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Improvement of a thermoelectric and vapour compression hybrid refrigerator

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ABSTRACT

This paper presents the improvement in the performance of a domestic hybrid refrigerator that combines vapour compression technology for the cooler and freezer compartments, and thermoelectric technology for a new compartment. The heat emitted by the Peltier modules is discharged into the freezer compartment, forming a cascade refrigeration system. This configuration leads to a significant improvement in the coefficient of operation. Thus, the electric power consumption of the modules and the refrigerator decreases by 95% and 20% respectively, with respect to those attained with a cascade refrigeration system connected with the cooler compartment.

The optimization process is based on a computational model that simulates the behaviour of the whole refrigerator. Two prototypes have been built and tested. Experimental results indicate that the temperature of the new compartment is easily set up at any value between 0 and −4 °C, the oscillation of this temperature is always lower than 0.4 °C, and the electric power consumption is low enough to include this hybrid refrigerator into energy efficiency class A, according European rules and regulations.

1. Introduction

The thermoelectric effects, namely, Joule, Seebeck, Peltier and Thomson, describe the interaction between thermal and electric fields, and are well known since the XIX century [1]. Back in 1885, John W. Strutt raised the possibility of using thermoelectric devices to produce electric power, though further developments were rejected because of the low efficiencies attained. The major breakthrough did not take place until the application of semiconductor materials to thermoelectric devices by Abram F. Ioffe in 1957 [2]. These materials feature high Seebeck coefficient, low electrical resistivity and low thermal conductivity, which entails high Figure of merit ($Z = \alpha^2/\rho k$), key parameter in the characterization of thermoelectric materials. Ioffe's development led to successful thermoelectric heating and cooling applications for military and aerospace purposes [3,4].

Nowadays, thermoelectric technology is making its way into the civil market, especially for applications that require high quality temperature control, such as precision instruments for medicine and research [5,6]. Moreover, several thermoelectric applications are attracting commercial attention owing to their great prospects for the future, such as dehumidifiers [7], air conditioners for domestic and automotive sectors, portable and domestic refrigerators, transports for perishable goods, etc, which compete with vapour compression based applications [8].

Thermoelectric refrigeration offers several advantages with respect to conventional vapour compression technology, since thermoelectric devices are more compact, free of noises and vibrations, provide high quality temperature control and require far less maintenance [9–11]. These significant facts led to the development of original and interesting thermoelectric refrigeration devices, subsequently released into the market [12–15].

Coefficient of operation (COP) of thermoelectric refrigerators, on the other hand, is significantly lower than that of vapour compression based devices, which explains the fact that vapour compression technology predominates in both industrial and domestic refrigeration markets. However, one of the main disadvantages of vapour compression based refrigerators lies on the oscillatory pattern of the inner temperature, caused by the characteristic stop and start cycles of the compressor. This effect leads to very significant oscillations in the temperature of the air enclosed in the refrigeration compartment, which worsens to a great extent the conservation of food or perishable goods [16].

Scientific literature shows some systems intended to reduce the cited temperature oscillation of vapour compression refrigerators, using either variable speed compressors [17,18], fixed speed compressors with improved temperature control systems [19,20] or new components such as thermostatic expansion valves, which regulate the mass flow of the cooling fluid [21,22]. However, these systems turn out to be excessively complex and expensive for being installed in commercial domestic refrigerators, given the competitiveness of the market, which explains the fact that manufacturers prefer cheaper and simpler devices, such as capillary tubes, which

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