11.75
0.26	---	---	11.63	---	---	11.68	---	---	11.70	---	---	11.80

TABLE III

Correlations for gas holdup in a slurry bubble column

Investigator	Correlation[a]
Reilly et al. [9]	$\epsilon_g = 0.009 + 296\, U_g^{0.44} \rho_L^{-0.98} \sigma_L^{-0.16} \rho_g^{0.19}$
Sada et al. [10]	$\epsilon_g = 0.32(1-\epsilon_g)^4\, Bo^{0.121}\, Ga^{0.086}\, Fr(\rho_g / \rho_L)^{0.068}$
Hikita et al. [11]	$\epsilon_g = 0.672(U_g \mu_L / \sigma_L)^{0.578} (\mu_L^4 g / \rho_L \sigma_L^3)^{-0.131} (\rho_g / \rho_L)^{0.062} (\mu_g / \mu_L)^{0.107}$
Smith et al. [12]	$\epsilon_g = \left[2.25 + \frac{0.379}{U_g}\left(\frac{\rho_{SL}\sigma_L}{72}\right)^{0.31} \mu_{SL}^{0.016}\right]^{-1}$ $\mu_{SL} = \mu_L \exp\left[\frac{(5/3)\, v_s}{(1 - v_s)}\right]$
Kumar et al. [13]	$\epsilon_g = 0.728U' - 0.485U'^2 + 0.0975\, U'^3$ $U' = U_g\left[\rho_L^2 / \{\sigma_L(\rho_L - \rho_g)g\}\right]^{\frac{1}{4}}$
Grover et al. [14]	$\epsilon_g = \left(\frac{1 + a P_v}{b P_v}\right)\left(\frac{U_g \mu_L}{\sigma_L}\right)^{0.76}\left(\frac{\mu_L^4 g}{\rho_L \sigma_L^3}\right)^{-0.27}\left(\frac{\rho_g}{\rho_L}\right)^{0.09}\left(\frac{\mu_g}{\mu_L}\right)^{0.35}$ $a = 1.1 \times 10^{-4}$ and $b = 5 \times 10^{-4}$
Roy et al. [15]	$\epsilon_g = 3.88 \times 10^{-3}\left[Re_T(\sigma_w/\sigma_L)^{\frac{1}{3}}(1 - v_s)^3\right]^{0.69}$ for $Re_T < 350$

	$\epsilon_g = 1.72 \times 10^{-2}\left[Re_T(\sigma_w/\sigma_L)^{\frac{1}{3}}(1 - v_s)^3\right]^{0.44}$ for $Re_T > 500$
	$v_s = \dfrac{(W_s / \rho_s)}{(W_s / \rho_s) + (W_L / \rho_L)}$
Zou et al. [16]	$\epsilon_g = 0.17283\left(\dfrac{\mu_L^4 g}{\rho_L \sigma_L^3}\right)^{-0.1544}\left(\dfrac{U_g \mu_L}{\sigma_L}\right)^{0.5897}\left(\dfrac{P + P_v}{P}\right)^{1.6105}$

[a] All quantities are in SI unit system.

TABLE IV

Correlations for heat transfer coefficient from an immersed surface in a slurry bubble column

Investigator	Correlation[a]
Hikita et al. [18]	$St\,(Pr)^{2/3} = 0.411\left(\frac{U_g\,\mu_L}{\sigma_L}\right)^{-0.851}\left(\frac{\mu_L^4 g}{\rho_L\,\sigma_L^3}\right)^{0.308}$
Zehner [21,22]	$h_w = 0.18\left(1-\epsilon_g\right)\left[k_L^2\,\rho_L^2\,C_{PL}\,V_F^2 / l\,\mu_L\right]^{\frac{1}{3}}$
	where $l = d_b\left(\pi/6\,\epsilon_g\right)^{\frac{1}{3}}$
	$V_F = \left[\frac{1}{2.5}\left(\frac{\rho_L-\rho_g}{\rho_L}\right)g\,D\,U_g\right]^{\frac{1}{3}}$
	and
	$\epsilon_g = U_g\left[0.25\exp\left(5\,\epsilon_g\right)\right]^{-1}$
Kolbel et al. [24]	$Nu = 350.8\,Re^{0.108}\left(d_p / d_o\right)^{0.05}$
	for $1 < (d_p / d_o)$. 5 and
	$d_o = 0.04$ mm
Mersmann et al. [23]	$h_{w\,max} = 0.12\left(\frac{g^2\rho_L}{\mu_L}\right)^{\frac{1}{6}}\left(\frac{\rho_L-\rho_g}{\rho_L}\right)^{\frac{1}{3}}\left(k_L\,\rho_L\,C_{PL}\right)^{\frac{1}{2}}$
	for $Ar \cdot Pr > 10^6$
Saxena et al. [26]	$h_{w\,max} = 0.12\left(\frac{g^2\rho_{sL}}{\mu_{sL}}\right)^{\frac{1}{6}}\left(\frac{\rho_{sL}-\rho_g}{\rho_{sL}}\right)^{\frac{1}{3}}\left(\bar{k}\,\rho_{sL}\,\bar{C}_p\right)^{\frac{1}{2}}$
	where
	$\rho_{sL} = v_s\,\rho_s + v_L\,\rho_L$

	$\mu_{sL} = \mu_L \; (1 + 4.5 \, v_S)$
	$\bar{k} = k_L \dfrac{2\,k_L + k_s - 2\,v_s\,(k_L - k_s}{2\,k_L + k_s + v_s\,(k_L - k_s}$
	and
	$\bar{C}_p = w_s\,C_{ps} + w_L\,C_{pL}$
Deckwer et al. [17]	$\overline{St} = 0.1\left[\overline{Re}\;\overline{Fr}\;\overline{Pr}^2\right]^{-0.25}$
	where
	$\overline{St} = h_w \,/\, \rho_{sL}\,\bar{C}_p\,U_g$
	$\overline{Re} = U_g\,d_p\,\rho_{sL} \,/\, \mu_{sL}$
	$Fr = U_g^2 \,/ g\,d_p$
	and
	$Pr = \bar{C}_p\,\mu_{sL} \,/\, \bar{k}$
Pandit and Joshi [8]	$h_w = 0.087\left(U_g - \epsilon_g\,U_{b\infty}\right)^{0.266} g^{0.26}$
	$\rho_{sL}^{0.8}\,\bar{C}_p^{0.34}\,\mu_{sL}^{-0.33}\,\bar{k}^{0.66}\,D^{0.06}\,\mu_L^{-0.14}$
	where
	$\epsilon_g = U_g / \left(a + b\,U_g\right)$
	a and b are functions of d_p and ϵ_s and their values are tabulated in reference 8.
Kim et al. [19]	$h_w = 0.0722\left(k_L\,\rho_L\,C_{pL}\left\{\left[U_g\left(\epsilon_g\,\rho_g + \epsilon_L\,\rho_L + \epsilon_s\,\rho_s\right)\right] g\left(\epsilon_L\,\mu_L\right)^{-1}\right\}^{\frac{1}{2}}\right)^{\frac{1}{2}}$
Suh and Deckwer [20]	$h_w = 0.1\left(k_L\,\rho_L\,C_{pL}\left\{\left[U_g\left(\epsilon_s\,\rho_s + \epsilon_L\,\rho_L + \epsilon_g\,\rho_g\right)\right] g\left(\epsilon_L\,\mu_b\right)^{-1}\right\}^{\frac{1}{2}}\right)^{\frac{1}{2}}$
	where
	$\mu_b = \mu_L \exp\left(\dfrac{2.5\,v_s}{1 - 0.609\,v_s}\right)$
Kato et al. [25]	$h_w = \left(\dfrac{2.0\,k_L\left(1 - \epsilon_L\right)U_g^{0.34}}{\epsilon_L\,d_p^{1.17}\,g^{0.17}}\right)$

[a] All quantities are in SI unit system.

