Effect of Corrugation Angle on the Thermal Behaviour of Power-law Fluids During a Flow in Plate Heat Exchangers

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Abstract

Local and average Nusselt numbers of power-law fluids were studied on PHE channels with different corrugation angles, being the effect of the temperature on viscosity also considered on the thermal correlations development.

Introduction

Heat transfer in a PHE is dependent of the passages geometrical properties and also influenced by the variation of temperature dependent physical properties. Nusselt numbers are commonly described by:

$$\mathrm{Nu} = a\,\mathrm{Re}^{m}\,\mathrm{Pr}^{0.3}\left(\frac{\eta}{\eta_w}\right)^{b} \qquad (1)$$

Problem Description

Thermo-rheological behaviour of the fluid

Constitutive model takes in account the influence of shear rate and temperature on viscosity (Eq. (2). Rheological parameters took the values: n = 0.5, K_c = 0.499 Pa $s^{0.5}$ and E/R = 3065K.

$$\eta(\dot{\gamma},T) = K_c\dot{\gamma}^{n-1}\exp\left(\frac{E}{RT}\right) \qquad (2)$$

Geometrical domain and boundary conditions

3D geometry constituted by three elements: channel, superior plate and inferior plate. A symmetry axis was established simplifying the geometry to half of a channel (Fig. 1). It was imposed a linear heat flux, $q(x)$, along the plates and non-slip conditions at the walls.

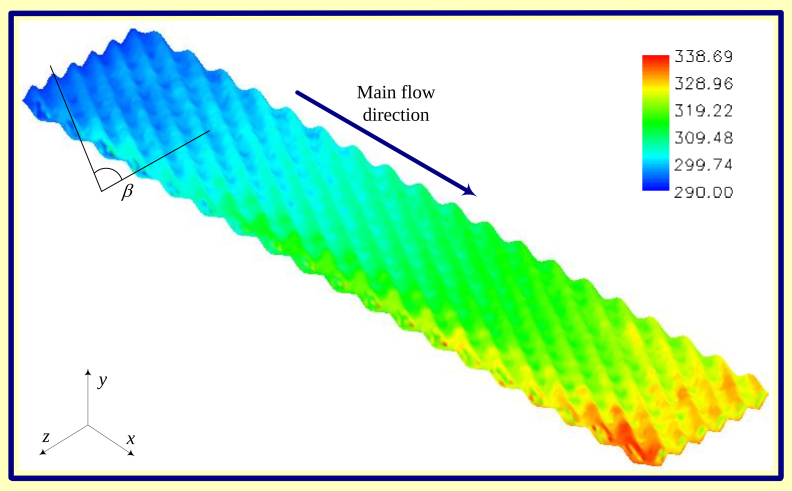


Fig. 1: Temperature distribution along a channel with β = 60º.

Results and Discussion

Fluid and wall temperatures for each x were obtained from the numerical results (Fig.2). The referred values allowed the calculation of local convective heat transfer coefficients (Eq. (3)) and local Nusselt numbers (Eq. (4)).

$$h(x) = \frac{q(x)}{\left(T_f - T_w\right)(x)} \qquad (3)$$

$$\mathrm{Nu}(x) = \frac{h(x)D_H}{k} \qquad (4)$$

Hydraulic diameter was defined as $D_H = 2b$, being b the inter-plates distance.

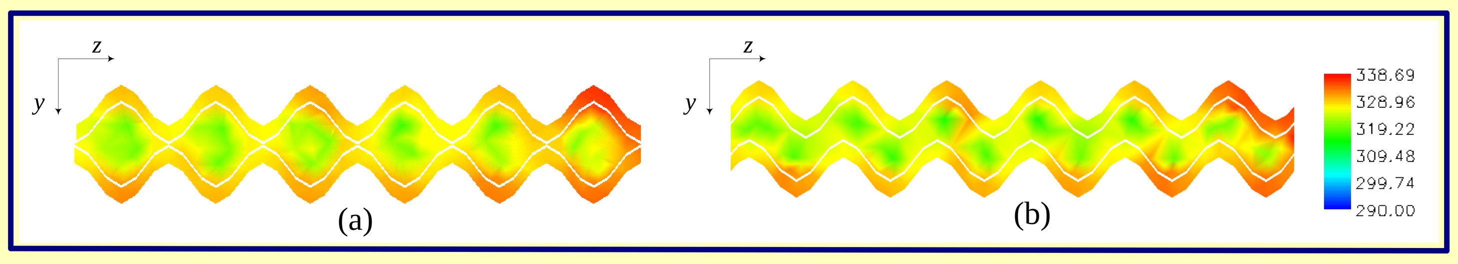
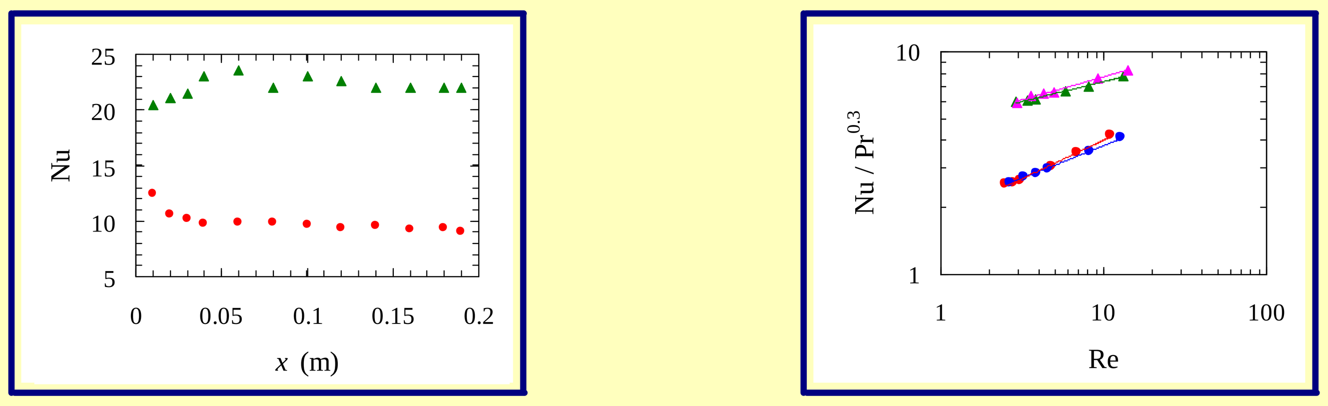


