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An experimental and numerical study of refrigerator heat leakage at the gasket region

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ABSTRACT

A combined experimental and computational approach was developed to measure the heat leakage through the refrigerator gasket region. The experiment was carried out by measuring the heat flux through the door gasket by Reverse Heat Load Method (RHLM). The experimental point measurements lie near to the continuous curve from Computational Fluid Dynamics (CFD) simulation, which makes it reasonable to provide a dimensionless shape profile by CFD to fill in the missing information between experimental measurement points in order to provide the actual effective heat leakage. The average effective heat leakage on the door gasket surface is determined as $0.2\ \mathrm{W\ m^{-1}\ K^{-1}}$ comprising 17% and 14% heat leakage of the total load in the fresh-food and freezer compartments, respectively. The electric fan and the hot pipe along the perimeter of the door contribute to an increase of 20% and 10% in the effective heat leakage on the door surface of the freezer, respectively.

Étude expérimentale et numérique portant sur la fuite thermique constatée dans un réfrigérateur au niveau du joint

Mots clés : Réfrigérateurs ; Fuite thermique ; Mécanique des fluides numérique ; Méthode inverse de la charge thermique ; Essais expérimentaux

1. Introduction

Refrigerators are one of the most widely used consumer appliances and are required to meet strict energy efficiency ratings. Investigating the heat leakage of refrigerators is of great practical meaning, especially concerning the reduction of unnecessary energy consumption. Although many researchers (Brent et al., 1995; Gupta et al., 2007; Xie and Bansal, 2000) have studied the influence of multiple variables on the energy consumption of refrigerators, little attention has been focused on the door gasket heat leakage of refrigerators. The heat

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Nomenclature

Symbols

A-F	heat flux sensors along gasket
c	specific heat of capacity [J kg^{-1} K^{-1}]
Cu	empirical constant
Exp_n	experimental point measurement of the heat flux sensors [W m^{-2} ($n = 1, 2, 3...6$)]
f_n	CFD measurement of the heat flux corresponding to the experimental measurement points [W m^{-2} ($n = 1, 2, 3...6$)]
F	blending function
g	gravity [m s^{-2}]
H	heat load [W]
h	effective heat leakage [W m^{-1} K^{-1}]
I	turbulence intensity
K	thermal conductivity [W m^{-1} K^{-1}]
L	gasket surface length [*m*]
l	turbulent length scale [*m*]
p	pressure [*Pa*]
P	power [W]
q	heat flux [W m^{-2}]
Q	heat leakage at the gasket region [W]
Ra	Raleigh number
S	invariant of strain rate [s^{-1}]
s	coordinate along the outside of the gasket surface [*m*]
s''	coordinate along the inside of the gasket surface [*m*]
T	temperature of the flow inside the compartment [*K*]
ΔT	temperature difference between the ambient environment and the refrigerator compartment [*K*]
t	time [*s*]
k	turbulence kinetic energy [m^2 s^{-2}]
u	velocity of flow inside the compartment [m s^{-1}]

Greek symbols

α	correction factor in Least Mean Square Error analysis
β	thermal expansion coefficient
β^*	model constant
η	percentage of heat leakage at the gasket region accounted by total energy
μ	turbulence eddy diffusivity [m^2 s^{-1}]
ρ	density [kg m^{-3}]
σ'	model constant
ω	turbulence dissipation rate [s^{-1}]

Subscripts

cmp	compressor
ef	electric fan
f	freezer
g	gasket
int	initial
m	insulation material
n	indication of number heat flux sensors ($n = 1, 2...6$)
o	operating
rhl	reverse heat load
rms	root mean square
t	turbulence

leakage at the door gasket contributes to a significant percentage of the energy consumption of the refrigerator and freezer. Most related research (Boughton et al., 1996; Flynn et al., 1992; Ghassemi and Shapiro, 1991; Hasanuzzaman et al., 2009; Hessami and Hilligweg, 2003; Tao and Sun, 2001) indicates that the heat leakage at the door gasket accounts for 10%–30% of the total energy consumption depending on the insulation material and refrigerator specifications. It is important for the gasket to conform to the contour of the refrigerator door surface and be compressible and flexible enough to overcome the geometrical tolerance (Bansal et al., 2011). The heat transfer at the gasket is further complicated by the non-uniform temperature distribution inside the refrigerator cabinet (Conceição António and Afonso, 2011; Fukuyo et al., 2003; Laguerre et al., 2007). For the purpose of reducing the energy consumption of the refrigerator, more attention should be focused on improving the efficiency of the gasket region of the refrigerator. One possible reason for the sparse available open literature on door gasket heat leakage is that the heat transfer at the gasket is largely dependent on the variations of the cabinet and door designs of different types of refrigerators. Furthermore, the difficulty of accurate measurement due to the complex curved surface of the refrigerator door is a challenge.

The most commonly used experimental method to investigate heat leakage is the Reverse Heat Load Method (RHLM) (Hessami and Hilligweg, 2003; Sim and Ha, 2011; Tao and Sun, 2001). RHLM is an experimental setup in which a heat source is placed inside the refrigerator which is generally put into a controlled temperature–humidity chamber. This method is based on the principle that the energy input to maintain steady state equates with the heat leakage of the refrigerator. However, challenges are exposed when measuring the heat transfer at the gasket region by RHLM. Firstly, only a limited number of thermocouples are used for point measurements while the heat transfer at the door gasket region varies due to the complex curve shape and different thermal properties of insulation materials, therefore, it is not accurate to estimate the total heat leakage at the gasket region based on a few point measurements. Secondly, the RHLM does not account for the effect of the compressor and the operation of the electric fan inside the chamber of the freezer compartment in real working condition of refrigerator. Furthermore, the hot loop (e.g., the perimeter of the freezer section) generates extra heat to prevent dewing at the door gasket, which should be considered as it may contribute more heat leakage.

Computational Fluid Dynamics (CFD) is a prevalent numerical method to study the heat transfer at the door gasket. Sim and Ha (2011) show that a stagnant zone is formed at the gasket such that the air inside the refrigerator chamber cannot