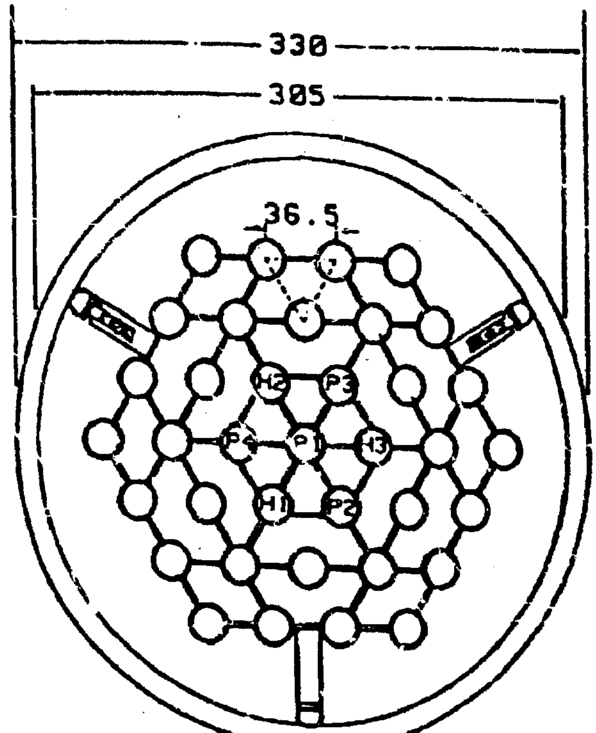

FIGURE 1 Cross-sectional view of the tube bundle configuration and the three-arm ring clamp with two arms having telescopic studs. All dimensions are in mm.

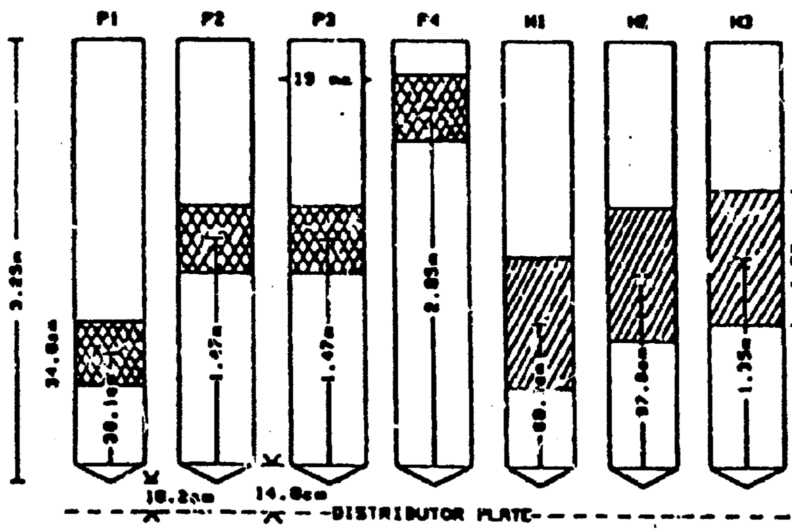

FIGURE 2 Seven probes of the tube bundle showing the positions of the heated sections of the probes (P1.....P4), and positions of the heaters (H1.....H3).

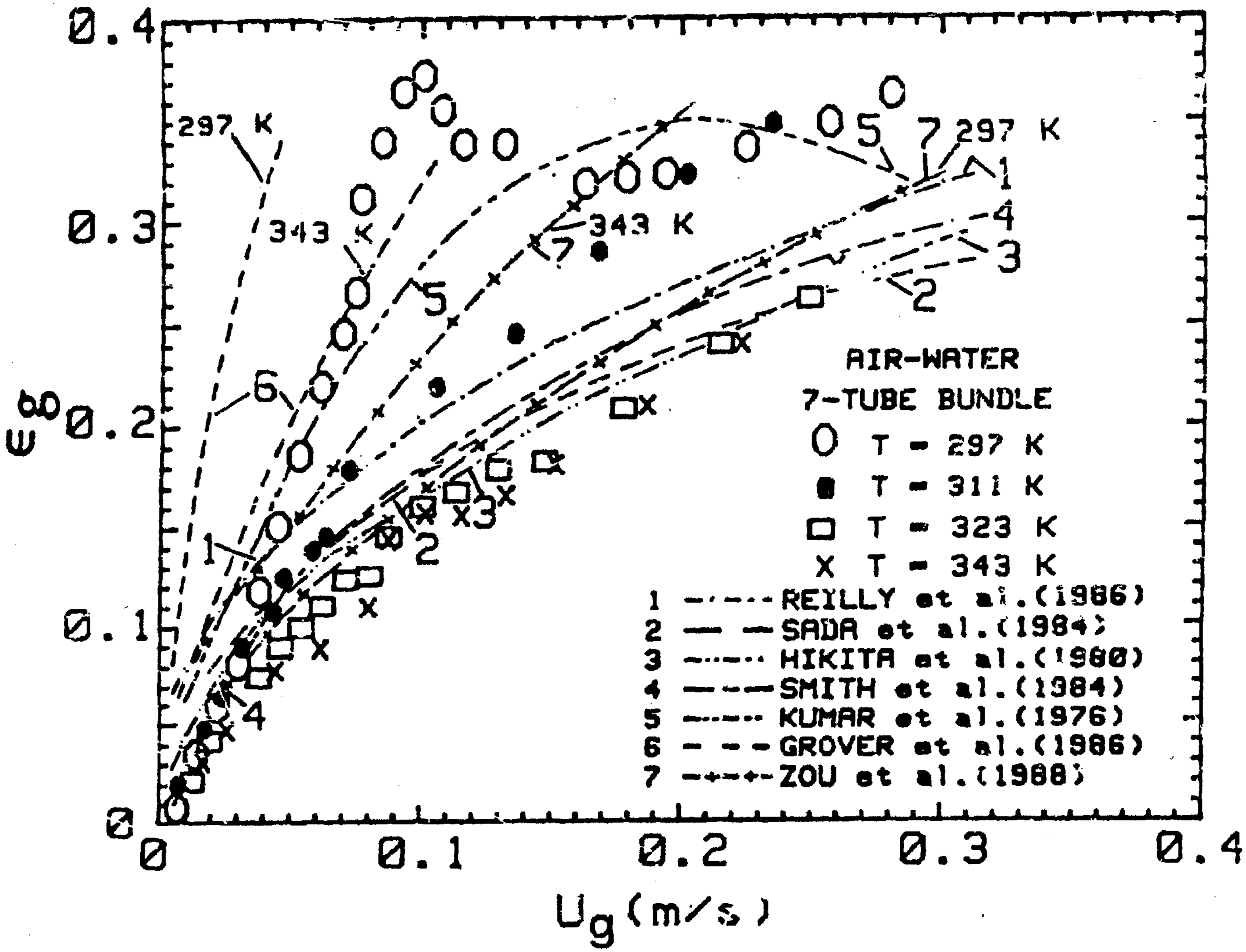

FIGURE 3 Comparison of experimental air holdup values as a function of air velocity at different temperatures with the predictions based on different correlations.

