Universidade do Minho

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LEPAE Laboratório de Engenharia de Processos, Ambiente e Energia

Influence of Corrugation Angle in the Stirred Yoghurt Processing in Plate Heat Exchangers

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1. Introduction

Research on heat transfer of non-Newtonian fluids during thermal processing is useful to optimise the heat exchanger design, as well as to define quality levels of the final product. In the present study, a non-isothermal and non-Newtonian flow in plate heat exchangers was simulated numerically, in order to evaluate the influence of corrugation angle on the thermal and hydrodynamics characteristics of yoghurt during cooling in a plate heat exchanger (PHE).

2. Problem Description

Cooling treatment of stirred yoghurt is usually carried out in PHEs since these equipments are suitable for liquid-liquid heat transfer duties that require uniform and rapid cooling or heating. In this operation, two mechanisms of heat transfer occur: conduction, in the plates, and convection inside the channels. The set of equations that describe mathematically the problem were the Navier-Stokes equations, for incompressible and stationary flow, and Fourier's law for the conduction problems. Additionally, a constitutive model that describes the rheological properties of yoghurt under the cooling conditions has to be established in order to define totally the problem. The used model was proposed by Afonso *et al*. (2003) and takes into account the influence of shear rate and temperature:

$$\mu_{app} = K\dot{\gamma}^{n} \exp\left(\frac{E}{RT}\right) \quad (1)$$

3. Numerical Simulation

The problem was solved using the commercial finite element method package POLYFLOW. Simulations were performed for PHEs with distinct corrugation angles: β = 30º and β = 60º.

Geometrical domain

The studied PHE had a parallel arrangement and admitting a uniform distribution of the total flow rate in the various channels, the flow simulations were carried out in a single channel. Additionally, uniform flow was considered inside each channel and, for this reason a symmetry axis was established simplifying the geometrical domain to half of a channel.

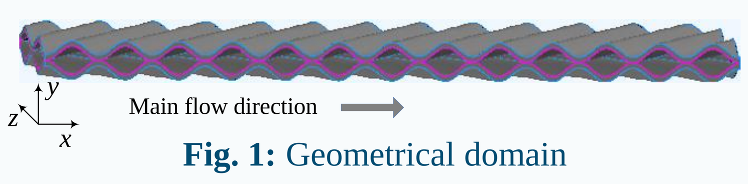

Fig. 1: Geometrical domain

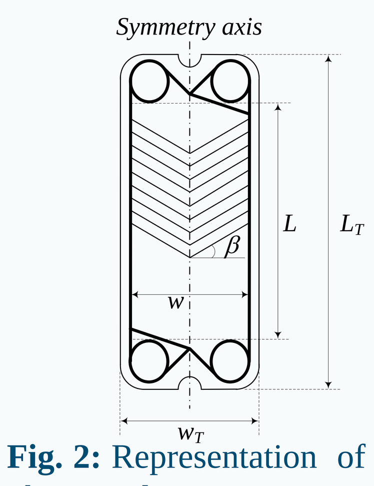

Fig. 2: Representation of a *chevron* plate

Boundary conditions

Flow rate and inlet temperature of yoghurt were established based on experimental data (Afonso *et al.*, 2003). Slip at the wall and heat losses to the surroundings were assumed to be non-existent and a variable heat flux have been imposed in the plates. The heat flux is given by the linear form of the expression:

$$q(x) = UF\left(T_{yog_{in}} - T_{wat_{out}}\right)\exp\left[2ULF\phi x\left(\frac{1}{M_{wat}C_{p\,wat}} - \frac{1}{M_{yog}C_{p\,yog}}\right)\right] \quad (2)$$

4. Results & Discussion

Numerical results concerning the difference between inlet and outlet yoghurt temperature obtained for the PHE with β = 30º were compared with experimental data and a mean deviation of 6.9% was observed.

Fig. 3 demonstrates the inexistence of recirculation zones, confirming this way a laminar flow in the present operation conditions. Another way to evaluate the flow regime consists in the determination of fanning friction factor, *f*. The obtained relation between this factor and Reynolds number, *Re*, was a typical relation for laminar flows (Kakaç, 2002). In Fig. 4, it is also possible to observe the decrease of the constant of proportionality between *f* and *Re* with the corrugation angle.

