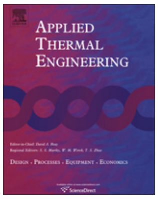
Applied Thermal Engineering 51 (2013) 239–245

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng



An experimental study on defrost heaters applied to frost-free household refrigerators

Cláudio Melo*, Fernando T. Knabben, Paula V. Pereira

POLO Research Laboratories for Emerging Technologies in Cooling and Thermophysics, Department of Mechanical Engineering,
Federal University of Santa Catarina, Campus Universitario, Trindade, 88040970 Florianópolis, SC, Brazil

HIGHLIGHTS

- ► A purposed designed testing apparatus was constructed and used during the experiments.
- ► The defrost efficiencies of three distinct heaters were measured and compared.
- ► The calrod heater was found to be the best option for the refrigerator under study.

ARTICLE INFO

Article history:
Received 6 June 2012
Accepted 25 August 2012
Available online 10 September 2012

Keywords:
Defrost
Heater
Refrigerator
Efficiency
Evaporator

ABSTRACT

In this study the performance of defrost systems applied to household refrigerators was experimentally evaluated through a purpose-built testing apparatus. The test bench is comprised of a calorimeter, a refrigerated cabinet and a humidifying system. Three distinct types of electrical heaters (distributed, calrod and glass tube) and three actuation modes (integral power, power steps and pulsating power) were investigated. The experiments were carried out under controlled conditions in order to ensure the same frost accumulation pattern over the evaporator. It was found that the defrost efficiency of the three types of heaters is practically the same for each operating mode. The highest efficiency of approximately 48% was obtained with the glass tube heater operating in power steps. However, this heater reached the highest temperature levels. The calrod heater seems to be the most appropriate not only because of its efficiency, which is compatible with the other options, but also due to its low cost and easy installation. However, standardized energy consumption tests need to be carried out before this finding can be generalized.

1. Introduction

Frost is essentially a porous medium composed of humid air and ice crystals, formed from the desublimation of the water vapor contained in the air stream. In a typical frost-free refrigerator frost should only form over the evaporator surface, which, unfortunately, rarely happens [1]. Frost formation is a common phenomenon observed in household refrigerators, being strongly dependent on the infiltration of warm and humid air due to periodic door openings and through the door gaskets.

The accumulation of frost over the evaporator surface reduces the cooling capacity and consequently the overall performance of the refrigerator. Such a loss occurs because the frost layer not only increases the thermal resistance between air and evaporator but also the air side pressure drop, decreasing the fan-supplied airflow rate. To avoid the evaporator blockage and the capacity reduction, defrosts must be periodically carried out. During defrost the compressor and fan remain off and part of the heat provided by the electrical heater is transferred to the refrigerated compartments. Therefore, the compressor on-time will be longer after defrost in order to compensate for this extra thermal load. Additionally, the defrost system increases the air side pressure drop, which reflects negatively on the product performance. Then, although needed, the defrost system increases the energy consumption of the household refrigerators.

Hot-gas, reverse-cycle and electrical heaters are the most common defrost techniques. The first two consume less energy but require some system modifications, which makes them unfeasible for household refrigerators. The electrical heaters consume more energy, increase the air side pressure drop and are subjected to corrosion problems, but are much cheaper and therefore are the most typical method for frost removal in low capacity evaporators of frost-free refrigerators [2], which are the scope of this study.

---

* Corresponding author. Tel.:+55 48 3234 5691; fax: +55 48 3234 5166.
E-mail address: melo@polo.ufsc.br (C. Melo).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2012.08.044

Nomenclature

Roman

c	specific heat, kJ/kg K
E	energy, kJ
h	water fusion latent heat, kJ/kg
k	student factor, dimensionless
m	frost mass, g or kg
t	time, s or min
T	temperature, °C
U	expanded propagated uncertainty
u	combined uncertainty
W	defrost power, W

Greek

η	defrost efficiency, dimensionless
σ	standard deviation

Subscripts

d	defrost
fz	freezer
h	heater
i	ice
id	ideal
melt	melt
p	constant pressure
r	real
sl	solid to liquid
w	evaporator wall

The most common types of heaters are: (i) aluminum tube (distributed), (ii) glass tube, and (iii) tubular metal sheathed (calrod). The aluminum heaters, shown in Fig. 1a, are widespread used in household frost-free refrigerators. In this case conduction heat transfer is dominant, since the heater is in direct contact with the evaporator fins. Such heaters, besides providing a uniform heat distribution, do not increase the tube temperature substantially. For this reason they are recommended for application with the refrigerant HC-600a, especially when the refrigerators are tested according to the ISO 8561 [3] standard, which uses the temperature of the warmest package contained in the freezer compartment as the reference for the energy consumption measurement.