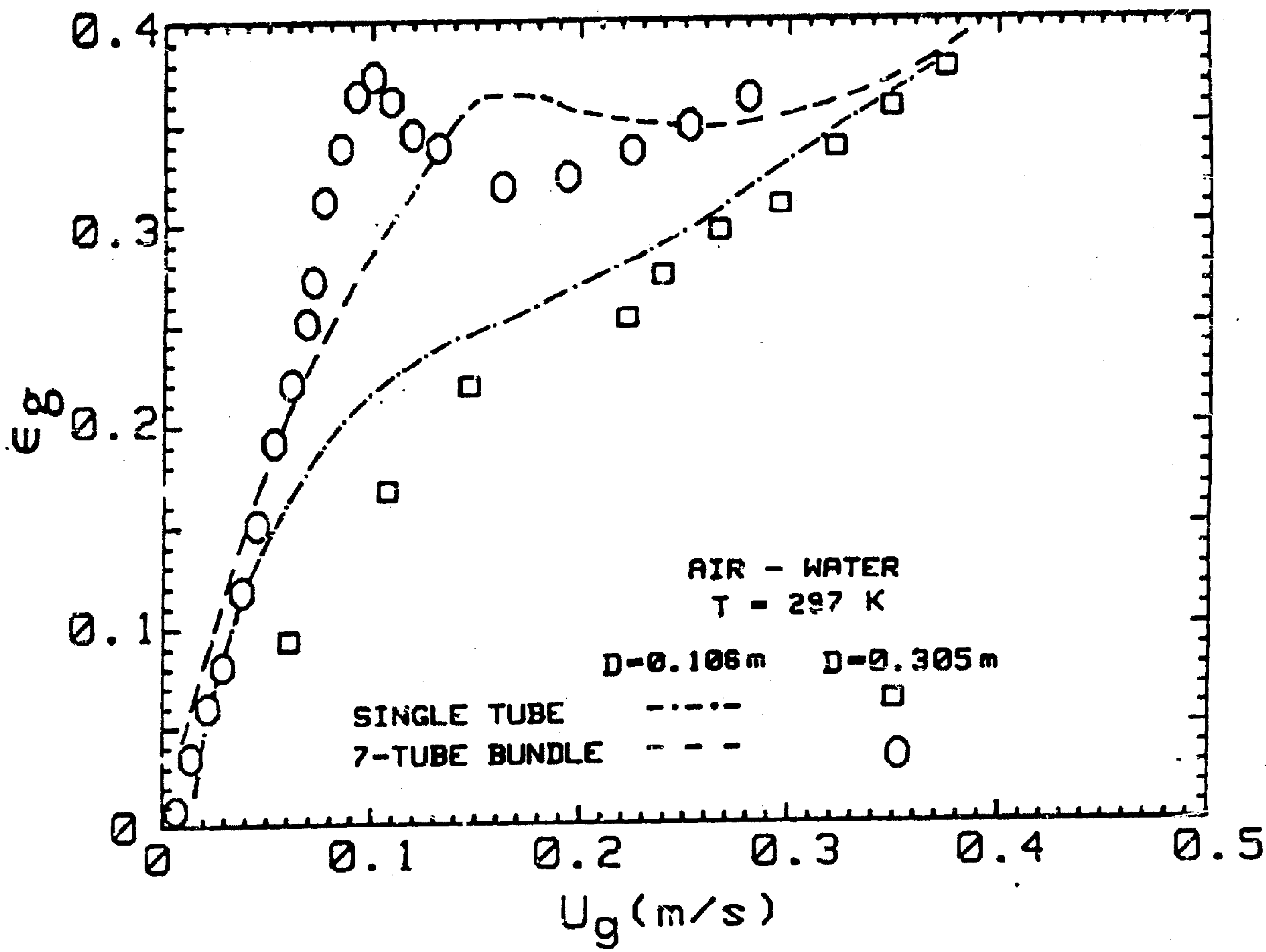

FIGURE 4 Influence of bubble column diameter and internals on air holdup at 297 K as a function of air velocity.

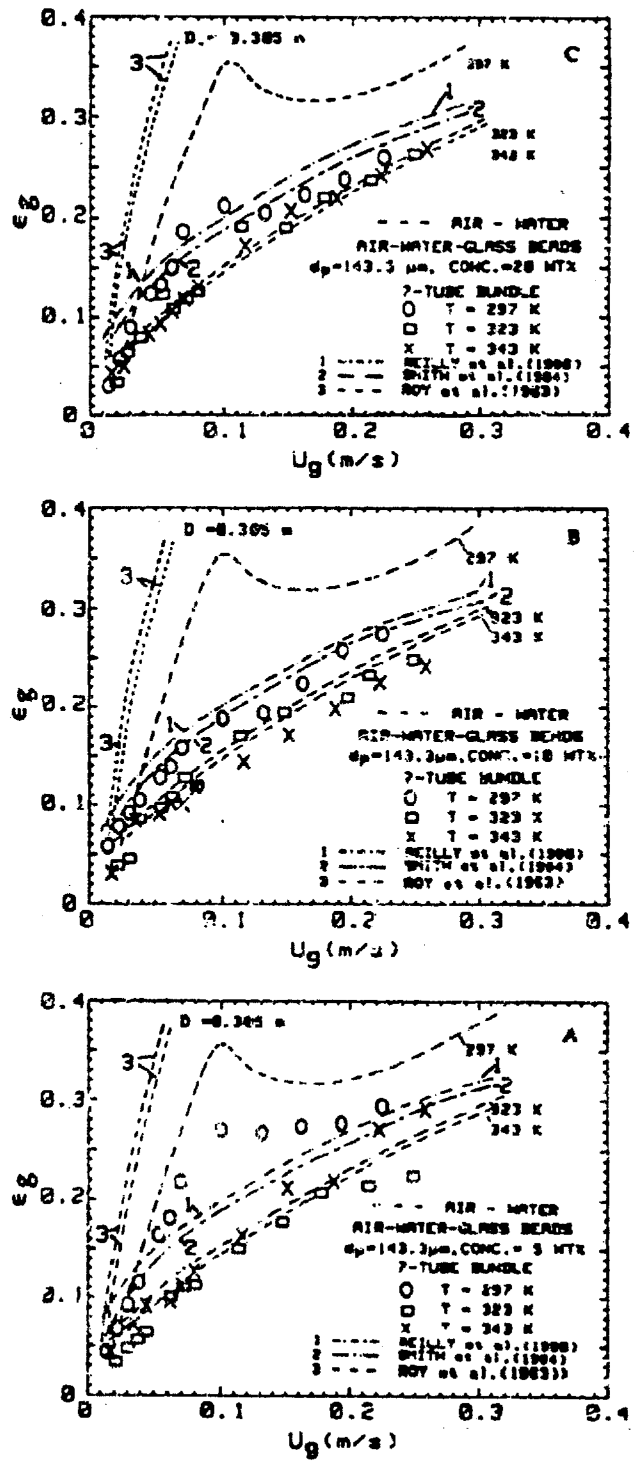

FIGURE 5 Dependence of air holdup data as a function of air velocity and temperature on solids concentration, and its comparison with the predictions of different correlations. The concentration of glass beads (d_p = 143.3μm) in the slurry is (A) five (52 kg/m^3), (B) ten (110 kg/m^3), and twenty (249 kg/m^3) weight percent.

