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Compressor Engineering Refrigeration and Air conditioning

High Performance Buildings

An Experimental Investigation of Convective Boiling Heat Transfer Using Alternative and Natural Refrigerants inside Horizontal Microchannels

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Contents

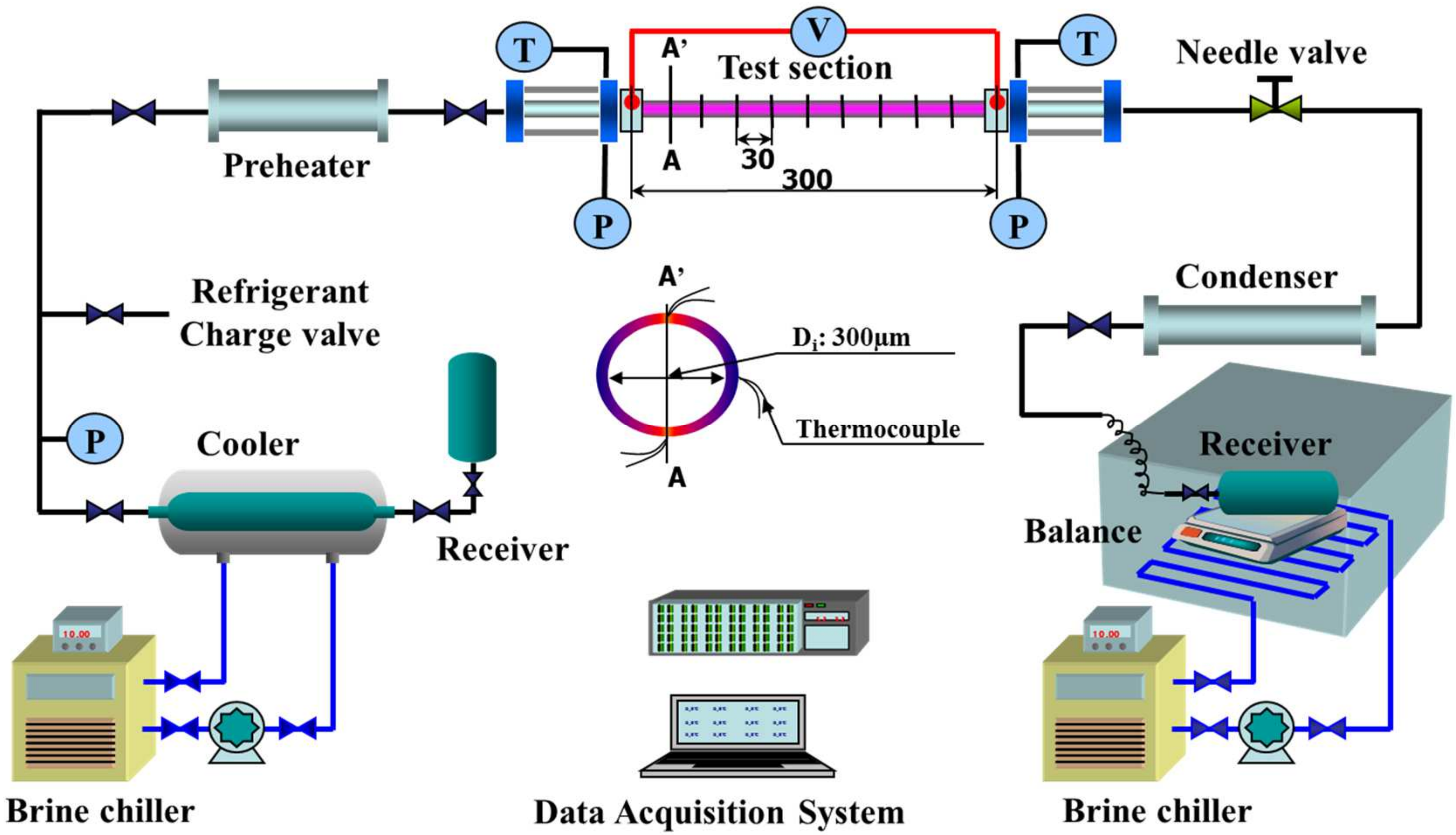
1. The advantage of small tube: high effective heat transfer and decreasing the size of heat exchanger.

