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Thermodynamic analysis of refrigerant mixtures for possible replacements for CFCs by an algorithm compiling property data

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Abstract

In this study, we formed an algorithm to find refrigerant mixtures of equal volumetric cooling capacity (VCC) when compared to CFC based refrigerants in vapor compression refrigeration systems. To achieve this aim the point properties of the refrigerants are obtained from REFPROP where appropriate. We used replacement mixture ratios—of varying mass percentages—suggested by various authors along with our newly formed mixture ratios. In other words, we tried to see the effect of changing mass percentages of the suggested (i.e. in the literature) replacement refrigerants on the VCC of the cooling system. Secondly, we used this algorithm to calculate the coefficient of performance (COP) of the same refrigeration system. This mechanism has provided us the ability to compare the COP of the suggested refrigerant mixtures and our newly formed mixture ratios with the conventional CFC based ones. According to our results, for R12 R290/R600a (56/44) mixture, for R22 R32/R125/R134a (32.5/5/62.5) mixture, and for R502 R32/R125/R134a (43/5/52) mixture are appropriate and can be used as replacements.

Keywords: Refrigerant mixtures; CFC replacements; COP; REFPROP

1. Introduction

Refrigerants have been widely used in several areas in the industry for a long time. After the discovery of the harmful effects of CFC based refrigerants on the ozone layer, search to finding alternatives to these working fluids gained more interest in the recent few years. Finding drop-in replacements for CFC based working fluids is important due to their harmful effects on the ozone layer and international conventions are requesting to reduce their usage. In [1] a thorough examination of the problem can be found.

Due to the reasons listed, the researchers prompted with the alternatives, which can be used instead of CFCs. Finding the alternatives has been mainly based on trial-error method. In other words in their experiments researchers have used varying mass/mol percentages of mixtures to obtain replacements. The suggested replacements can be divided into two groups; namely, the mixtures that can be used as substitute in current cooling systems and the mixtures, which can provide better performance in the systems to be developed in the future. Numerous studies can be found in the literature on this matter including [2–4].

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Nomenclature

CFC	chlorofluorocarbon
COP	coefficient of performance
CSD	Carnahan De Starling
f	heat transfer ratio
HC	hydrocarbon
HFC	hydrofluorocarbon
MP	mass percentage (%)
P	pressure (kPa)
ΔP	pressure difference (kPa)
T	temperature (K)
VCC	volumetric cooling capacity (kJ/m^3)

Subscripts

a	air
c	condenser
e	evaporator
s	saturation region
sh	superheat region
sc	subcooled region

In finding the alternatives to the CFC based cooling refrigerants often, mixtures of binary, ternary, or even quartet are suggested. Mixing two or more refrigerants gives us a chance to obtain the desired thermodynamic properties (i.e. often closing to CFC based ones for current systems) of the refrigerants by changing the mixture ratios. However, considering varying mass percentages of these mixtures, finding their effects on a cooling system experimentally is almost impossible due to the number of experiments that need to be done. This is one of the reasons why simulation platforms such as REFPROP are developed. Using the REFPROP the user can select either pure or mixture refrigerants and make a series of analysis to find their thermodynamic properties. Thus, reducing the time and the effort spent for the evaluation when compared to the experimental approach.

Using the abilities of the REFPROP we devised a schema which is a modified version presented in [5] to examine the behavior of refrigerant mixtures in vapor compression refrigeration systems which in turn puts us in a position to make evaluation and suggestions about them. In this approach we use the first law of thermodynamics as the starting point. According to this law, the performance calculation of a cooling system is called the coefficient of performance of the system and calculated as, dividing cooling load by compressor work. Section 2 provides the system layout used as a test-bed for our calculations. In Section 3 the details of our schema used to find VCC of various mixtures and COP calculations are presented. Section 4 provides results and finally Section 5 concludes this paper.

2. The system layout

Fig. 1 illustrates the overview of our cooling system [5]. The main components of the cooling system include

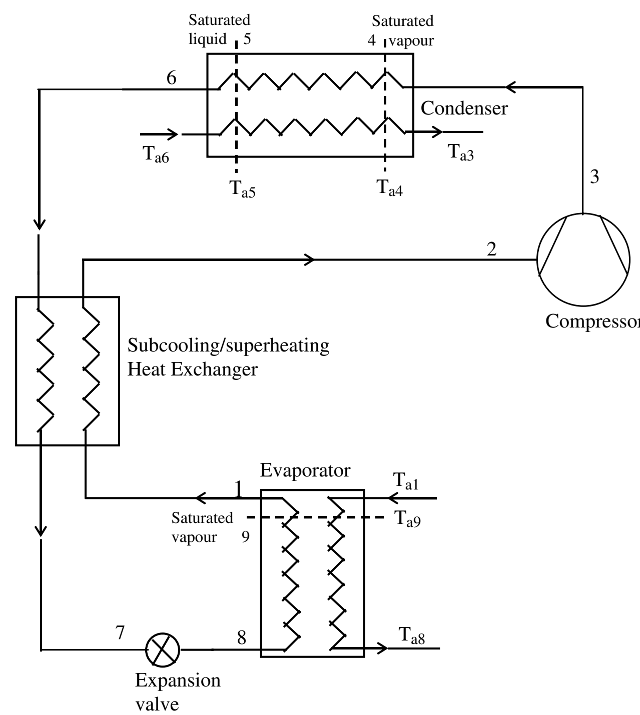

Fig. 1. Refrigeration system with subcooling/superheating heat exchanger.

air-cooled condenser and evaporator, compressor, SLHE, and expansion valve.

In a cooling system, evaporation and condensing processes occurring in refrigeration systems and heat pumps are as a result of the heat transfer process occurring by means of refrigerants. The design of a cooling system largely depends on the properties of the refrigerants. The negative side effects of CFC based refrigerants have been mentioned earlier. Instead of CFCs alternative refrigerant mixtures have been suggested [6]. This is due to the lack of pure refrigerants, which may be ac-