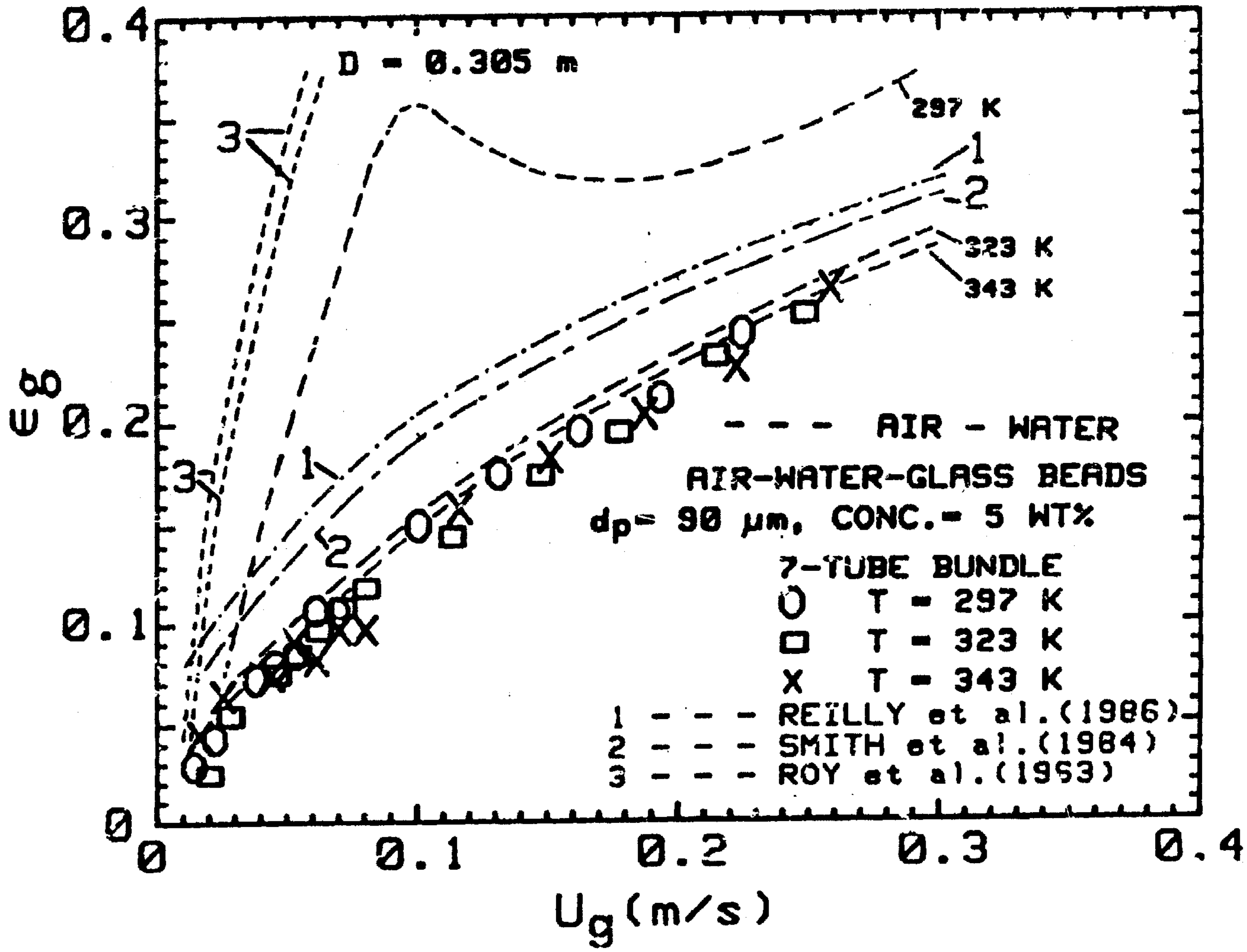

FIGURE 6 Dependence of air holdup on air velocity and temperature for 90 µm and 5 weight percent (52 kg/m^3) slurry, and its comparison with the predictions of different correlations.

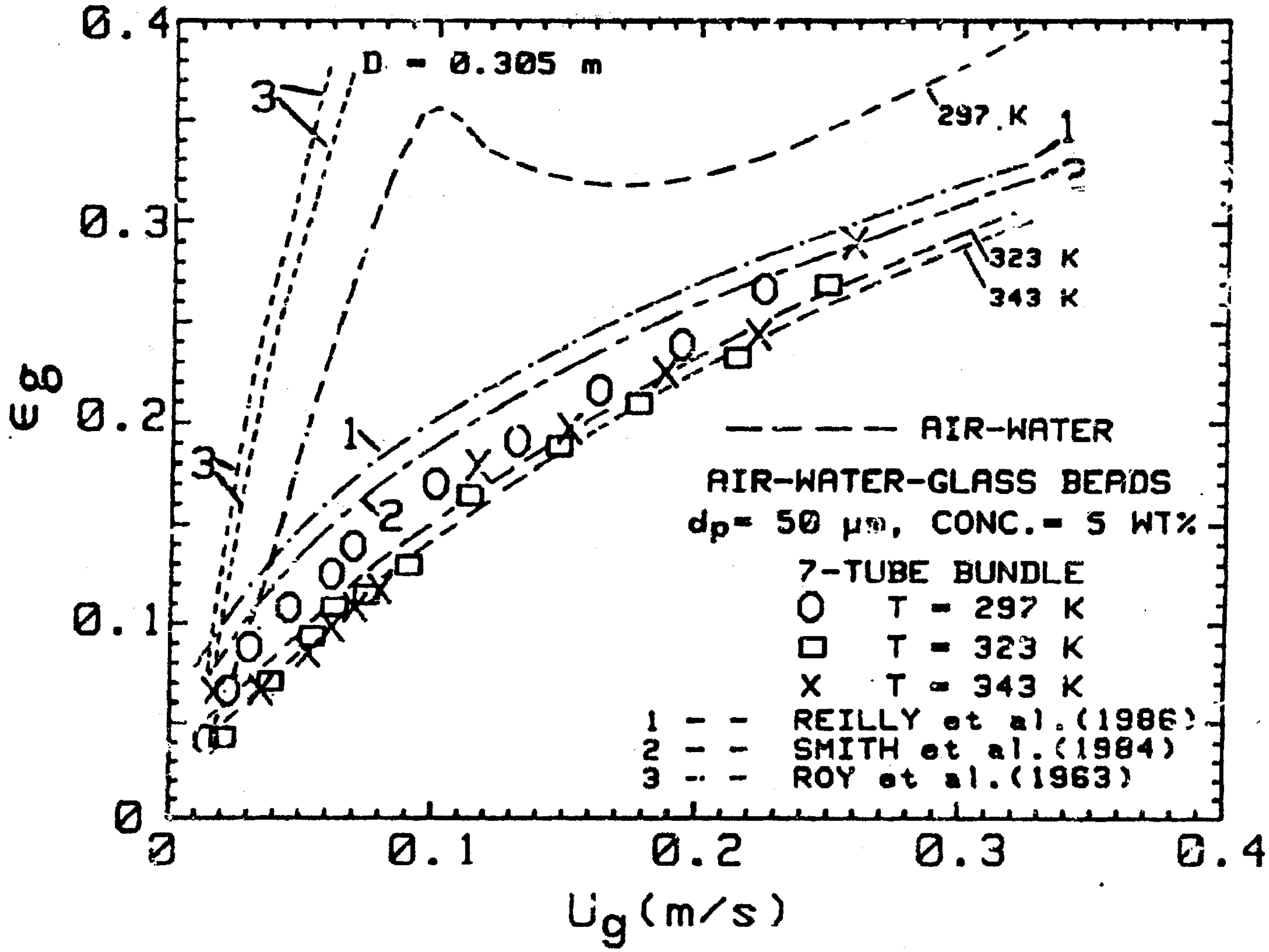

FIGURE 7 Dependence of air holdup on air velocity and temperature for 50 μm and 5 weight percent (52 kg/m^3) slurry, and its comparison with the predictions of different correlations.