2. R410A has been widely used in many refrigeration and heat pump applications.

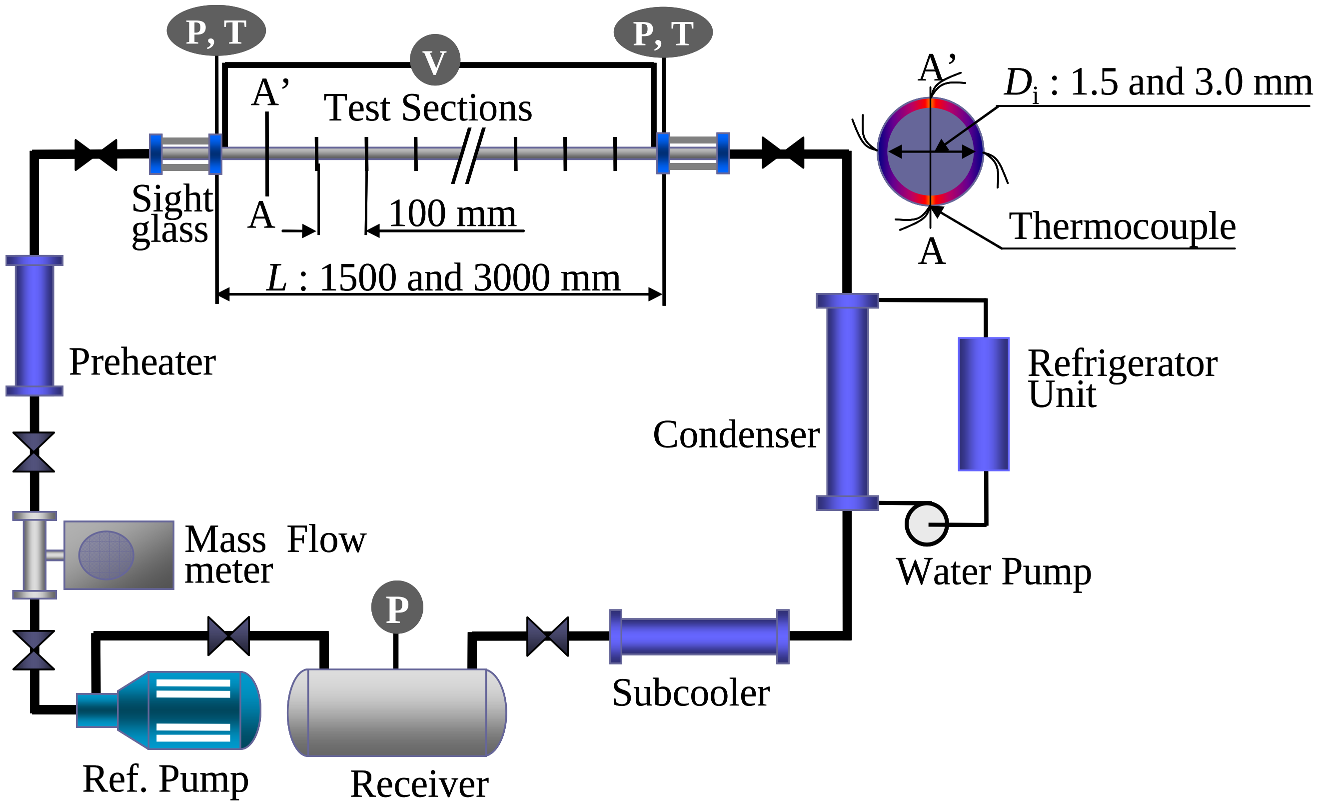
3. R32 and R290 are environmentally-friendly refrigerants. They are considered as promising candidates for the next refrigerant generation.

4. Limited studies about boiling heat transfer coefficient of R410A, R32 and R290 in mini- and micro-scale channels → Experimentally investigating and proposing a modified heat transfer coefficient correlation

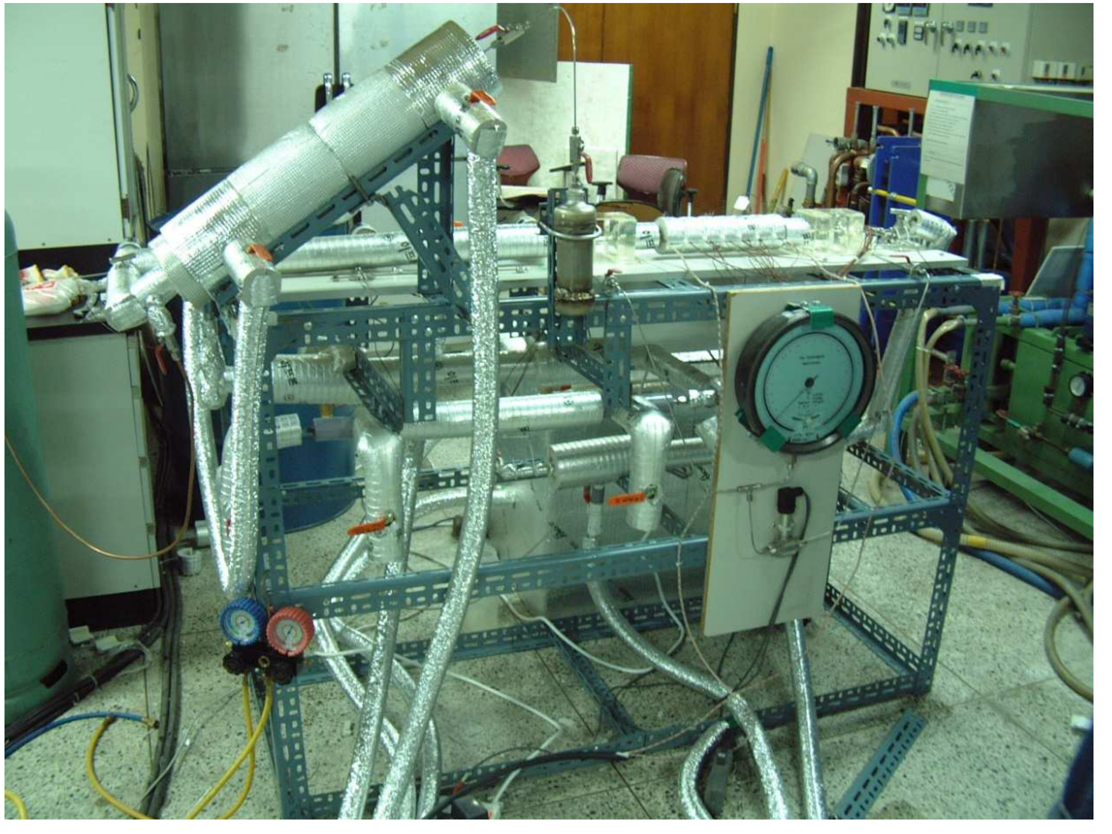
1.Experimental Model for 0.3 mm inner diameter



