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Numerical and experimental study on heat transfer characteristic and thermal load of the freezer gasket in frost-free refrigerators

Gang Yan *, *Qi Chen*, *Zhaolei Sun*

Department of Refrigeration and Cryogenic Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China

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ABSTRACT

The present study has been carried out to analyze the heat transfer characteristics and thermal load near the freezer gasket region of a 649 L domestic frost-free refrigerator/freezer. Both 3D numerical simulations and experimental test were performed. The numerical models for different freezer gasket sections were developed, while considering the non-uniform distribution of temperature inside the freezer cabinet. The calculated temperatures showed acceptable agreement with the measured temperatures. The total thermal load of gasket region is 10.57/6.68 W, in the status of compressor on/off. Thermal load of cold-bridge accounts for 23.8%/25.8% of the total thermal load, and thermal load of gasket bulk holds 76.2%/74.2%, respectively. When the compressor on–off time ratio is 7:3, total thermal load near the freezer gasket region is 9.40 W during an on–off cycling operation of compressor, accounting for 17.1% of the total thermal load in the freezer cabinet.

Étude numérique et expérimentale sur les caractéristiques de transfert de chaleur et la charge thermique du joint de congélateur dans des réfrigérateurs exempts de givre

Mots clés : Joint ; Réfrigérateur exempt de givre ; Charge thermique ; Transfert de chaleur

1. Introduction

As a conventional appliance to preserve the quality of fresh food, household refrigerator/freezers (RFs) have been in great demand. In developing countries, the production of RF is rising steadily, and total production rose 30% (Billiard, 2005). Besides, domestic RFs consume a large amount of energy, accounting for about 6% of the electrical energy produced worldwide (Melo and Silva, 2010). In the open literatures, many researchers have

* *Corresponding author.* Department of Refrigeration and Cryogenic Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China. Tel.: +86 29 82668738; Fax: +86 29 82668729.

E-mail address: gyan@mail.xjtu.edu.cn (G. Yan).

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Nomenclature

h	heat transfer coefficient [W m^{-2} K^{-1}]
l	length of gasket section [m]
q	heat transfer rate per unit length [W m^{-1}]
Q	thermal load [W]
T	temperature [°C]
t	time [s]
U	velocity of incoming flow [m s^{-1}]

Subscripts

cycle	during a complete on and off running cycle of compressor
F,in	incoming flow of freezer cabinet
f-c	from cold-bridge to cabinet
g-a	from ambient to gasket
g-d	from door to gasket
g-b	from freezer body to gasket
g-f	from freezer cabinet to gasket
g	gasket bulk
i	the ith gasket section
in	incoming flow
on	compressor on
off	compressor off
R,in	incoming flow of refrigerating cabinet
tot,i	total of the ith gasket section
tl	total of all gasket section
tl,on	total of all gasket section when the compressor runs
tl,off	total of all gasket section during the compressor off cycle

studied the heat transfer characteristics, both experimentally and theoretically, in the refrigerators. Several studies (Bayer et al., 2013; Laguerre and Flick, 2004; Laguerre et al., 2007) have been carried out on heat transfer and air flow by natural convection in domestic refrigerators when unloaded, under the consideration of radiation. In fact, the refrigerator is in loaded condition. Experimental studies have investigated heat transfer in loaded condition. Moisture transport has a significant influence on heat transfer behavior in domestic refrigerator, which must be taken into account (Laguerre et al., 2005, 2012). Literatures (Laguerre et al., 2010; Saidur et al., 2007) present the moisture transfer phenomenon in a domestic refrigerator. Experimental studies have been conducted to obtain heat transfer characteristics by reverse heat loss method (Sim and Ha, 2011; Tao and Sun, 2001). Some researchers have investigated the air flow and heat transfer in a ventilated domestic RF (Gupta et al., 2007; Lee et al., 1999).

The gasket of RF plays an important role in keeping the cabinets a cold space to preserve fresh food. Studies on gasket have drawn an increasing attention in recent years. Stein et al. (2002) developed an experimental method to obtain the moisture transport characteristics in a refrigerator. The result shows that gasket infiltration is a function of the difference in water vapor partial pressure between the fresh food and freezer cabinets and the outside air. Hessami (1997) calculated energy rating of domestic refrigerators through both experimental and computer simulation methods. The author pointed out that heat transfer through gasket accounted for 13% of power consumption. Boughton et al. (1996) used a Fortran program to estimate the thermal load through the door seal. An assumption was made that the cross section of seal is a hollow square with a square cavity located centrally. The result shows the heat load directly through seal accounts for 2.7% of the thermal load on the cabinet. Afonso and Castro (2010) used the tracer gas technique to analyze the influence of magnetic seal conservation condition on the air exchange rates of refrigerator. They have presented that the air infiltration rate of the refrigerator cabin is twice than that of freezer cabin, and the air infiltration load of refrigerator with new gasket accounts 3.6% of energy consumption, while it reaches 18% when the gaskets are old. Melo et al. (2000) presented an experimental analysis of heat transfer paths of a 230 L refrigerator. The result shows that the heat transfer rate through gasket accounted for 3% of the total heat transfer rate measured by the heat flux meters in the reverse heat loss experiment. Huelsz et al. (2011) evaluated the gasket total thermal load of freezer gasket of a 708 L frost-free refrigerator. The authors presented that gasket heat transfer load is 6.28 W, accounting for 4.7% of the total thermal load of freezer cabinet. Unfortunately, they did not consider the effect of the anti-sweat condenser tube. Kim et al. (2011) analyzed the quantitative heat transfer characteristics near the magnetic door gasket of a residential refrigerator. The result of the two dimensional numerical analysis shows that the heat loss near the gasket region is 3.52 W m^{-1}. Actually, the flow near the gasket region is a complicated three dimensional flow.

In order to analyze the heat transfer characteristics and thermal load near the gasket region, a three dimensional numerical simulation method is presented in this study. Considering the non-uniform distribution of temperature inside the freezer cabinet, several numerical models are developed to obtain different heat transfer characteristics in various sections along the perimeter of gasket. This modeling method considers the air flow in both gasket air cavities and freezer cabinet, and the compressor on–off time ratio. Besides, the effect of anti-sweat condenser tube is involved. The cold-bridge consisting of ABS panel and steel sheet is considered, too. The calculated temperatures are compared with the measured temperatures to validate the accuracy of the simulation method. The practical objective of this study is to obtain the heat transfer rate per unit length along the perimeter of freezer gasket and thermal load near the freezer gasket region.

2. Experimental method

The refrigerator for the study is a 649 L domestic frost-free side-by-side RF, of which the freezer volume is 236 L. As shown in Fig. 1a, the freezer compartment is on the left side. The RF has only one evaporator, mounted in back-side wall of the freezer cabinet. The nominal dimensions in the freezer cabinet are 1.65 m high and 0.35 m wide. The perimeter of the freezer gasket is 4 m. In this paper, the freezer cabinet and freezer gasket were studied.

Experiments were carried out in a constant temperature (25 °C) and constant relative humidity (75%) chamber. Experi-