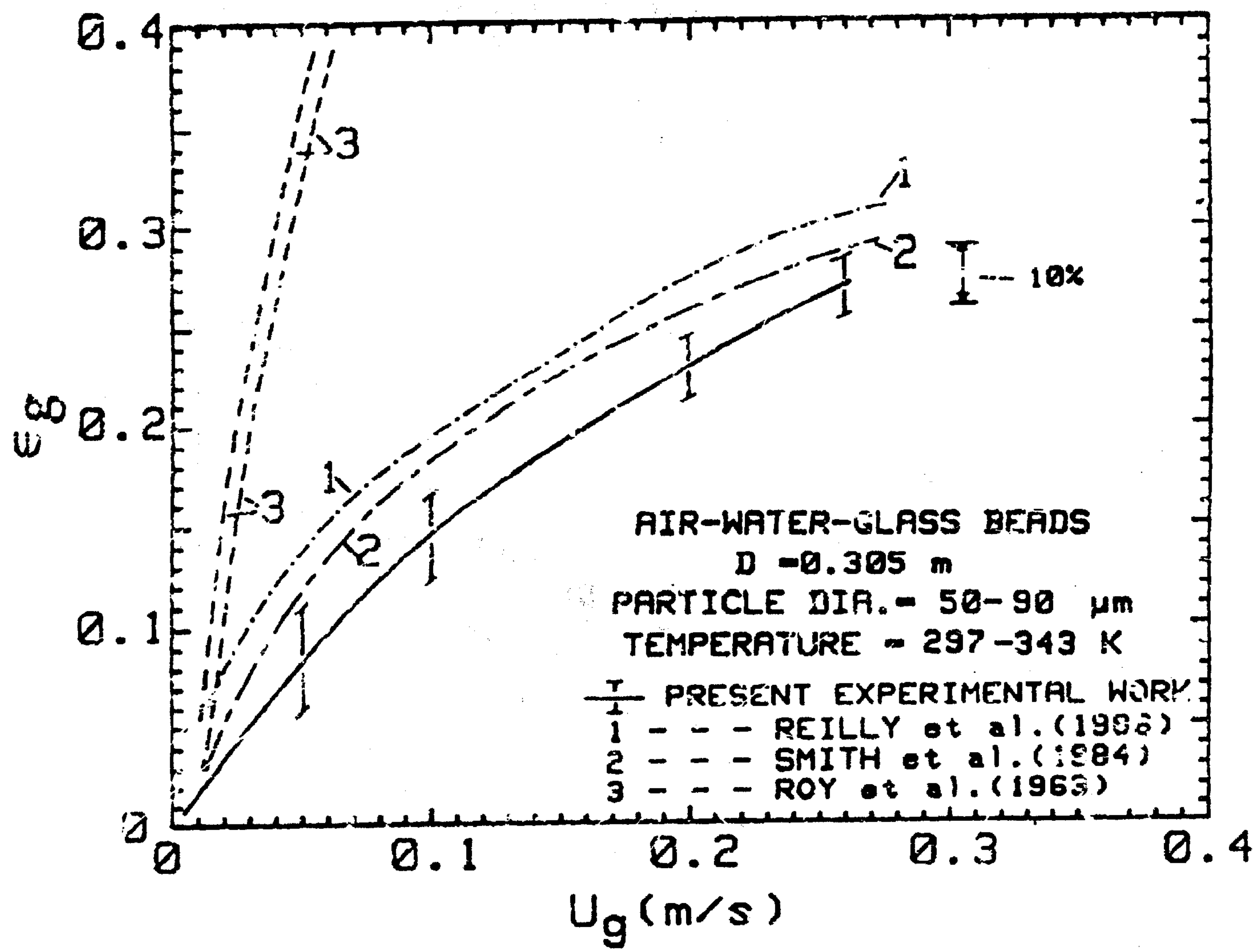

FIGURE 8 Comparison of the averaged air holdup values for a range of particle sizes, slurry concentrations and temperatures as a function of air velocity with the predictions of different correlations.

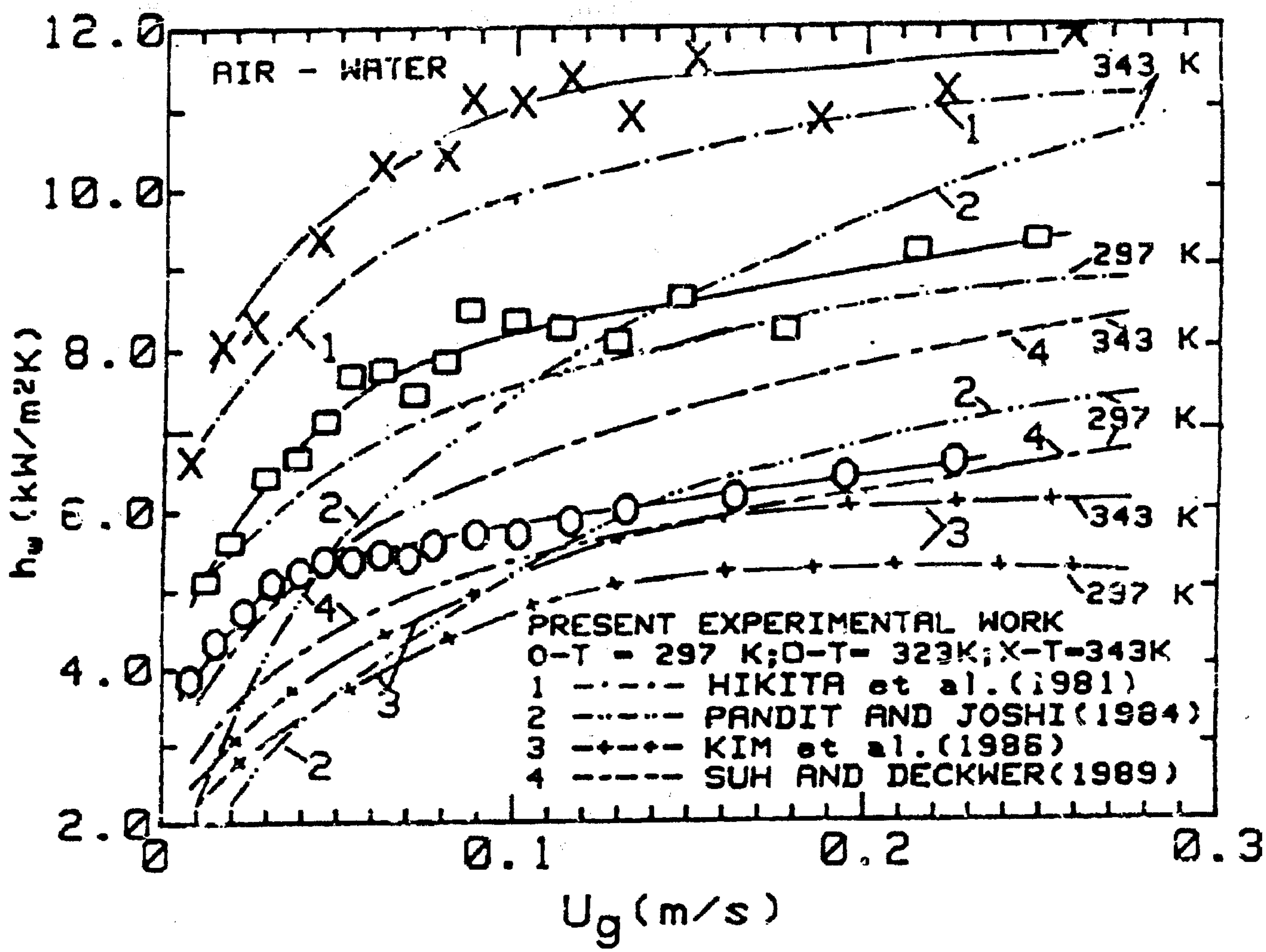

FIGURE 9 Dependence of heat transfer coefficient for the air-water system on air velocity and temperature. Comparison of experimental data with the predictions of different correlations.