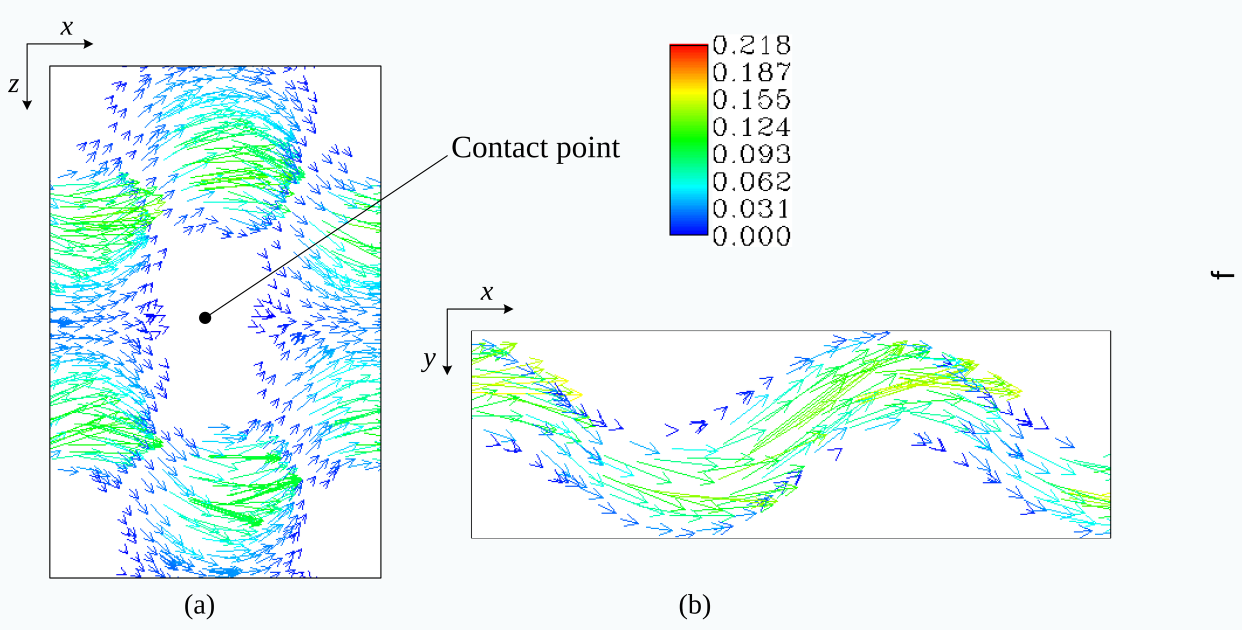

Fig. 3: Velocity vectors in plane of contact points (a) and in a plane z = 0.022 (b) for β = 30º