In addition, the distributed heater rarely damages the internal plastic and polystyrene parts near the evaporator. On the other hand, it considerably increases the air side pressure drop, may present corrosion problems [2] and its manufacturing and installation procedures are more complex.

The glass tube heaters have quite a simple design, as shown in Fig. 1b, do not present corrosion problems but increase the air side pressure drop because they are installed at the evaporator leading edge. In addition they require a protection cover to avoid the shattering of the glass when hit by melted water droplets, which increases further the pressure drop. The calrod heaters are also installed at the evaporator leading edge, with a negative impact on the air side pressure drop (see Fig. 1c). Such heaters might overheat the plastic parts if the heat flux exceeds a certain limit. On the other hand they are extremely simple and easy to install. Both calrod and glass tube heaters dissipate heat mostly by radiation and convection and may reach temperatures of over 300 °C whereas the distributed models rarely exceed the 100 °C barrier.

A large number of publications have focused on the defrost process in evaporators for commercial applications [4–9]. Stoecker [4] conducted one of the first studies on hot-gas defrosting, providing recommendations for the appropriate design of the by-pass lines. Niederer [5] observed that only 15–25% of the released heat is effectively used during the defrosting. Cho et al. [6] compared two defrost strategies in a three-evaporator system: hot-gas by-pass and cycle defrost. The authors reported that the temperature fluctuations within the refrigerated compartments were lower when the hot-gas technique was adopted. Byun et al. [7] studied the effect of the refrigerant by-pass mass flow rate on the performance of hot-gas defrost systems. They concluded that the fluctuations in the operating conditions of the refrigeration system increase with the by-pass mass flow rate. Minglu et al. [8] installed a heat exchanger with PCM (phase change material) at the internal coil of a heat pump whose defrost was performed by reversing the cycle. They verified that the prototype developed attenuated the temperature variations inside the occupied environment, improved the thermal comfort and reduced the defrost time. Dong et al. [9] carried out a theoretical and experimental study to investigate the time and efficiency of a heat pump reverse-cycle defrost process. The authors observed that when the internal coil fan was kept on during the defrost efficiencies up to 60% were obtained. They emphasized, however, that removing more energy from the internal environment to improve the defrost process could affect the thermal comfort, which would require the use of alternative sources of thermal energy, such as PCMs.

The heat exchangers used in the above-mentioned studies differ from those employed in domestic refrigerators. The face area is considerably larger, the evaporation temperature is higher and the temperature, humidity and airflow profiles at the evaporator inlet are uniform. In duplex frost-free refrigerators the evaporator is submitted to two air streams, one from the freezer compartment (colder, dry and with a higher airflow) and another from the fresh-food compartment (hotter, humid and with a lower airflow), which causes non-uniform frost accumulation over the evaporator. In spite of the large amount of publications related to defrost in commercial tube-and-fin heat exchangers, when it comes to domestic appliances the literature is scarce. Notable publications include those by Kim et al. [2], Bansal et al. [10] and Ozkan et al. [11]. Kim et al. [2] conducted a comparative study of different types of defrost heaters applied to a side-by-side refrigerator. The authors provided no information on the operating conditions or on how these conditions were controlled. It is worth mentioning that for an appropriate comparison it is essential that the frost mass is the same for all tests and this can only be ensured by an appropriate control system. Bansal et al. [10] studied the heat distribution from a calrod heater within a vertical freezer. They estimated the distribution through a mathematical model based on the association of convection and radiation thermal resistances and noted that only 32% of the total energy is effectively absorbed by the frost layer. Ozkan et al. [11] experimentally analyzed the defrost process in a two-compartment refrigerator with an aluminum distributed heater. The authors, however, removed the wall that separates the compartments (mullion), turning a dual-refrigerator into an all-refrigerator. With the aid of an endoscopic camera they observed that the frost formation is more intense on the first rows of the evaporator, which indicates that most of the defrost power should be dissipated in this region. This finding corroborates the observations presented by Knabben et al. [12] where the same type of heater was tested in a similar refrigerator. Knabben et al. [12] also noted that the gradual reduction of the heater power during the defrost process increased the efficiency by 118%.