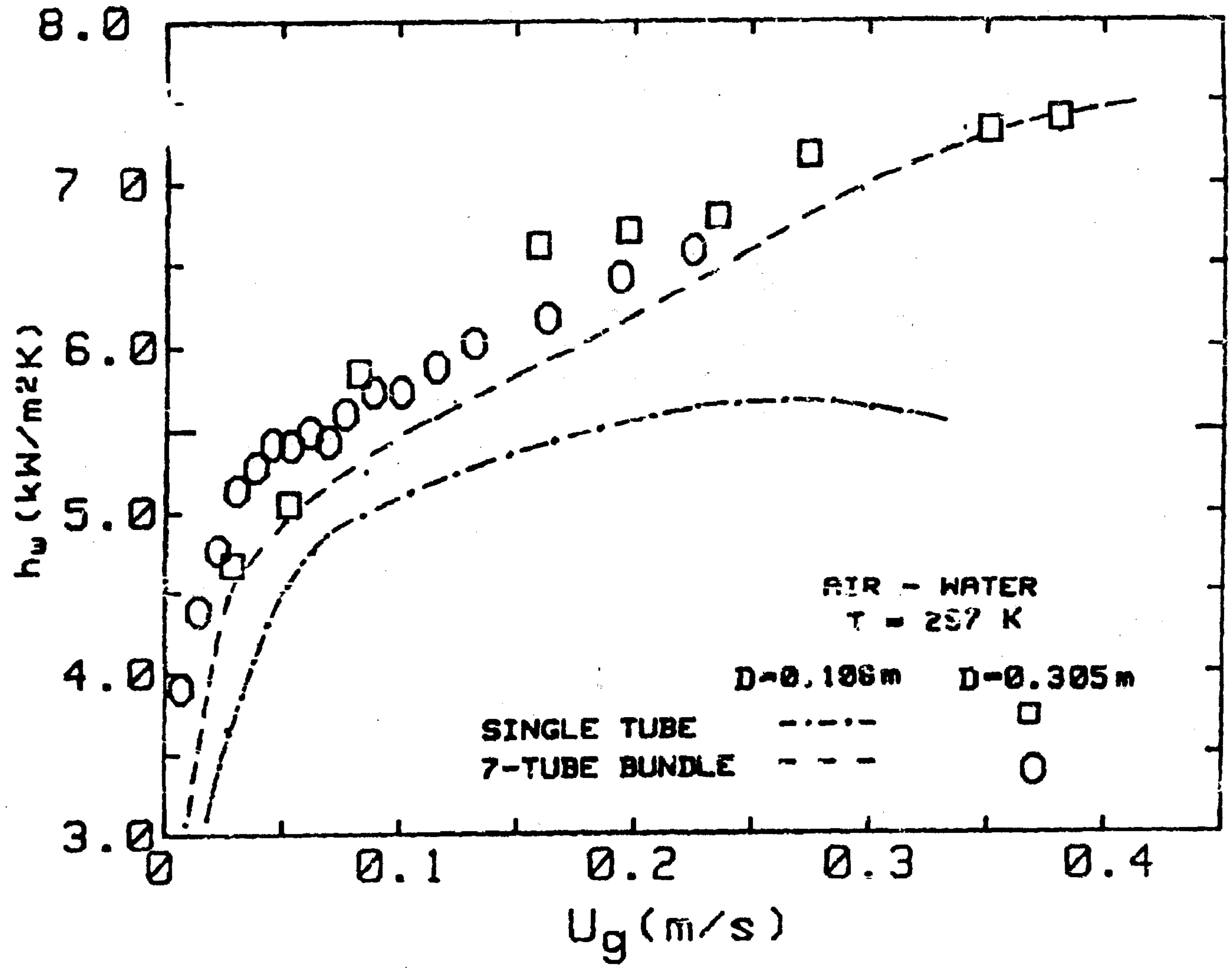

FIGURE 10 Influence of bubble column diameter and internals on heat transfer coefficient at 297 K as a function of air velocity.

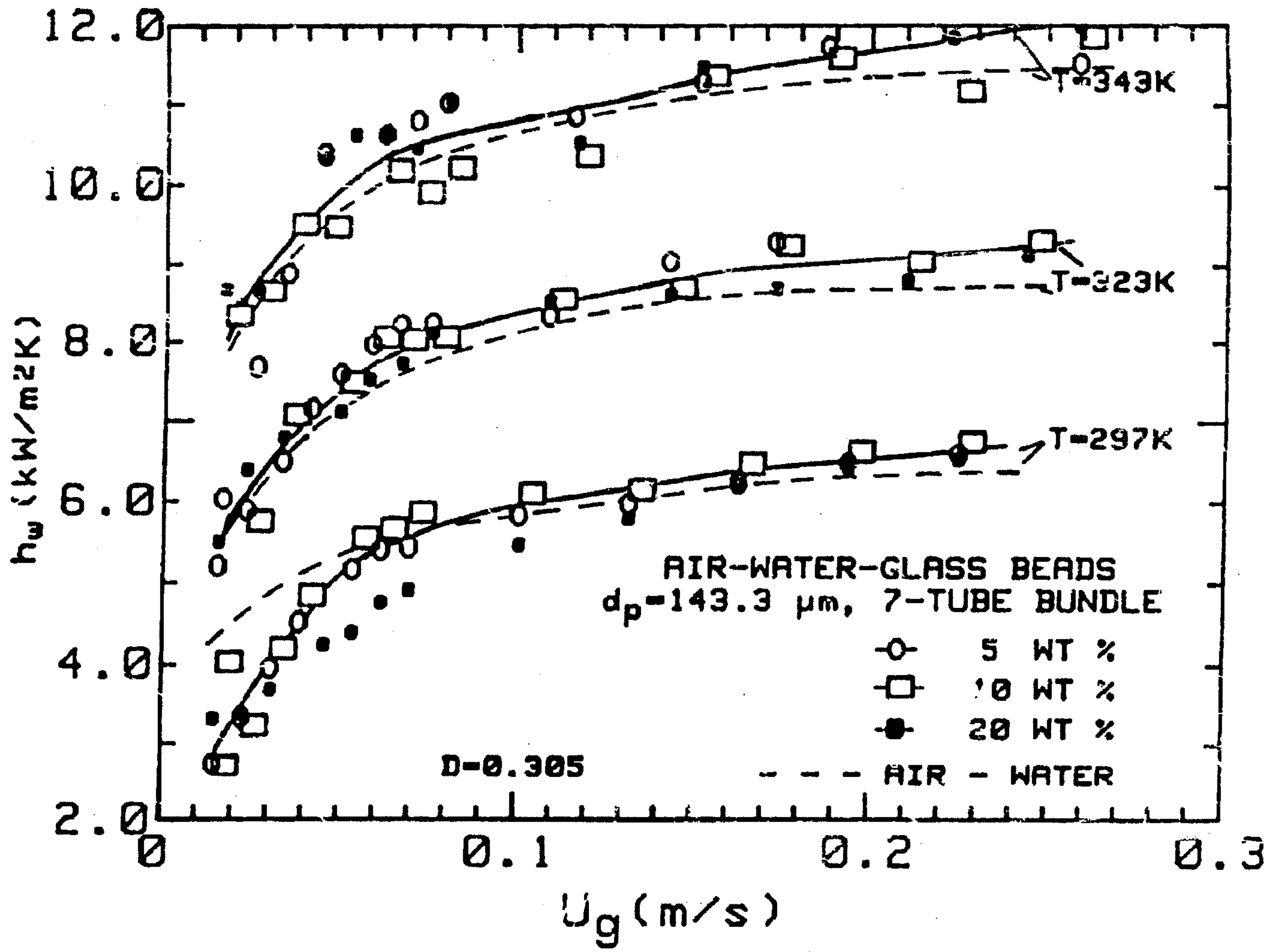

FIGURE 11 Dependence of heat transfer coefficient data as a function of air velocity and temperature on slurry concentration of 143.3 μm glass beads.

