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Optimal design of an innovative microwave-based fluid heater

Diego Alcañiz [a], Paolo Caccavale [b], Maria Valeria De Bonis [b], Ruth de los Reyes [a], Maria Dolores Ortolá [a], Gianpaolo Ruocco [b,*]

[a] *Instituto Universitario de Ingenieria de Alimentos para el Desarrollo, Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain*
[b] *Scuola d'Ingegneria, Università degli Studi della Basilicata, Campus Macchia Romana, 85100, Potenza, Italy*

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ABSTRACT

New heating technologies are constantly being developed worldwide, specially the electrical ones that take advantage of renewable energy. In this paper, the Basic Cell of Energy Transference (BCET) is proposed as an innovative fluid heater, carrying a microwave-fed heat transfer plate for thermal contact. A fully-dimensional thermo-fluid analysis was implemented and validated to determine the key design parameters and operation features for heat transfer to temperature-sensitive working fluids.

Circulation patterns were observed, when using certain fluids, in turn causing strong temperature non-uniformities. As fluid treatment in the heater relies on the thermal contact at its active plate, the model was used to ascertain the undesired excess/lack temperature range for quality/safety treatments, with reference to a final effective process temperature. Therefore, a geometry optimization by means of internal baffles was carried out which ensured variation to fluid pattern and more uniform active plate temperature. In a base case, the new design allowed to limit the uncontrolled temperature excess by almost 30%, while favouring the pressure drop reduction across the flow device by more than 10%.

1. Introduction

Nowadays, new heating technologies are being developed all around the world, specially, technologies that can be feed with electricity. Over the past two decades, rapid growth in the development of adaptation responses to climate change has occurred around the world [1]. Therefore, the interest in the electrical-feed heating in common processes (such as in the food industry) has risen considerably as it can take advantage of renewable sources of energy, and as it has far less associated CO_2 emissions than the fossil fuels technologies. Process heating is an area of interest for emission reduction as the 70% of the total energy cost of some sectors of the food industry comes from heating processes [2].

There are many novel technologies that can be used for heating applications and, specifically, to heat liquids, like ohmic heating [3], irradiation [4] or microwave (MW) [5]. One such example is the Basic Cell of Energy Transference (BCET) [6], which consists, in its simplest configuration, in two flow boxes interspersed by an active heat transfer plate. The working fluid flows sequentially through the two box, making thermal contact with the active ceramic plate, which is heated by conducted MW. Due to its specifically-designed composition and dimensions, optimized to absorb MW, the active part of the BCET provides precise, efficient and flexible operation to heat fluids in a similar way than a Plate Heat Exchanger (HEX) the most widespread device for heating fluids industrially [7]. Thanks to its compact design and working simplicity (no auxiliary fluid is necessary), it finds its application for precise liquid thermization and in rural areas installations, that can benefit of solar- or wind-driven energy and cannot depend upon a regular water supply. Its feeding technology allows for precise hold-up times, e.g. for pasteurization processes [8,9] and finely-tuned power modulation from the active plate, e.g. with oscillating/periodic heat flux as in nanofluids thermization [10], which requires more immediate response to temperature changes.

HEX and heater design optimization is a very active area of research an development. Recently, Yang et al. [11], Picon-Nuñez et al. [12], Caputo et al. [13] confirmed that the pressure drop is correlated with the heat transfer coefficient, which is the key concept at stake here. While higher heat transfer contact and removal from the heater's active plate (or heater efficiency) is ensured by turbulent flow conditions, laminar flows are preferred instead to decrease the cost associated with pumping power [14]. On the other hand, the increment of heater efficiency, for a given active surface area, may lead to a more affordable device, due to

* Corresponding author.
E-mail address: gianpaolo.ruocco@unibas.it (G. Ruocco).

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