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Advanced sequential dual evaporator domestic refrigerator/freezer: System energy optimization

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ABSTRACT

Fundamental energy efficiency advantage of the sequential dual evaporator (SDE) refrigeration circuit in domestic refrigerator/freezer appliances arises from the ability of evaporating refrigerant at elevated temperature during cooling of refrigeration compartment (RC) and consequently achieving higher RC COP. Frequently RC evaporator is foamed-in driven by natural convection with very low heat transfer coefficient which practically limits evaporation temperature. The paper presents experimental results of the SDE prototype appliance with visible RC roll-bond evaporator in direct contact with phase change material (PCM) to increase RC evaporation temperature. Melting PCM is absorbing cabinet heat in continuous manner thus we could keep natural convection as preferred mode of heat transfer in RC. Control including pump out phase and particular components were implemented to deal with refrigerant charge migration between refrigerator and freezer evaporators. RC evaporation temperature was increased by maximum 8.4 K. Energy consumption during RC operation was reduced by 19.9% and overall energy consumption dropped by 5.6% after condenser fan was installed. At least 8.1% energy saving was predicted if condenser with 30% higher UA value was implemented instead of the condenser fan.

Congélateur/réfrigérateur domestique avancé à évaporateur séquentiel double : optimisation de l'énergie du système

Mots clés : Réfrigérateur domestique ; Evaporateur séquentiel double ; Matériau à changement de phase ; Matériau à changement de phase ; Consommation d'énergie

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Nomenclature

COP	[–] coefficient of performance
E	[Wh/day] energy consumption
n	[–] run time
p	[pa] pressure
P	[W] electric power
Q	[W] heat
T	[°C] temperature
UA	[W/K] global heat transfer coefficient
DAQ	data acquisition
FC	freezer compartment
FC-CV	freezer evaporator check valve
NTC	negative temperature coefficient thermistor
P/O	pump out
PCM	phase change material
RC	refrigeration compartment
RPM	rotations per minute
SDE	sequential dual evaporator

Subscripts

disch	discharge
cond	condensation
shell	compressor shell
evap	evaporation
filter	filter/drier
suct	suction
ACC	accumulator

1. Introduction

Very common type of domestic refrigerator/freezer in EU is called bottom-mount. It contains two compartments with different temperatures placed over each other where the freezer is the lower one. Freezer compartment (FC) is dedicated to deeply frozen food with corresponding average air temperature bellow −18 °C. Refrigerator compartment (RC) is devoted to fresh food kept at temperatures above freezing point (>0 °C). Common configuration of appliances with two-evaporator is with a refrigeration circuit where two evaporators are connected in series and refrigerant evaporates at the same temperature both in FC and RC compartments. As a consequence, heat is extracted from RC with low temperature and, therefore, low thermodynamic efficiency (Jung and Radermacher, 1991). Circuit with two capillary tubes, single evaporator and air by-pass between the FC and RC compartments was also proposed but negative impact of decreased air humidity in RC was observed (Park et al., 1998). Dual loop appliances, with completely separate two refrigeration circuits, one for each compartment, were also presented by Baskin and Delafield (1999). In spite of high energy efficiency potential this configuration is not widespread due to high cost related to two compressors.

Appliance equipped with sequential dual evaporator (SDE) refrigeration circuit contains one compressor and condenser followed by flow diverting electro-valve and two evaporators connected in parallel and placed in corresponding compartments as it's shown in Fig. 1a. The circuit extracts heat from FC and RC in alternating mode, in other words only one evaporator works at a time. Therefore during RC operation it allows higher evaporation temperature and lower exergy losses as it was discussed in Visek et al. (2012). This leads to higher compressor COP as it's visible from the p–h diagram in Fig. 1b. There is no air exchange between two compartments and as the system requires only one compressor it has a considerable cost advantage versus dual loop appliances. Even though the SDE circuit domestic refrigerators are very rare on the consumer market nowadays.

Sand et al. (1992) experimentally tested SDE circuit charged with R12 and R152a and found out 2.3% and 6% energy saving over single evaporator system charged with R12. They claimed

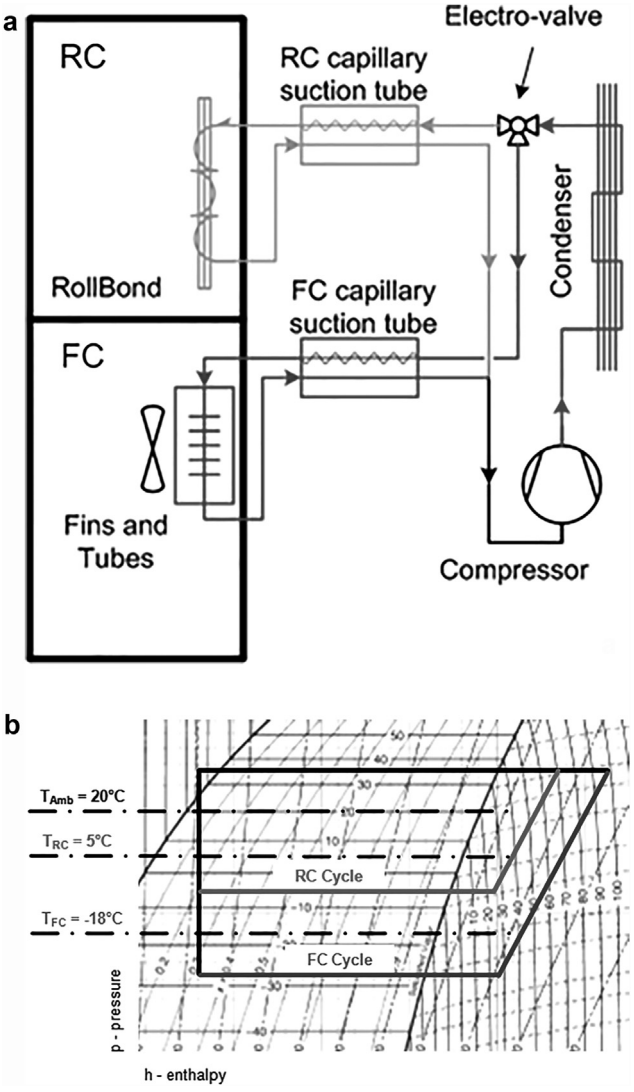

Fig. 1 – a. Traditional sequential dual evaporator refrigeration circuit design. b, Enthalpy-pressure diagram revealing energy efficiency advantage of sequential dual evaporator circuit.