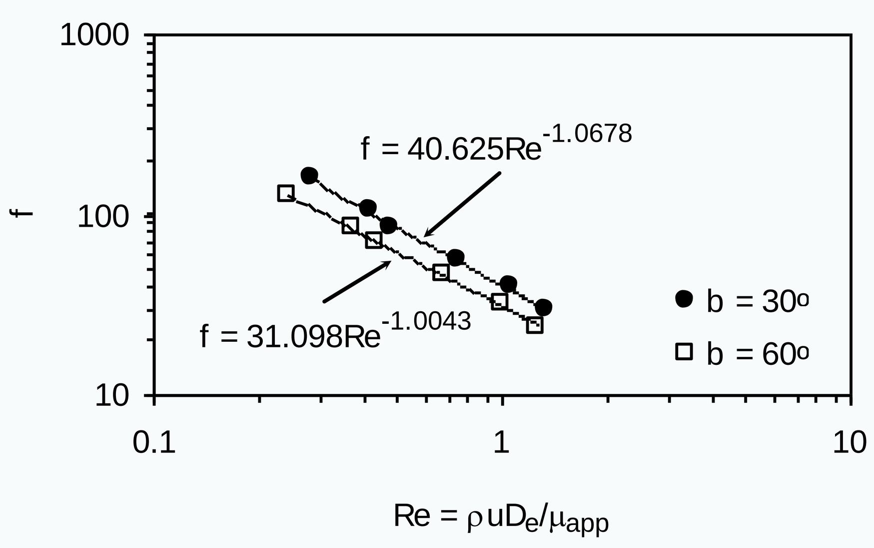

Fig. 4: Fanning friction factors for PHE studied

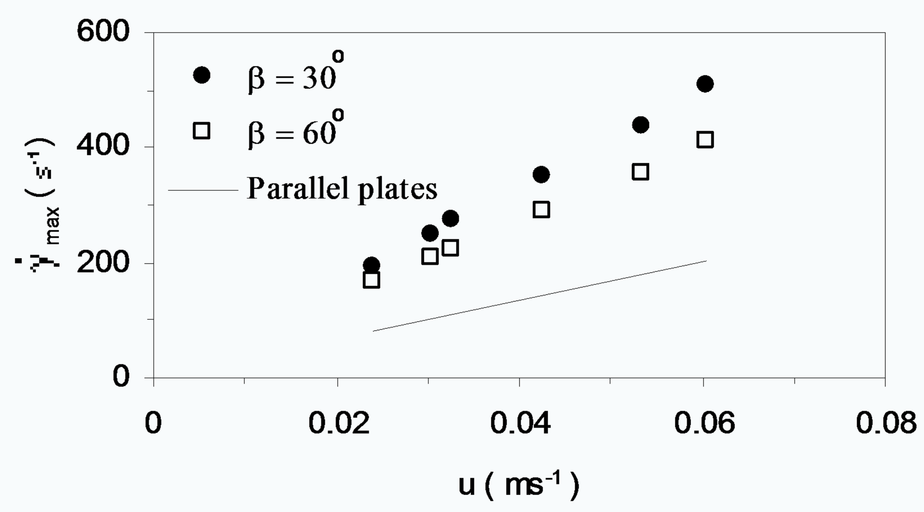

Fig. 5: Maximum shear rate for PHE studied and parallel plates

Maximum shear rate decrease when β increase from 30º to 60º as can be seen in Fig. 5. Infinite parallel plates, correspondent to β = 90º, is the lower limit for maximum shear rate.

5. Conclusions

It was obtained a good agreement between numerical results, for β = 30º, and temperature experimental data. Analysing velocity fields and fanning friction factors was concluded that flow is laminar for both PHEs in the present operation conditions. Higher flow rates of stirred yoghurt can be processed in a PHE with β = 60º, having in mind pressure losses and maximum shear rates.