1.Experimental Model for 1.5 mm inner diameter

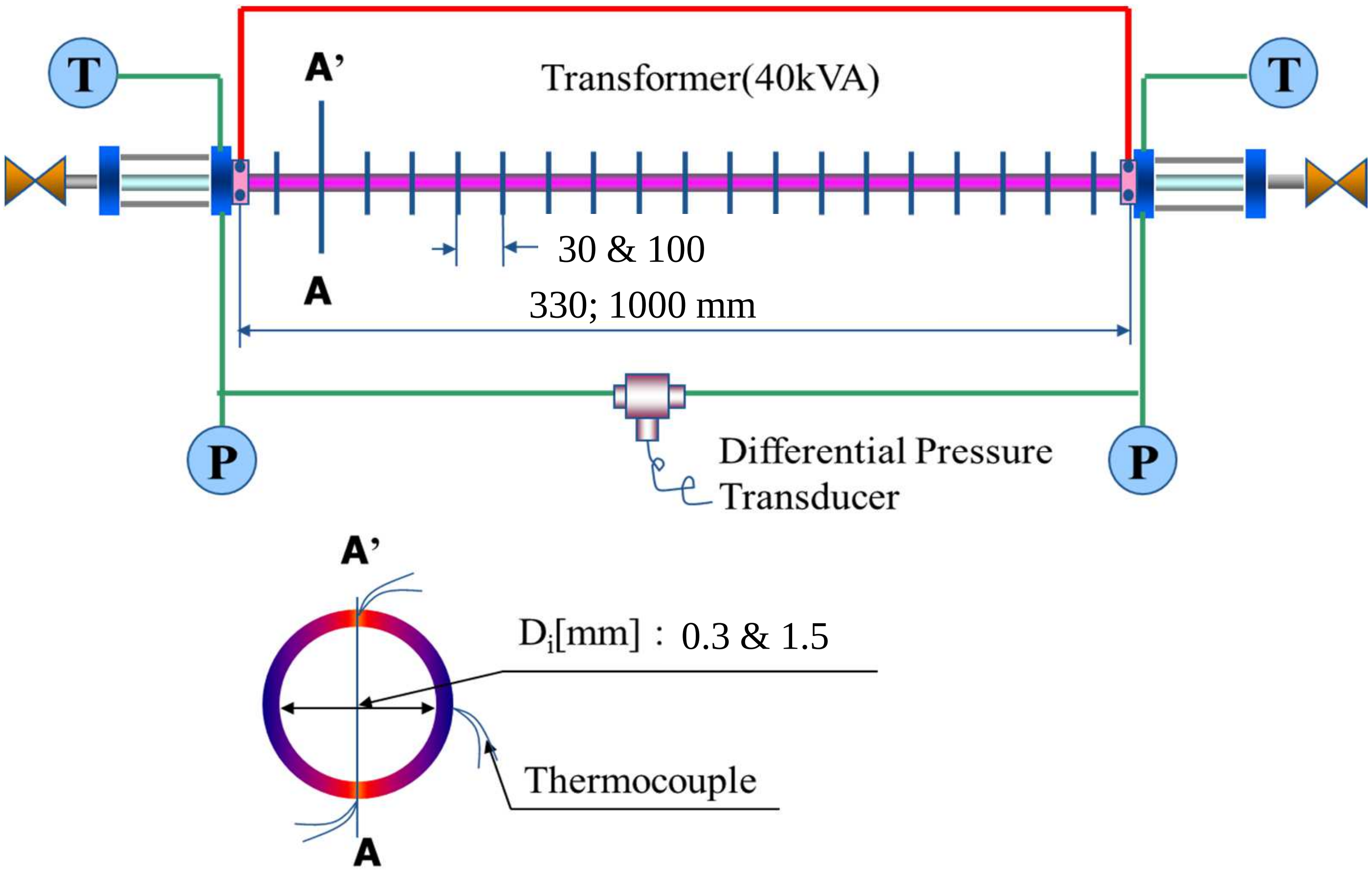


1.Experimental Apparatus (0.3 mm)



1.Experimental Apparatus (1.5 mm)

2. Test section



3.Conditions and Uncertainty

Working refrigerant	**R410A; R32 & R290**
Test section	Horizontal smooth stainless steel mini-channel
Quality	Up to 1.0
Inner tube diameter (mm)	0.3,1.5 & 3.0
Tube length (mm)	330; 1000
Mass flux (kg/m²s)	200 – 500
Heat flux (kW/m²)	10 - 20
Inlet T_{sat} (ºC)	10

Parameters	**Uncertainty**
T_{wi} (˚C)	0 (at 100˚C)
P_{dif}(kPa)	±2.5
G (%)	±5.66
Q (%)	±3
x (%)	±1.79 to ±9.89
h (%)	±10

4.1.Properties of R410A

Refrigerant	T_{sat} (°C)	P (Mpa)	ρ_f (kg/m³)	ρ_g (kg/m³)	ρ_f/ρ_g	μ_f (10^{-6}Pas)	μ_g (10^{-6}Pas)	μ_f/μ_g	σ (10^{-3}N/m)
R410A	5	0.936	1149	35.86	32.04	151.8	12.47	12.17	8.28
	10	1.088	1128	41.91	26.91	142.76	12.75	11.19	7.51
	15	1.258	1106	48.85	22.64	134.11	13.04	10.28	6.75

4.2. Properties of R32

Refrigerant	T_{sat} (°C)	P (Mpa)	ρ_f (kg/m³)	ρ_g (kg/m³)	ρ_f/ρ_g	μ_f (10^{-6}Pas)	μ_g (10^{-6}Pas)	μ_f/μ_g	σ (10^{-3}N/m)
R32	5	0.9514	1037	25.89	40.05	142.34	11.75	12.11	10.11
	10	1.1069	1019	30.23	33.7	134.63	11.99	11.22	9.25
	15	1.280	1000	35.19	28.41	127.31	12.25	10.39	8.41

4.3.Properties of R290

Refrigerant	T_{sat} (°C)	P (Mpa)	ρ_f (kg/m³)	ρ_g (kg/m³)	ρ_f/ρ_g	μ_f (10^{-6}Pas)	μ_g (10^{-6}Pas)	μ_f/μ_g	σ (10^{-3}N/m)
R32	5	0.5511	521.7	11.96	43.62	119.3	7.59	15.71	9.48
	10	0.6366	514.7	13.78	37.35	113.3	7.75	14.61	8.84
	15	0.7315	507.5	15.81	32.09	107.6	7.91	13.60	8.21

4.4. Properties of NH3

Refrigerant	T_{sat} (°C)	P (Mpa)	ρ_f (kg/m³)	ρ_g (kg/m³)	ρ_f/ρ_g	μ_f (10^{-6}Pas)	μ_g (10^{-6}Pas)	μ_f/μ_g	σ (10^{-3}N/m)
R290	5	0.515	631.66	4.11	153.68	161.23	9.20	17.52	3.12
	10	0.615	624.64	4.86	128.39	153.03	9.36	16.34	2.95
	15	0.728	617.49	5.72	107.95	145.42	9.51	15.29	2.79

