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International Journal of Refrigeration 23 (2000) 243–254

REVUE INTERNATIONALE DU FROID
INTERNATIONAL JOURNAL OF
refrigeration

www.elsevier.com/locate/ijrefrig

Performance analysis and simulation of automobile air conditioning system

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Received 15 July 1998; received in revised form 13 April 1999; accepted 24 April 1999

Abstract

Performance analyses of separate components of an automobile air conditioning system have been carried out under various operating conditions. The air conditioning system consists of a laminated type evaporator, a swash plate type compressor, a parallel flow type condenser, a receiver drier and an externally equalized thermostatic expansion valve. A computer program for performance analysis of the laminated type evaporator has been developed on the basis of the overall heat transfer coefficient and pressure drop which were obtained experimentally. A computer program for performance analysis of the parallel flow type condenser, using an empirical equation for the heat transfer coefficient, has been developed, which demonstrates that the predicted condensing capacity agrees very well with the experimental data. Then, a model for combining the performance analysis programs of separate components of an automobile air conditioning system is proposed, which simulates very well the performance of the integrated automobile air conditioning system. Further, the effects of condenser size and refrigerant charge on the performance of the integrated automobile air conditioning system are discussed.

Keywords: Air conditioning; Automobile; Operating; Performance; Simulation

Analyse de la performance et simulation d'un système de conditionnement d'air automobile

Résumé

L'analyse de la performance des composants d'un système de conditionnement d'air automobile a été effectué sous diverses conditions de fonctionnement. Le système étudié comporte un évaporateur de type laminé, un compresseur à plateau oscillant, un condenseur en écoulement parallèle, un récipient muni d'un dispositif déshydratant et un détendeur thermostatique à égalisation externe. Un programme informatique permettant l'analyse de la performance de l'évaporateur de type laminé a été développé en tenant compte du coefficient de transfert de chaleur global et de la chute de pression obtenus de façon expérimentale. Un programme informatique permettant l'analyse de la performance du condenseur à écoulement parallèle (utilisant une équation empirique pour le coefficient de transfert de chaleur) a été développé et montre que la capacité de condensation prévue concorde bien avec les données obtenues de façon expérimentale. Les auteurs proposent ensuite un modèle permettant de combiner les programmes informatiques des composants séparés d'un système de

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0140-7007/00/$20.00
PII: S0140-7007(99)00047-X

conditionnement d'air automobile. Les effets de la taille du condenseur et la charge frigorifique sur la performance du système de conditionnement d'air automobile intégré sont également exposés.

Mots clés: Conditionnement d'air; Automobile; Fonctionnement; Performance; Simulation

Nomenclature

A	area (m^2)
C	specific heat (kJ kg^{-1} K^{-1})
C_{min}	minimum heat capacity (kW K^{-1})
C_{max}	maximum heat capacity, (kW K^{-1})
COP	coefficient of performance
D	diameter, (m)
D_h	hydraulic diameter (m)
f	friction factor
f_e	ratio of enthalpy difference
G	refrigerant charge (g)
G_r	mass flow rate of refrigerant (kg h^{-1})
g	acceleration of gravity (m s^{-2})
h	heat transfer coefficient (kJ m^{-2} K^{-1})
H	enthalpy (kJ kg^{-1})
K	thermal conductivity (kJ kg^{-1} K^{-1})
k	specific heat ratio
L	length (m)
L_{eq}	equivalent length (m)
n	compressor speed (rpm)
P	pressure (kPa)
Pr	Prandtl number
Q	heat transfer rate (kJ h^{-1})
Ra	Rayleigh number
Re	Reynolds number
R_h	air humidity (%)
r_i	inside radius (m)
r_o	outside radius (m)
T	temperature (°C)
ΔT_{sh}	amount of superheat (°C)
ΔT_{sc}	amount of subcooling (°C)
U	overall heat transfer coefficient (kJ m^{-2} K^{-1})
u	velocity (m s^{-1})
V	volume flow rate (m^3 h^{-1})
V_{dis}	compressor displacement volume (cc s^{-1})
W	overall heat transfer coefficient based on logarithmic mean enthalpy difference (kJ h^{-1} kJ^{-1} kg m^{-2})
W_c	compressor work (kW)
x	refrigerant quality

Greek letters

β	coefficient of thermal expansion
η_c	compressor efficiency (%)
η_v	volumetric efficiency (%)
μ	dynamic viscosity (Pa s)
ν	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})

Subscripts

a	air
ad	adiabatic process
c	condenser
d	discharge
e	evaporator
g	gas
i	inlet, or inner
l	liquid
o	outlet, or outer
r	refrigerant
s	saturation state, or suction
w	wall surface

Diversification of ground vehicles to meet various regulations and customer tastes necessitates prompt development of automobile air conditioning systems. In particular, environmental damage like ozone depletion and global warming call for higher efficiency and optimization of each component of an automobile air conditioning system. Researches have been performed extensively to improve the efficiencies of heat exchangers used in automobile air conditioning systems, which are usually restricted to installation space and weight limits. In the early years, evaporators and condensers were made of fin-and-tube type. Later, evaporators have evolved from serpentine tube type to laminated type [1,2], while condensers have evolved to parallel flow type [3]. Currently, laminated type evaporators and parallel flow type condensers are being used for most automobile air conditioning systems.In developing an automobile air conditioning system, an optimized design through computer simulation [4,5] will reduce cost and manpower considerably. In 1972, Davis et al. [6] presented a computer program for performance analyses of separate automobile air conditioning components as well as that for performance simulation of the integrated air conditioning system. At that time, fin-and-tube type heat exchangers were used for evaporators and condensers alike. Kyle et al. [7] carried out a performance simulation of an automobile air conditioning system on the basis of the performance analysis program written for the residential heat pump model. The condenser was of fin-and-tube type and the