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Performance analysis of a vapor compression heat pump using zeotropic refrigerant mixtures

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Abstract

This paper presents the performance analysis of an air-to-water vapor compression heat pump system using pure refrigerants and zeotropic refrigerant mixtures. The heat pump system is composed of a compressor, condenser, air cooled evaporator, expansion valve, a receiver tank, a superheater/subcooler, refrigerant mixture unit and some auxiliary and measurement devices. The study focuses on the second law efficiency characteristics of the heat pump system. Comparisons are made between the pure refrigerants and refrigerant mixtures on the basis of the COP and second law efficiency. Also, the effect of the evaporator source inlet temperature on the COP and second law efficiency is presented. It was found that the mixture ratio affects the COP and second law efficiency significantly, and the COP and second law efficiency for the pure refrigerants could be improved by using an appropriate mixture of the refrigerants.
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Keywords: Heat pump; Zeotropic; Non-azeotropic; Refrigerant mixtures; COP; Second law efficiency

1. Introduction

Since the action of chlorine atoms liberated from chlorofluorocarbons (CFCs) used in refrigeration technology as catalysts in ozone depleting reactions and their contribution to the greenhouse effect have been discovered, many actions have been performed by different countries and international organizations to reduce the production and consumption of CFCs. According to these regulations, fully halogenated halocarbons, known as CFCs, will ultimately be phased out in

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Nomenclature

CFC	chlorofluorocarbons
COP	coefficient of performance
GWP	global warming potential
NR	natural refrigerant
ODP	ozone depletion potential
$\dot{Q}_c$	condenser heat load (kW)
s	entropy (kJ/kg K)
T	temperature (°C)
T_L	low temperature (°C)
T_H	high temperature (°C)
$\dot{W}_{comp}$	power supplied to compressor (kW)
η_{II}	second law efficiency

all developed countries, while developing countries will benefit from a more relaxed phase out schedule [1,2].

There are two types of measures to reduce CFCs emissions: short term measures and long term measures. Short term measures include a more accurate design of the plants, better maintenance operations and by recycling the fluids whenever possible. Long term measures involve: (i) substitution of the actual refrigerants with non-polluting ones that could meet the requirements of absence of toxicity, flammability and all exigences from the thermodynamic and thermophysical points of view and (ii) use of alternative refrigeration systems as compared to the vapor compression ones, such as air refrigerating machines, steam jet refrigerating machines, absorption refrigerating machines using different circuit types, reverse Stirling refrigerating machines etc. The new refrigerants can be grouped into three main categories: natural refrigerants, HFCs and mixtures of (environmentally friendly) refrigerants [1–3].

Considering the negative role of CFCs on ozone depletion and the greenhouse effect as well as the positive impact of heat pumps for reduction of CO_2-emissions, research and development work has not only to be concentrated on environmentally benign fluids with no or negligible ozone depletion potential (ODP) and global warming potential but also on improved energy efficiency, heat pump performance and lower primary energy consumption compared with conventional heating systems. The interest in the use of zeotropic mixtures of refrigerants in compression heat pumps and other vapor compression cycles has grown in recent years. In heat pump systems, zeotropic mixtures have several advantages over pure refrigerants [4–7]:

(1) *Improved system performance:* A zeotropic mixture is one whose components do not form a zeotrop, i.e. it never performs as a pure fluid. Isobaric phase change operations do not occur at constant temperature. Rather, there is a range of temperatures over which the mixture exists in a two phase state. Therefore, the temperature of a zeotropic mixture during evaporation or condensation at constant pressures will vary. By approximating this temperature variation in the working fluid to the temperature profile of the source or sink fluid, the average temperature

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