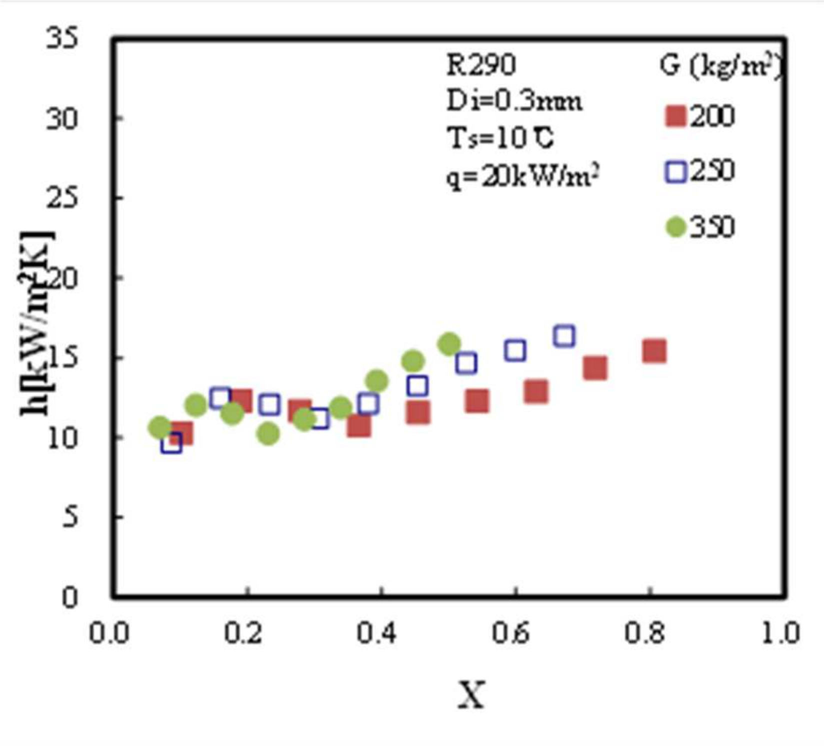
5.1.Data Reduction – Heat transfer

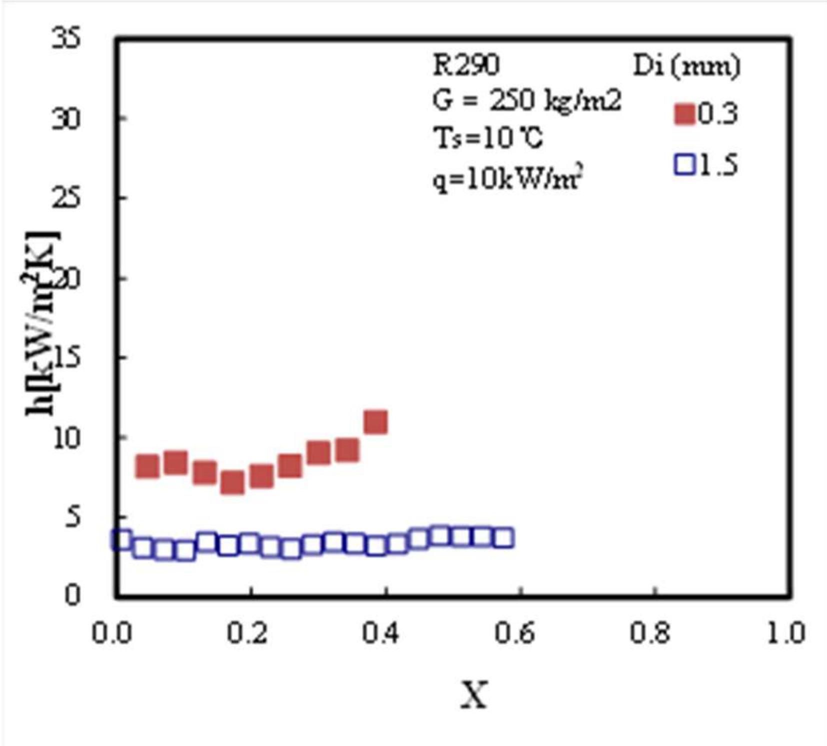
Steady-state one-dimensional radial conduction heat transfer through the wall.	
Inside wall temp.	$T_{\mathrm{wi}} = T_{\mathrm{wo}} + \frac{Q}{16k}\left(D_{\mathrm{o}}^2 - D_{\mathrm{i}}^2\right) - \frac{Q}{8k} D_{\mathrm{o}}^2 \ln \frac{D_{\mathrm{o}}}{D_{\mathrm{i}}}$
Vapor quality (Pre-heater)	$x_{\mathrm{o}} = \frac{\Delta i + i_{\mathrm{f,in}} - i_{\mathrm{f}}}{i_{\mathrm{fg}}}$
Vapor quality (Test section)	$x = \frac{i - i_{\mathrm{f}}}{i_{\mathrm{fg}}}$
Heat transfer coefficient	$h = \frac{q}{T_{\mathrm{wi}} - T_{\mathrm{sat}}}$

5.2.Data Reduction – Pressure drop

Pressure	$\Delta p_{total} = \Delta p_{static} + \Delta p_{mom} + \Delta p_{frict}$
Momentum Pressure	$-\left(\frac{dp}{dz}a\right) = G^2 \upsilon_f \left[\frac{x^2}{\alpha}\left(\frac{\upsilon_g}{\upsilon_f}\right) + \frac{(1-x)^2}{1-\alpha} - 1\right]$
Friction factor	$\mathrm{Re}_{fo} < 2300: f_{laminar} = \frac{16}{\mathrm{Re}_{fo}}$ $\mathrm{Re}_{fo} > 3000: f_{Blausius} = 0.079\,\mathrm{Re}_{fo}^{-0.25}$ $2300 \le \mathrm{Re}_{fo} \le 3000: f_{trans} = \frac{f_{Blausius} - f_{laminar}}{3000-2300}(\mathrm{Re}_{fo} - 2300) + f_{laminar}$
Frictional Pressure gradient of "liquid only"	$\left(\frac{dp}{dz}F\right)_{fo} = \frac{2 f_{fo} G^2}{D\rho_l}$
Void Fraction (Steiner (1993))	$\alpha = \frac{x}{\rho_g}\left[(1+0.12(1-x))\left(\frac{x}{\rho_g} + \frac{1-x}{\rho_f}\right) + \frac{1.18(1-x)\left[g\sigma(\rho_f - \rho_g)\right]^{0.25}}{G\rho_f^{0.5}}\right]^{-1}$