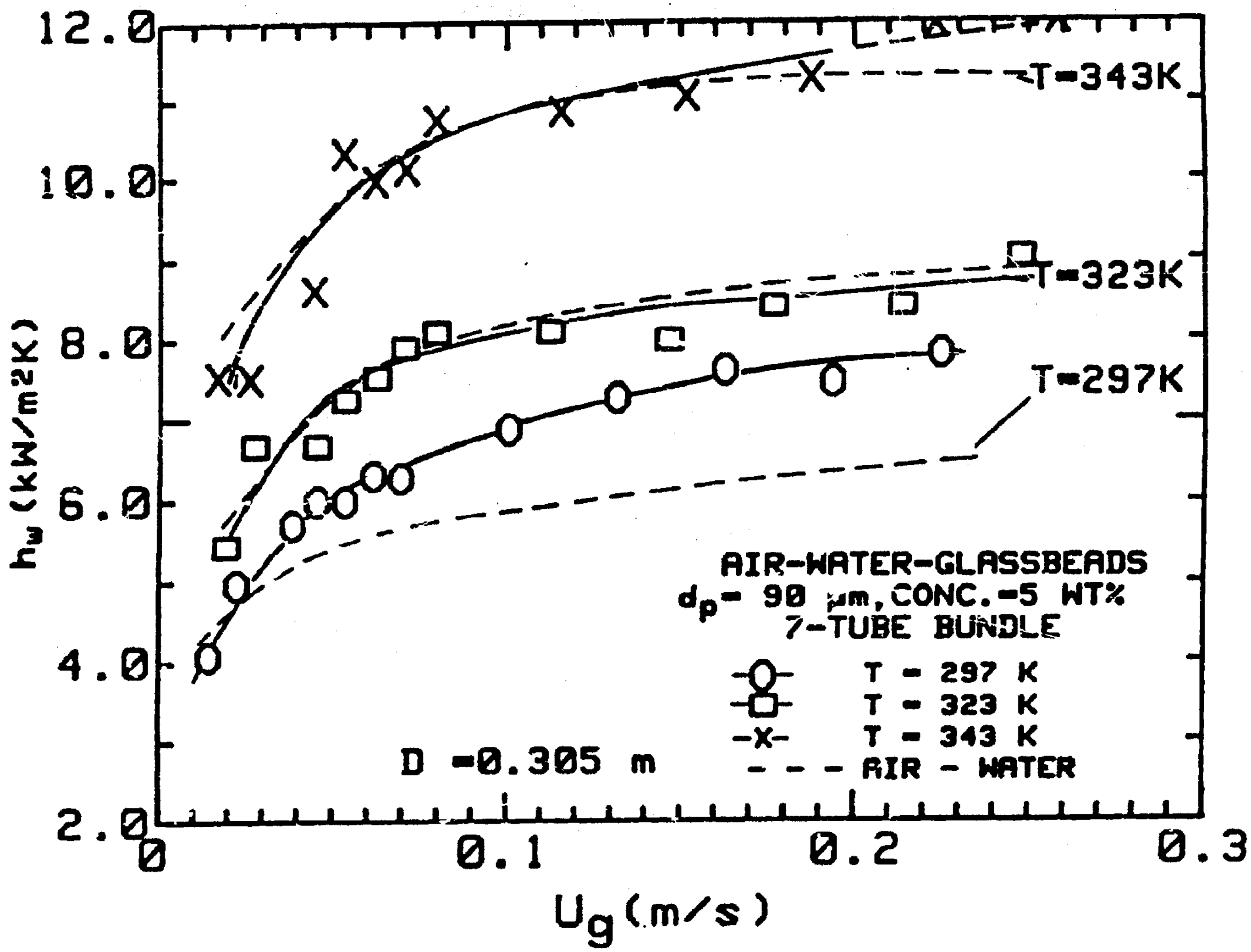

FIGURE 12 Dependence of heat transfer coefficient data on air velocity and temperature for a 90 μm, and 5 weight percent slurry.

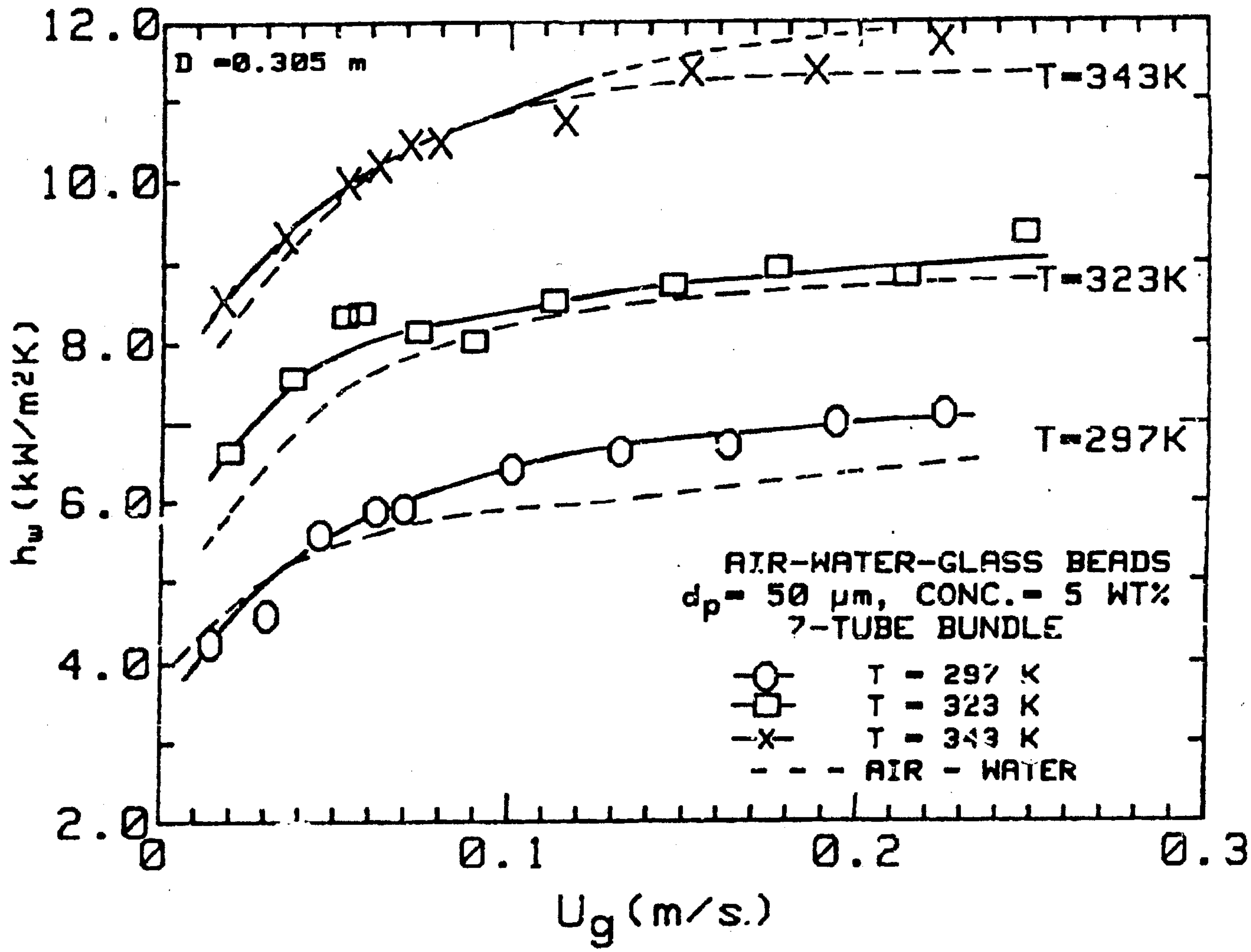

FIGURE 13 Dependence of heat transfer coefficient data on air velocity and temperature for a 50 μm, and 5 weight percent slurry.