References

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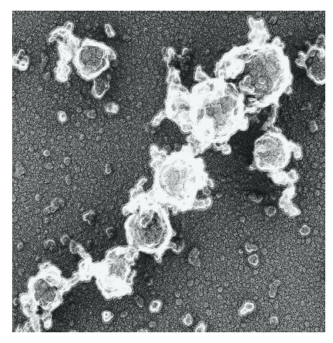
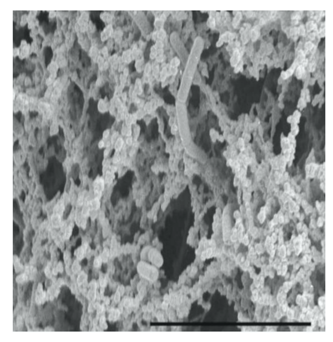
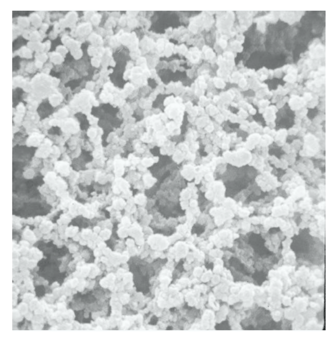
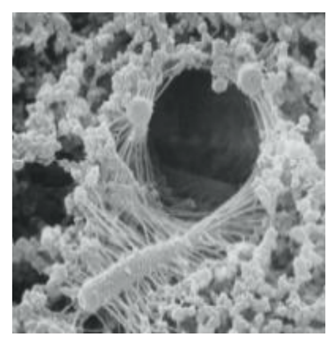
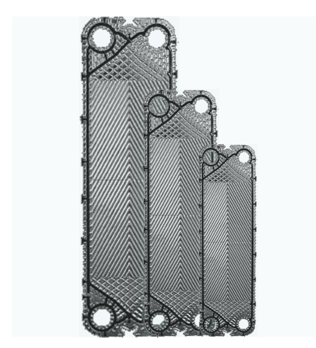
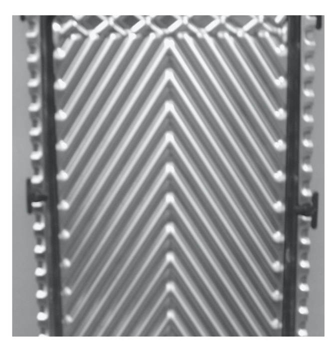
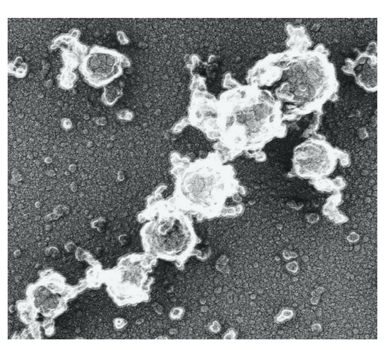
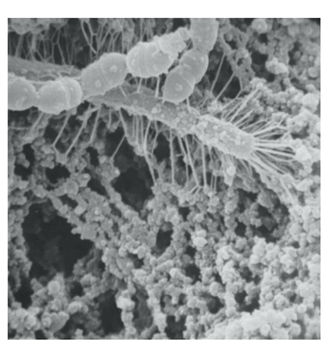
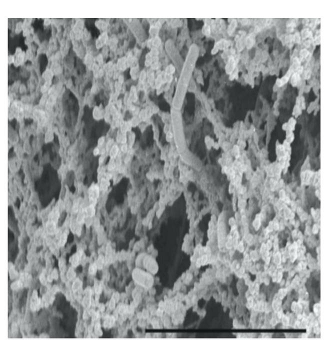
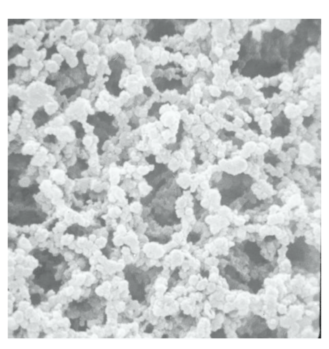
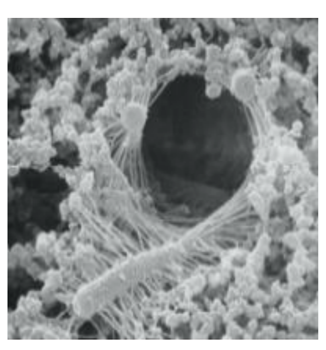
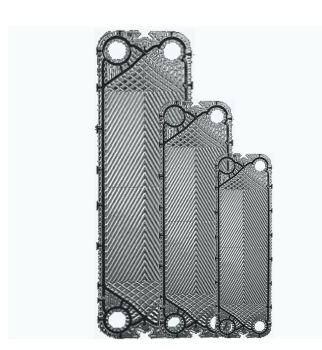
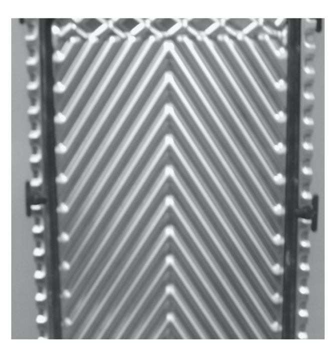
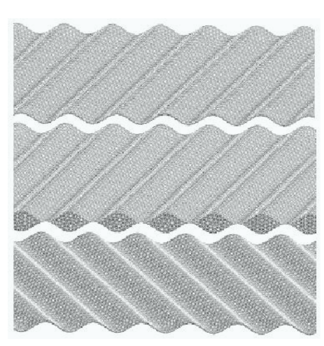
Kakaç, S. & Liu, H. (2002). *Heat exchangers- selection, rating and thermal design*, 2nd edit., CRC Press, pp. 379-396.

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