Effect of Mass Fluxes on HTCs





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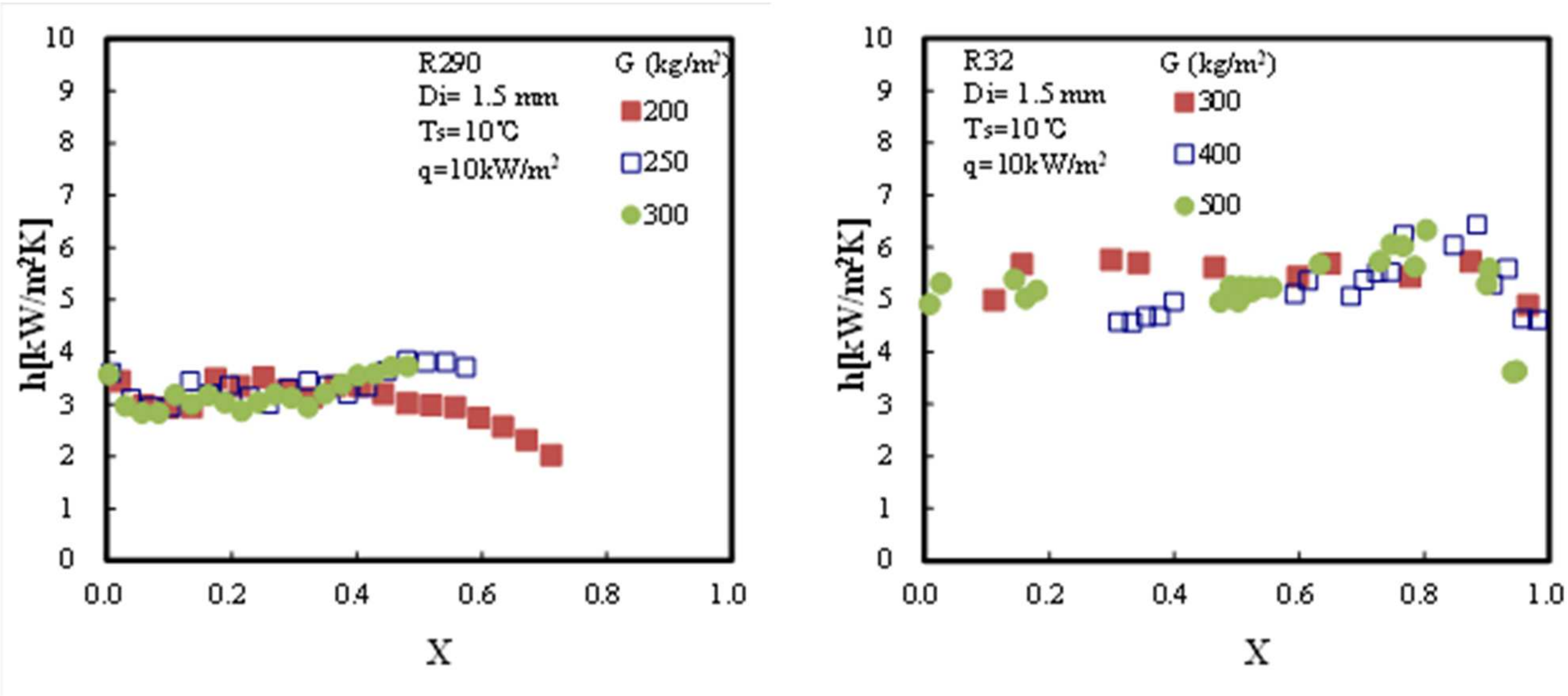

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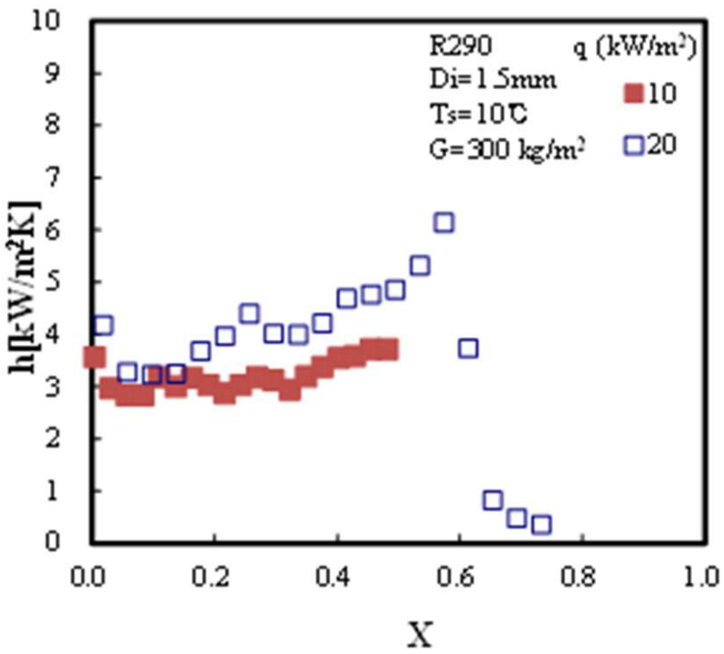