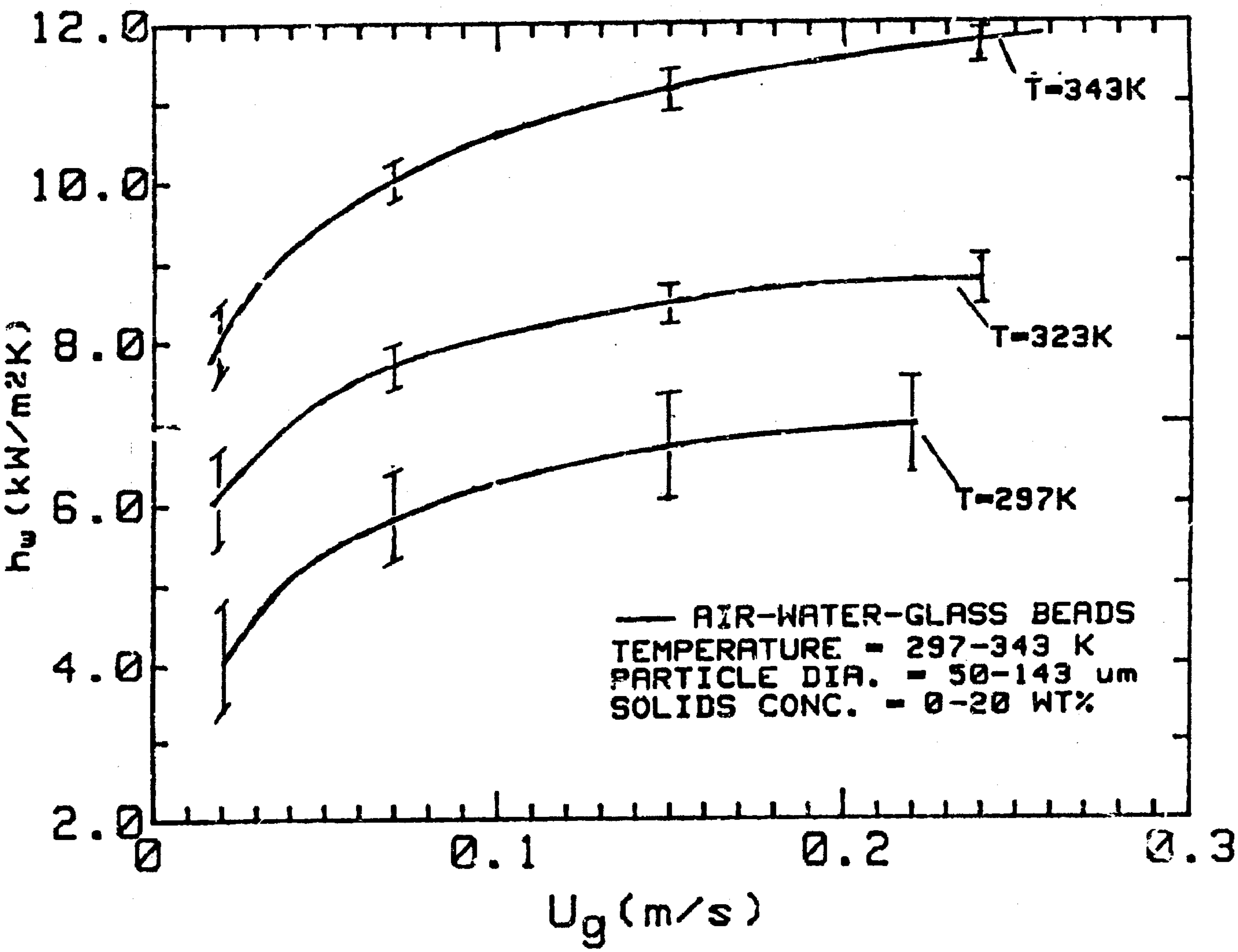

FIGURE 14 Dependence of average (solids concentrations and particle size in the slurry) heat transfer coefficient on air velocity and temperature.

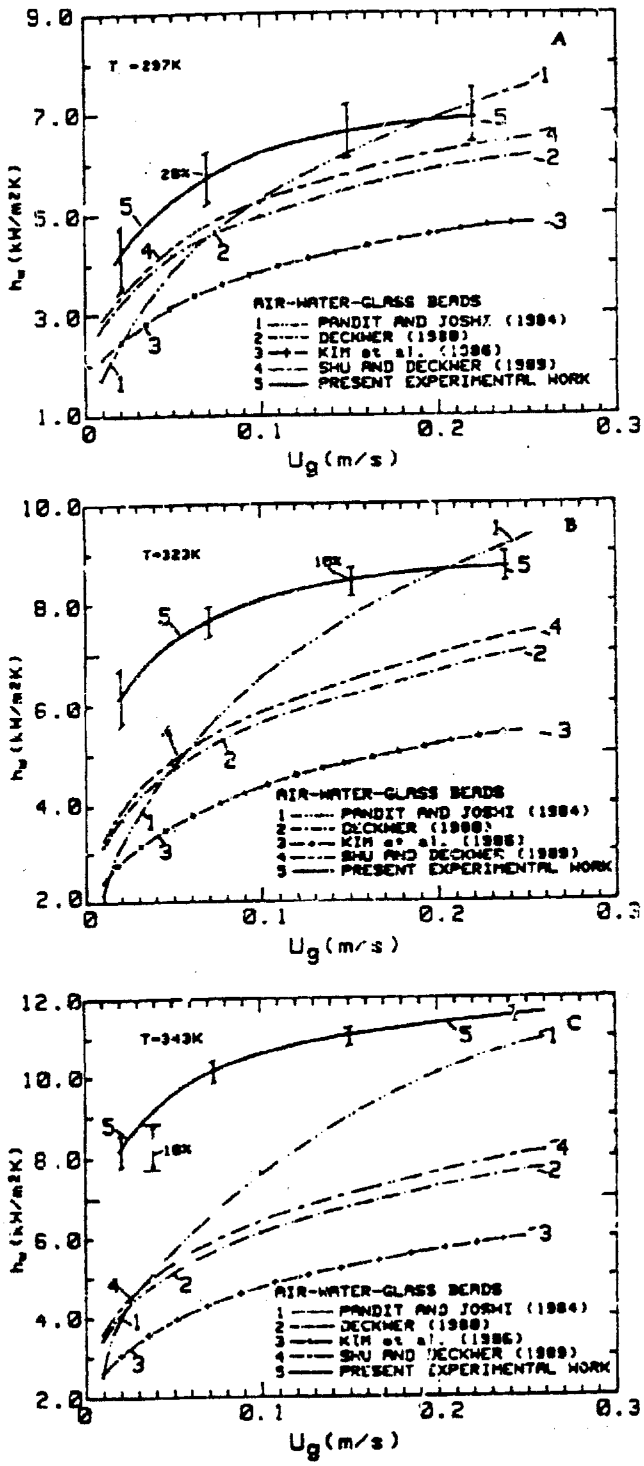

FIGURE 15 Comparison of averaged heat transfer coefficient values as a function of air velocity with the predictions of different correlations at (A) 297, (B) 323, and (C) 343 K.