Applied Thermal Engineering 103 (2016) 212–225

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Modeling and combined application of the modified NSGA-II and TOPSIS to optimize a refrigerant-to-air multi-pass louvered fin-and-flat tube condenser

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HIGHLIGHTS

- A multi-pass louvered fin-and-flat tube condenser model is presented and validated.
- An optimization to maximize Q and minimize N_s, ΔP_{ref} and ΔP_{air} is applied.
- Trade-off optimum design points are determined using TOPSIS and NIP method.
- The sensitivity analysis of optimum Q and ΔP_{ref} is performed.

ARTICLE INFO

Article history:
Received 16 December 2015
Accepted 19 April 2016
Available online 20 April 2016

Keywords:
Multi-pass louvered fin-and-flat tube condenser
Entropy generation number
Modified NSGA-II
Pareto front
TOPSIS

ABSTRACT

In the present work, the performance of a refrigerant-to-air multi-pass louvered fin-and-flat tube condenser is optimized without changing the condenser dimensions include length, width and depth. In order to achieve this aim, a one dimensional finite element model is developed to predict the condenser performance. The developed model is then used for optimization procedure after validating by the experimental data. The modified NSGA-II approach is applied to maximize heat transfer rate (Q) and minimize entropy generation number (N_s), refrigerant pressure drop (ΔP_{ref}) and air pressure drop (ΔP_{air}) as the objective functions. The non-dominated optimum design points are then plotted and trade-off optimum points are obtained using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Nearest to the Ideal Point (NIP) method. Comparing the results of four-objective optimization with the results of separately run three and two-objective optimization problems reveals that Q and N_s can be used interchangeably. An independent two-objective optimization of Q and ΔP_{ref} results in heat transfer rate increase of about 4% and refrigerant pressure drop reduction of about 85%. In addition, the calculations show that in this case the effectiveness of the optimized condenser increases 3.3% in comparison with the base line condenser. Also, the results of sensitivity analysis of change in the optimum heat transfer rate and refrigerant pressure drop with change in the decision variables are reported.

1. Introduction

Application of compact heat exchangers in automotive air conditioning (AAC) systems has been increased in recent years due to energy concerns. Proper design of heat exchangers plays an important role in improving the efficiency of a vapor compression refrigeration system and optimum system design. Compactness, higher performance, lower weight and reliability are some of the main advantages of compact heat exchangers in comparison with conventional heat exchangers. Investigation of compact heat exchangers performance has been subject of many studies.

Tian et al. [1] proposed a new correlation for flow boiling heat transfer in minichannels and developed a distributed parameter model for minichannel evaporator based on the suggested correlation. The results of the numerical model were validated against the experimental data. Also, comparing the effects of four flow boiling heat transfer correlations on numerical model results showed that the model with the new correlation has the highest precision. Qi et al. [2] applied new microchannel heat exchangers in AAC system. They compared the performance of the enhanced AAC system using microchannel evaporator and subcooling parallel flow condenser with that of a baseline AAC system experimentally. Cooling

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http://dx.doi.org/10.1016/j.applthermaleng.2016.04.093
1359-4311/

Nomenclature

A	area (m^2)
A_c	minimum free-flow area for air side (m^2)
A_{fin}	fin surface area (m^2)
A_{fr}	frontal area (m^2)
c_p	specific heat capacity (kJ/kg K)
C	heat capacity rate (kW/K)
D_h	hydraulic diameter (m)
f	friction coefficient
F_d	fin width (m)
F_p	fin pitch (m)
G	mass flux (kg/m^2 s)
h	heat transfer coefficient (kW/m^2 K)
H	fin height (m)
j	Colburn j-factor
k	thermal conductivity (kW/m K)
k_{fin}	fin thermal conductivity (kW/m K)
L_1	louver height (m)
L_a	louver angle (°)
L_p	louver pitch (m)
MAE	mean absolute error
$\dot{m}$	refrigerant mass flow rate (kg/s)
N_s	entropy generation number
NTU	number of transfer units
P	pressure (Pa)
Pr	Prandtl number
ΔP	pressure drop (Pa)
Q	heat transfer rate (kW)
Re	Reynolds number
Re_{D_h}	Reynolds number based on hydraulic diameter
s	specific entropy (kJ/kg K)
$\dot{S}_{gen}$	entropy generation rate (kW/K)
T	temperature (K)
T_p	tube pitch (m)
u	face air velocity (m/s)
UA	overall heat transfer coefficient (kW/K)
V_C	maximum air velocity ($u\, A_{fr}/A_c$) (m/s)
x	refrigerant quality