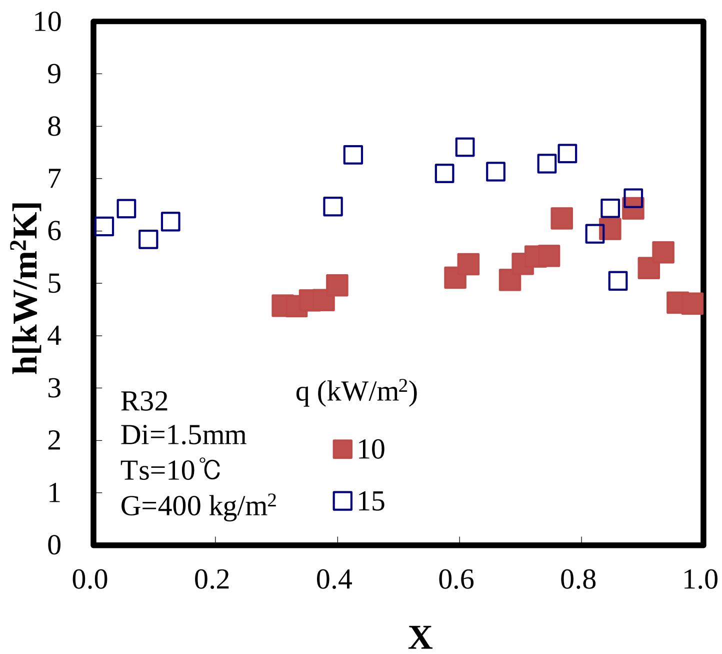

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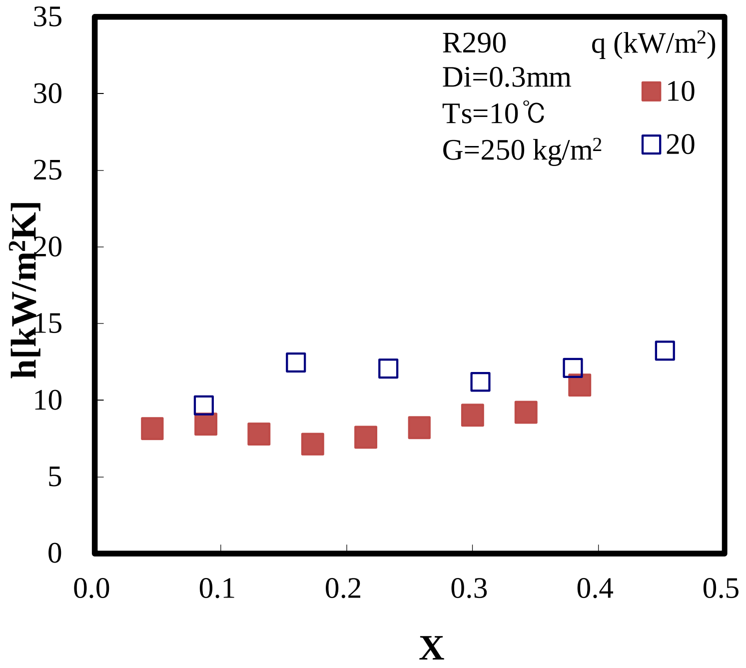
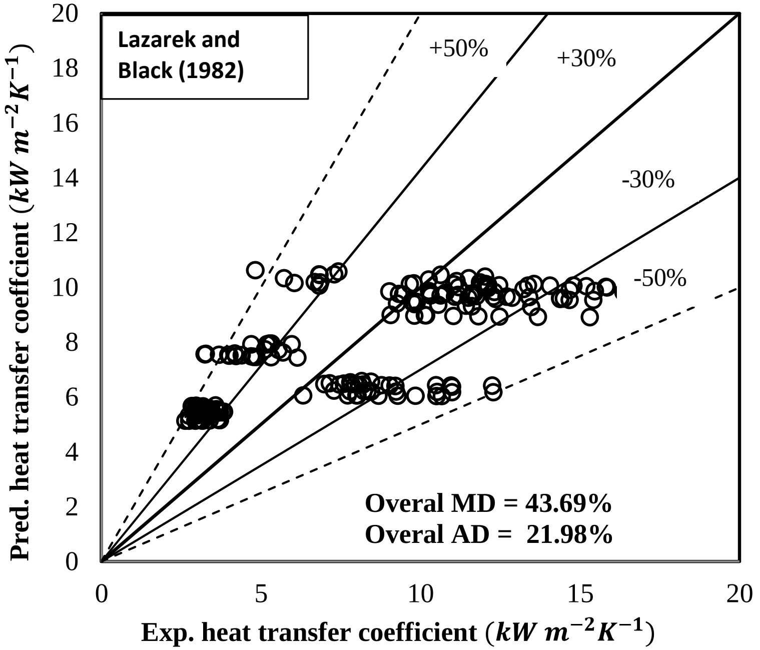
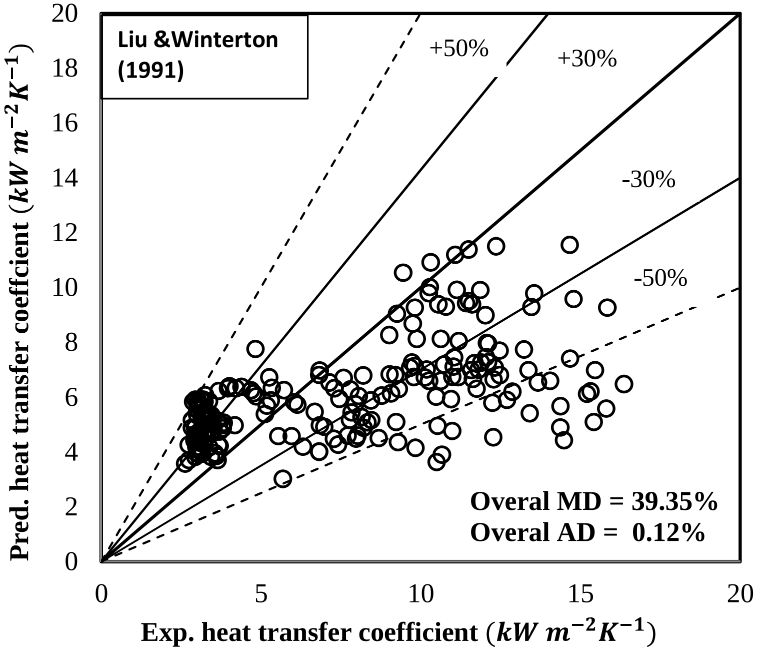


