Available online at www.sciencedirect.com

ScienceDirect

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

Thermal analysis of airflow inside a refrigerated container

Nuri Kayansayan [a,*], *Ersin Alptekin* [b], *Mehmet Akif Ezan* [b]

[a] *Department of Mechanical Engineering, Near East University, Mersin 10, Turkiye*
[b] *Department of Mechanical Engineering, Graduate School of Natural & Applied Sciences, Dokuz Eylül University, Tinaztepe Campus, Buca, Izmir 35397, Turkiye*

ARTICLE INFO

Article history:
Received 7 February 2017
Received in revised form 28 July 2017
Accepted 20 August 2017
Available online 25 August 2017

Keywords:
Refrigerated vehicle
Mixed convection
Finite-volume
Refrigeration
Meshing
Numerical

ABSTRACT

A numerical study of conjugated heat transfer in ceiling-slot refrigerated containers is carried out to analyze the temperature distribution effectiveness and to determine the ventilation characteristics. The effect of slot size on thermal characteristics is studied by considering half-span and full-span injection. The container walls are defined as conductive opaque and are interacting with outside environment. The outer surface heat transfer coefficients of conductive walls are computed by studying the flow around the refrigerated truck. The Reynolds number at the slot exit varied between $2 \times 10^4 \leq Re \leq 2 \times 10^5$. The gravity effect is taken into account, and the coupled mass, momentum, and energy equations are discretized in finite volumes. The heat transfer coefficients of inner flow are presented as plots of the mean Nusselt number versus the modified Reynolds number. The maximum dispersion in the numerical data being at 14.54-percent, the mean Nusselt number, the modified Reynolds number, and the aspect ratio of the container are correlated.

Analyse thermique du débit d'air à l'intérieur d'un conteneur réfrigéré

Mots clés : Véhicule frigorifique ; Convection mixte ; Volume fini ; Froid ; Maillage ; Numérique

1. Introduction

Absence of effective food refrigeration causes several changes in food structure and accelerates food deterioration in cold chain (Derens-Bertheau et al., 2015; Hoang et al., 2012; Laguerre et al., 2013). The process of creating adequate conditions for slowing down these changes can be divided into two categories: efficient ventilation of air within the storage space and cooling to achieve the desired temperature. Ceiling-slot-ventilated

---

* *Corresponding author.* Department of Mechanical Engineering, Near East University, Mersin 10, Turkey.
E-mail address: nuri.kayansayan@deu.edu.tr (N. Kayansayan).

https://doi.org/10.1016/j.ijrefrig.2017.08.008
0140-7007/

Nomenclature

A	Cross-sectional area [m^2]
C's	Turbulence model coefficients [-]
c_p	Specific heat of air [Jkg^{-1}K^{-1}]
d_h	Hydraulic diameter of the injection slot [m]
E	Temperature effectiveness [-]
e	Percent error in mean Nusselt number correlation [%]
Gr_J	Grashof number of J^{th} surface, $Gr_J = \frac{g\beta(T_{smJ} - T_m)H^3}{\nu^2}$ [-]
g	Gravity constant [ms^{-2}]
H	Container height [m]
h	Convective heat transfer coefficient [Wm^{-2}K^{-1}]
I_{solar}	Solar irradiation reaching the earth surface [Wm^{-2}]
k	Kinetic energy of turbulence [m^{2}s^{-2}]
L	Container length [m]
l	Related to evaporator size (see Fig. 1) [m]
Nu	Nusselt number, $Nu = \frac{hH}{\lambda}$ [-]
Pr	Prandtl number, $\mathrm{Pr} = \frac{\mu c_p}{\lambda}$ [-]
p	Pressure [Pa]
q	Heat transfer rate through a conductive surface [W]
Re	Reynolds number of injection, $\mathrm{Re} = \frac{\rho u_{inj} d_h}{\mu}$ [-]
Re*	Modified Reynolds number, $\mathrm{Re}^* = \frac{\rho u_{inj} H}{\mu}$ [-]
Ri	Richardson number, $\mathrm{Ri} = \frac{\mathrm{Gr}}{\mathrm{Re}^{*2}}$ [-]
T	Local temperature [°C]
T_x	Mass averaged air temperature at a cross-section x (Eq. (16)) [°C]
ΔT	Temperature difference (T_s–T_m) [°C]
V	Volume [m^3]
W	Container width [m]
$\overline{u_i u_j}$	Reynolds stress component [m^{2}s^{-2}]
u, v, w	Velocity components [ms^{-1}]
y^+	The wall unit, $y^+ = \frac{y\sqrt{\tau_s/\rho}}{\nu}$ [-]
x, y, z	Cartesian axis directions

Greek letters

α_s	Surface absorptivity [-]
β	Thermal expansion coefficient [K^{-1}]
δ_{ij}	Kronecker symbol
ε	Turbulence energy dissipation rate [m^{2}s^{-3}]
ε_s	Surface emissivity [-]
η	Ventilation effectiveness [-]
θ	Non-dimensional temperature, $\theta = \frac{T_{in} - T}{T_{in} - T_{inj}}$ [-]
λ	Thermal conductivity [Wm^{-1}K^{-1}]
μ	Dynamic viscosity [Pa.s]
ν	Kinematic viscosity [m^{2}s^{-1}]
ϑ	Volume flow rate [m^{3}s^{-1}]
ρ	Air density [kgm^{-3}]
σ	Stephan-Boltzmann constant [-]
τ	Shear stress [Pa]

Subscripts

a	air
cr	critical
in	Inlet to evaporator
inj	Exit from evaporator
i,j,k	Vector directions in x,y,z
J	Identifies a conductive surface
m	Mean value
ref	Reference
s	Surface inside
so	Surface outside
t	Turbulent
w	Wall
∞	Surroundings

Superscripts

'	Fluctuations in velocity and temperature
''	Flux
t	Truck

enclosures are commonly used in transport refrigeration systems where the cold air is supplied into the enclosure by a turbulent air jet. The information on this paper focuses on such ventilation system with high injection velocities of air. Moureh and Flick (2003) have studied the essential aerodynamic features of air flow inside a rectangular cavity with cold air injected through a slot at the upper half of the container front surface. The suction slot located at the lower half of the same front surface completes the air circulation in the container. Similarly, Moureh and Flick (2005) also analyzed the effect of the inlet-slot positioning on container ventilation effectiveness. In both of these analyses, a single value of the cold air blown rate is considered, and more importantly the flow geometry studied lacks representing the flow of a common ceiling-slot-ventilated enclosure used for refrigeration purposes. The container type generally accepted for perishable food transport is equipped with an evaporator that protrudes into the cold space. The injection and suction slots of the evaporator located at different surfaces provide the circulation of inside air. Smale et al. (2006) indicated that the Coanda effect which