Greek symbols

ε	effectiveness
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
ρ_m	mean average air density (kg/m^3)
η	fin efficiency
δ_{fin}	fin thickness (m)
α	void fraction

subscripts

air	air
crit	critical
exp	experimental
g	gas
in	inlet
k	f or g for liquid and vapor phases
l	liquid
max	maximum
min	minimum
out	outlet
ref	refrigerant
tot	total
wall	wall

capacity and coefficient of performance of the enhanced system increased under high vehicle speed condition. Also, reduction of the system charge amount by using new compact heat exchangers was observed. Ye et al. [3] analyzed a new design of multiple parallel-pass microchannel tube condenser based on flow distributor concept. The test results indicated 9.5% increase in heat transfer rate by mass flow rate increment of 13.34% when comparing with the baseline condenser.

Yin et al. [4] investigated the effects of different factors on performance of a microchannel condenser by developing a numerical model. The obtained results were compared with the test data and also the results of changing the number of flat tubes in each pass were analyzed. Experimental and simulation study of automotive heat exchangers focusing on the air side thermal hydraulic performance were conducted by [5]. A distributed parameter model was developed and validated via coil designer software. It was found that condensers with shorter louvered fins have 3–8.6% higher heat capacity than condensers with longer louvered fins. Huang et al. [6] presented a finite volume-based model to simulate microchannel heat exchangers with variable tube and fin geometries. Enhancing the heat exchanger performance and improving the material utilization were reported as the benefits of the proposed design.

Zhao et al. [7] developed and validated a distributed parameter model of minichannel evaporator using R-1234yf refrigerant. It was found that R-134a has higher two-phase heat transfer coefficient than R-1234yf and the model predicts the capacity of the evaporator using R-134a better than the evaporator using R-1234yf. Garcıa-Cascales et al. [8] analyzed compact heat exchangers via numerical modeling with focus on condensation. Also, different correlations for refrigerant side heat transfer coefficient were evaluated comparing the forecasted data against the experimental data. Peuker [9] used one dimensional finite element modeling for predicting charge inventory in a microchannel condenser. The developed model predicted the overall heat transfer within ±10% and refrigerant outlet temperature within ±5 °C. Yin et al. [10] modeled a CO_2 gas cooler using a one dimensional finite element approach. The predicted capacity was within ±2% of the experimental data.

Jabardo et al. [11] simulated an AAC system based on steady state mathematical models of different components. The used microchannel condenser was divided into superheated, condensation and subcooled regions in the condenser submodel. Comparison of the obtained results with experimental data showed the absolute deviations within the range of 20%. Traeger and Hrnjak [12] examined the charge minimization of microchannel heat exchangers both experimentally and numerically. Comparison of the experimental and numerical results revealed that the capacity prediction is within ±10% of the experimental data for the serpentine and one pass microchannel condenser. An investigation of a multilouver fin, microchannel condenser was performed in [13]. A design procedure was developed which led to a 19% condenser mass reduction for uniform air flow.

Kim and Bullard [14] studied the air-side heat transfer and pressure drop of multi-louvered fin and flat tube heat exchangers experimentally. General correlations were developed for Colburn (j) and Fanning friction (f) factors with root mean square (RMS) errors of ±14.5 and ±7%, respectively. Kim and Mudawar [15] proposed a universal approach for predicting two-phase frictional pressure drop of mini/micro-channel flows. A wide database of 7115 data points was used and the proposed correlation provided