Comparison of exp. data with some well known heat transfer correlations





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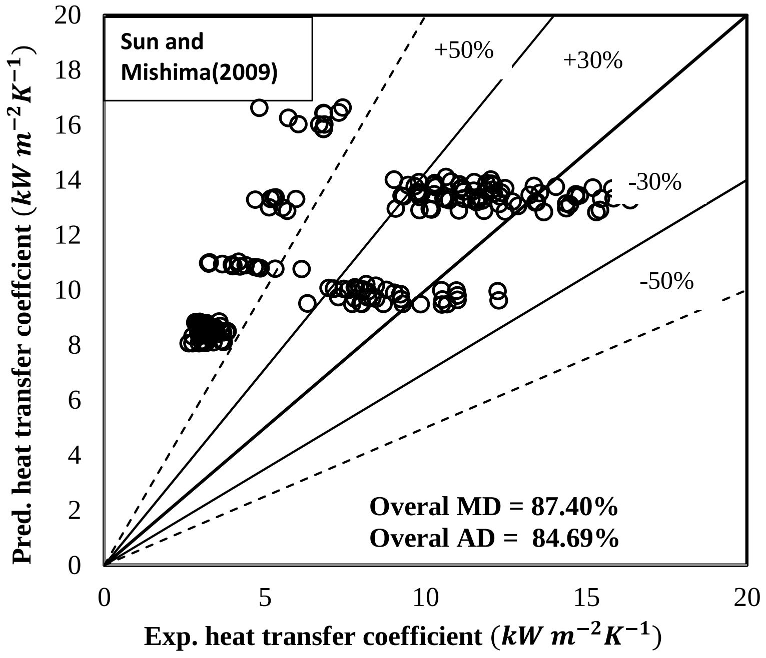
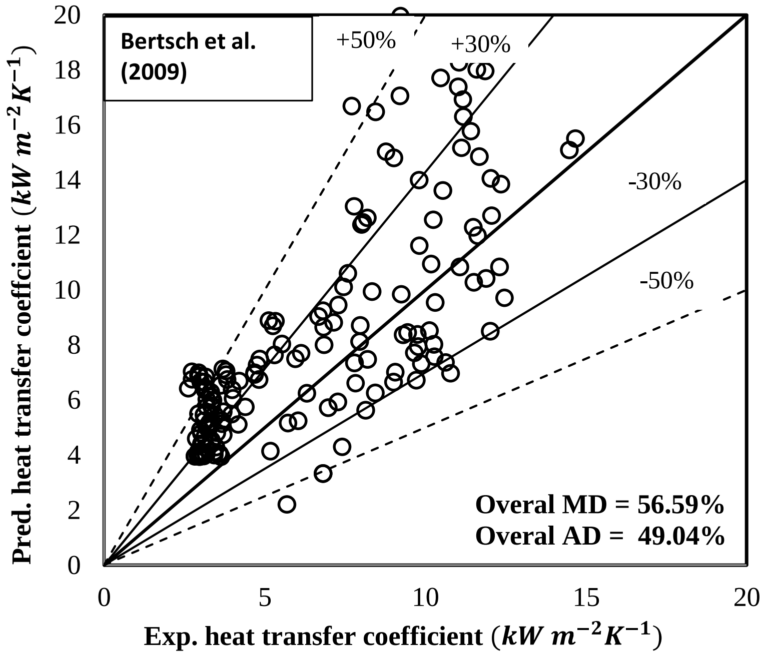




Developing new HTC correlation

$$h_{tp} = Sh_{nbc} + Fh_f$$

$$S = 0.13\left(\phi_f^2\right)^{0.12} Bo^{-0.235}$$

$$F = \left[\left(0.006\phi_f^2 + 1.15\right)\right]$$

$$h_{nbc} = 55P_r^{0.12}\left(-0.4343\ln P_r\right)^{-0.55} M^{-0.5} q^{0.67}, \text{ where } q \text{ is in W m}^{-2}$$

$$h_f = 0.023\frac{k_f}{D}\left[\frac{G(1-x)D}{\mu_f}\right]^{0.8}\left(\frac{C_{pf}\mu_f}{k_f}\right)^{0.4} \quad \text{if } \mathrm{Re}_f \ge 5\times10^6$$