Fig. 2: Plates and fluid temperature distribution for β = 60º and for different x.



(a) (b)

Fig. 3: (a) Local Nusselt number; (b) Thermal correlations. (●) E/R = 3065 K and β = 30º; (▲) E/R = 3065 K and β = 60º; (●) E/R = 0 K and β = 30º; (▲) E/R = 0 K and β = 60º.

Local Nusselt numbers (Fig. 3 (a)) were studied for different Reynolds numbers which allowed the calculation of average Nusselt numbers and the development of thermal correlations (Fig. 3(b)). The parameters from Eq. (1), obtained on the different types of simulation, are shown on Tab. 1.

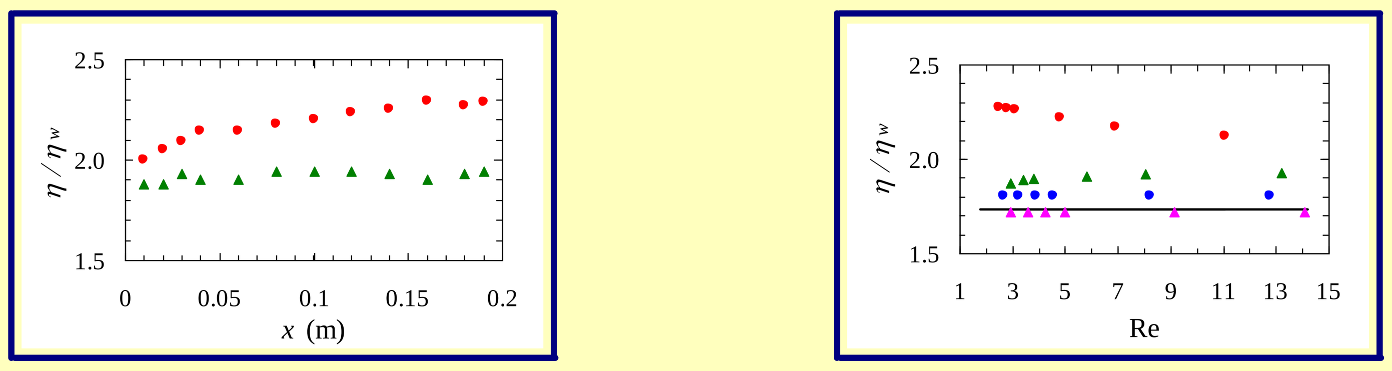
Tab. 1: Parameters of thermal correlations.

β (º)	E/R (K)	b (-)	a (-)	m (-)
30	3 065	0	1.809	0.347
		0.14	1.602	0.353
	0	0	1.924	0.295
		0.14	1.772	0.295
60	3 065	0	4.859	0.180
		0.14	4.458	0.178
	0	0	4.772	0.210
		0.14	4.423	0.210

On the development of the thermal correlations the ratio between bulk and wall viscosity (Fig. 4) was estimated by Eq. (5), which was reduced to Eq. (6) when E/R = 0 K.

$$\frac{\eta}{\eta_w} = \left(\frac{\dot{\gamma}_w}{\bar{\dot{\gamma}}}\right)^{1-n}\exp\left(\frac{E\left(T_w - T_f\right)}{RT_wT_f}\right) \qquad (5)$$

$$\frac{\eta}{\eta_w} = \left(\frac{\dot{\gamma}_w}{\bar{\dot{\gamma}}}\right)^{1-n} \cong \left(\frac{n+1}{n}\right)^{1-n} \qquad (6)$$



(a) (b)

Fig. 4: Ratio between bulk viscosity and viscosity near the wall (a) along the channel; (b) for different Reynolds number. (●) E/R = 3065 K and β = 30º; (▲) E/R = 3065 K and β = 60º; (●) E/R = 0 K and β = 30º; (▲) E/R = 0 K and β = 60º and line (—) represents Eq. (6).

Conclusions

The obtained Nusselt numbers are higher than the typical for Newtonian fluids due to the shear thinning effects. For the same Reynolds number, convective heat transfer coefficients using a corrugation angle of 60 º are about two times higher than the obtained for 30º.

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