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Multi-objective optimization of household refrigerator with novel heat-storage condensers by Genetic algorithm

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ABSTRACT

A novel multi-objective global optimization method combining refrigerator dynamic model and Genetic algorithm NSGA-II is proposed for increasing overall performance of household refrigerator. A novel refrigerator with heat-storage condensers and an ordinary refrigerator with conventional hot-wall condensers are optimized by the method for multi-objectives of minimizing total cost and energy consumption per 24 h. After the optimization, overall performances of the novel refrigerator and ordinary refrigerator are both increased. Optimized curves on multi-objectives of the novel refrigerator and ordinary refrigerator are obtained and compared with each other. In the optimized curve, for one value of energy consumption per 24 h, a corresponding optimized total cost is acquired. Optimization result of the novel refrigerator is better than that of the ordinary refrigerator. Under the condition of same total cost, energy saving of optimized novel refrigerator compared with optimized ordinary refrigerator is from 20% to 26%. Under the condition of same energy consumption per 24 h, cost saving of optimized novel refrigerator compared with optimized ordinary refrigerator is from \$1.8 to \$3.4.

1. Introduction

Household refrigerators are widely used in the world now and consume a large amount of energy. Energy-saving technology of the refrigerators is very useful for alleviating energy scarce and reducing greenhouse gas emission. Therefore, many researchers are interesting in the research on refrigerators and achieved many good results [1–4]. In the refrigeration system, condenser is an important component. Thermal load generated from refrigeration system is transferred to ambient by condensers. Improvement of condenser performance is important for reducing energy consumption of household refrigerator. Because of the compact structure, durable and easy-to-perform characteristics, hot-wall condensers are widely used in household refrigerators [5]. However the overall heat-transfer performances of the hot-wall condensers are hard to be improved by some conventional methods. For example, if the contact area between the condensers and the cabinet is enlarged, the increase in the heat transfer capacity is only 2% [6]. Because household refrigerators work in an intermittent mode, the heat dissipation of hot-wall condensers is intermittent. The off-time is usually over 2 times of the on-time during a complete cycle of a household refrigerator [7]. If the condenser tube is encased by phase change material (PCM) to construct the heat-storage condensers shown in Fig. 1, a part of condensation heat from condenser tube is stored in the PCM during on-time period and is released to ambient during off-time period. Therefore intermittent heat dissipation of hot-wall condensers is replaced by continuous heat dissipation of heat-storage condensers in a complete cycle [7]. In this way, the overall heat transfer performance of condensers, subcooling degree at condenser outlet during on-time and COP (coefficient of performance) of the household refrigerator are increased; the condensing temperature during on-time and energy consumption of the household refrigerator are decreased [7].

A shape-stabilized phase change material (SSPCM) [8] was prepared and used to construct the heat-storage condensers. The SSPCM prepared in our laboratory has many advantages such as low cost, no corrosion, no liquid leakage, low packaging cost, high latent heat, high thermal conductivity, and suitable phase change temperature for the condenser. For a double-door three star household refrigerator under ISO standard test conditions [9], energy saving of the novel refrigerator with heat-storage condensers compared to the ordinary refrigerator with hot-wall condensers is 12% in the experiment [7]. A refrigerator dynamic model was established later and agrees well with the experimental data [10]. COP, refrigerating capacity, heat leakage (heat transfer from ambient to inner air of the refrigerator), ambient temperature,

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Nomenclature

C	specific heat capacity (J kg^{-1} K^{-1})
T	temperature (K)
t	time (s)
k	thermal conductivity (W m^{-1} K^{-1})
X	X coordinates (m)
Y	Y coordinates (m)
Z	Z coordinates (m)
S	coordinate direction (m)
M	mass (kg)
Q	heat transfer rate (W)
Q	heat flux (W m^{-2})
U	heat transfer coefficient (W m^{-2} K^{-1})
A	area (m^2)
m	mass flow rate (kg s^{-1})
h	specific enthalpy (J kg^{-1})
V	volume flow rate (m^3 s^{-1})
P	power (W)
p	pressure (Pa)
n	polytropic index
D	diameter (m)
G	mass velocity (kg m^{-2} s^{-1})
L	length (m)
f	coefficient of friction resistance, objective function
x	decision variable, mass quality
g	constraint function
R	gas constant (J kg^{-1} K^{-1}), real number
a	width (mm)
b	length, thickness (mm)
d	spacing, thickness increment (mm)

Greek letters

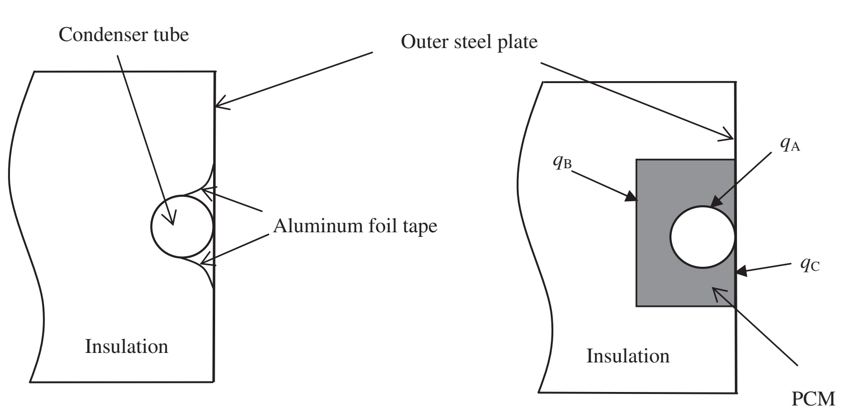
ρ	density (kg m^{-3})
σ	blackbody radiation constant (W m^{-2} K^{-4})
ε	emissivity
λ	compressor volumetric efficiency
υ	specific volume (m^3 kg^{-1})
η	efficiency coefficient
χ	length ratio

Subscripts

pcm	PCM
ins	insulation
plate	outer steel plate
am	ambient
ref	refrigerant
ct	condenser tube wall
in	inlet
out	outlet
i	inside
o	outside
et	evaporator tube wall
air	air
com	compressor
cham	chamber
shell	compressor shell
mot	electromotor
c	condenser
e	evaporator
cap	capillary
sh	superheat region
tp	two-phase region
sc	subcooling region
sp	single phase
r	fresh-food compartment
f	frozen-food compartment
leak	heat leakage
Tp	test package
h	high temperature side
l	low temperature side

freezer temperature and so on have been discussed by the refrigerator dynamic model for further analyzing the energy-saving mechanism of the novel refrigerator [10]. However, if the condenser tube is encased by PCM, the overall performance of the novel refrigerator with heat-storage condensers is not optimal and needs to be increased by the global optimization, which was not researched in the previous work.

Although there are many good optimization methods [11–13] used in energy field, Genetic algorithm is recommended in the multi-objective optimization of the refrigerator. Reducing the energy consumption per 24 h is one objective. Reducing total cost of refrigerator is another objective. Although the objectives of refrigerator optimization conflict each other, Genetic algorithm can lead to global optima solutions which avoid the fact that optimizing a single objective results in inappropriate results of another objective. The optimized result of minimizing or maximizing the conflicting objectives is a set of multiple optimal solutions commonly called Pareto optimal solutions. The region of corresponding



(a) Conventional hot-wall condensers (b) Novel heat-storage condensers with PCM

Fig. 1. Structure diagram of the condensers and the location of boundary conditions (heat flux q) of PCM.