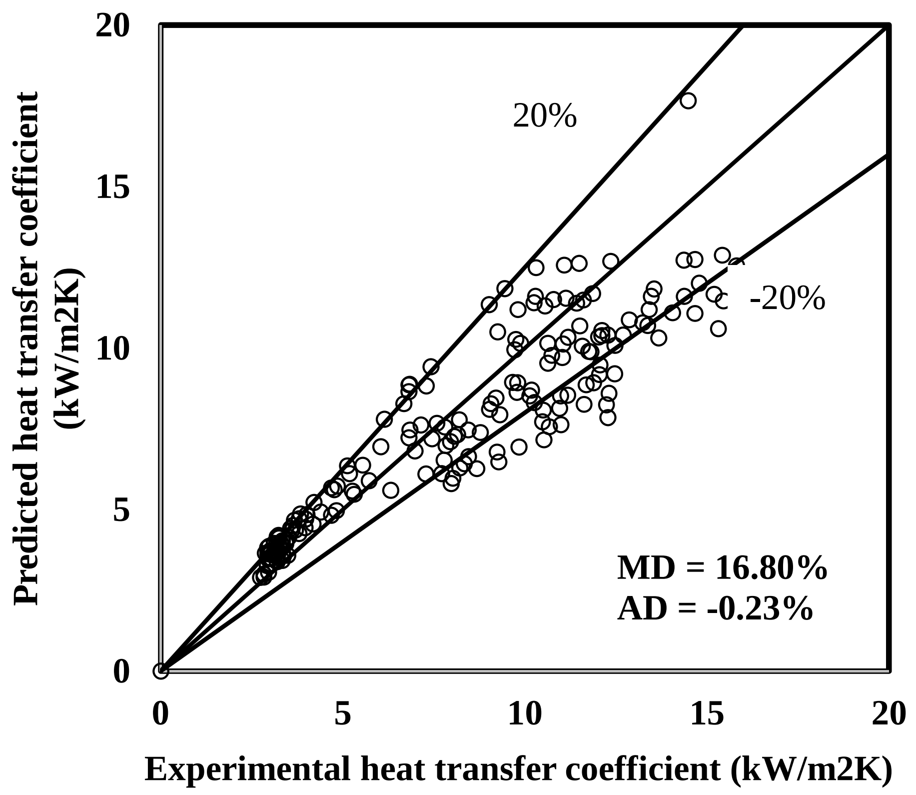
$$f = \begin{cases} 16\mathrm{Re}^{-1} \ \textit{for} \ \mathrm{Re} < 2300 \\ 16\mathrm{Re}^{-1} + \dfrac{0.079\mathrm{Re}^{-0.25} - 16\mathrm{Re}^{-1}}{3000-2300}(\mathrm{Re}-2300) \text{ for } 2300 < \mathrm{Re} < 3000 \\ 0.079\mathrm{Re}^{-0.25} \ \text{for } \mathrm{Re} > 3000 \end{cases}$$

$$\phi_f^2 = 1 + \frac{C}{X} + \frac{1}{X^2}$$

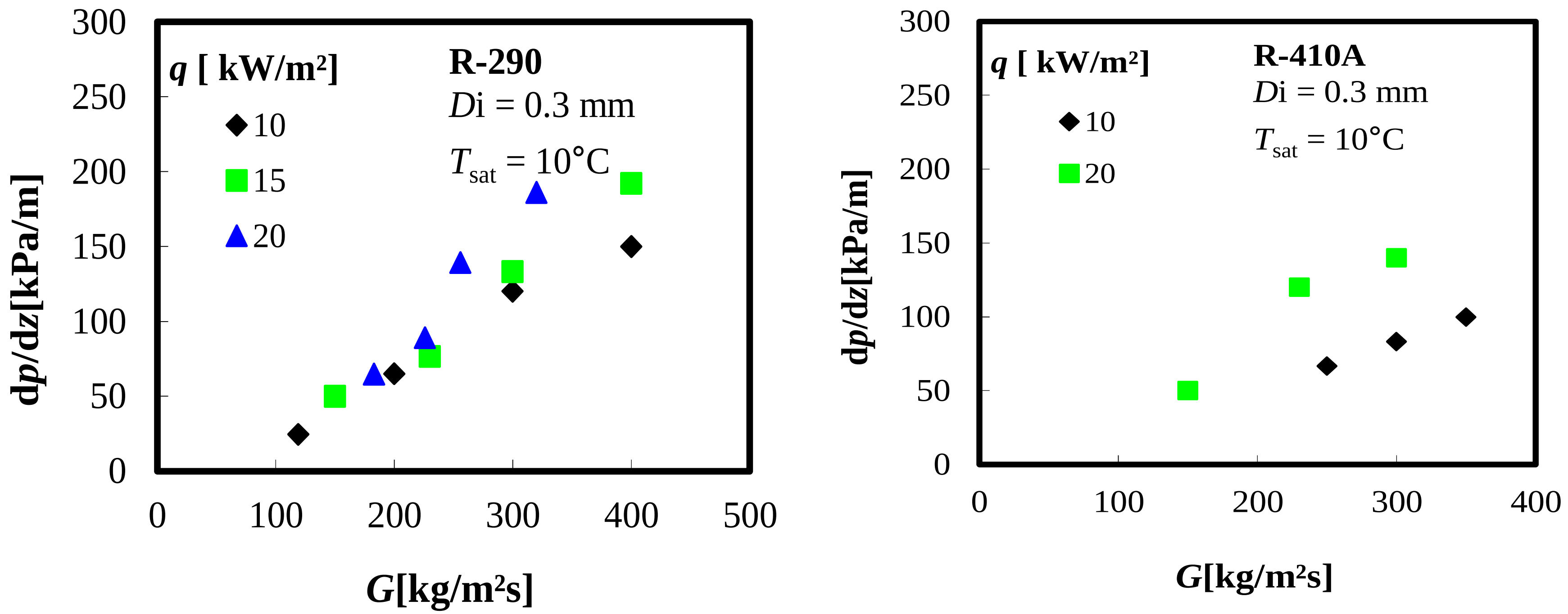
$$X = \left(\frac{f_f}{f_g}\right)^{1/2}\left(\frac{1-x}{x}\right)\left(\frac{\rho_g}{\rho_f}\right)^{1/2}$$

$$C \begin{cases} = 5 \text{ for } \mathrm{Re}_f < 2300 \text{ and } \mathrm{Re}_g < 2300 \\ = 10 \text{ for } \mathrm{Re}_f > 3000 \text{ and } \mathrm{Re}_g < 2300 \\ = 12 \text{ for } \mathrm{Re}_f < 2300 \text{ and } \mathrm{Re}_g > 3000 \\ = 20 \text{ for } \mathrm{Re}_f > 3000 \text{ and } \mathrm{Re}_g > 3000 \end{cases}$$

Comparison of HTCs b/w predicted and experimental data



II. Pressure drop



1. The heat transfer coefficient of R32 and R290 increased with the increasing of heat flux. The contribution of nucleate boiling is dominant.

2. The frictional pressure gradient is higher with the higher mass flux and heat flux

3. The experimental data was compared with some well-known heat transfer coefficient correlations. Among them, the one proposed by Liu and Winterton (1991) shows the best prediction

4. A new heat transfer coefficient correlation were developed with the mean deviations of 16.80% and -0.23%, respectively.

Thank you for your attention!