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Influence of compressor oil admixtures on theoretical efficiency of a compressor system

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ABSTRACT

This paper presents a theoretical evaluation of the influence of compressor oil admixtures on the thermodynamic performance of a vapor compression system using natural refrigerant R600a. The performance determination is based on the developed pressure–enthalpy diagrams (*P*–*h*) for the refrigerant oil solution (isobutane-mineral compressor oil Azmol). A method for calculating the enthalpy of refrigerant–oil solutions has been proposed and the influence of the compressor oil admixtures to isotherms the pressure–enthalpy diagrams has been analyzed. The change of enthalpy at the different oil concentrations in the working fluid in an evaporator has been investigated. An application of the developed refrigerant–oil *P*–*h* diagrams for the theoretical evaluation of the efficiency of the vapor compression systems is also demonstrated.

Influence des mélanges d'additifs sur l'efficacité théorique d'un système à compresseur

Mots clés : Système frigorifique ; Système à compression ; Isobutane ; Calcul ; Chauffage ; Enthalpie ; Mélange ; Huile ; Efficacité

1. Introduction

The main function of compressor oil is to reduce friction and minimize the wear of moving parts in a refrigeration system. The oil entrainment from the compressor considerably influences the performance of a refrigeration system. In the middle of the last century Bambach (1955) and Spauschus (1963) demonstrated that performance of the refrigeration system

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Nomenclature

b	coefficient in equation (4)
C_P	heat capacity, kJ kg^{-1} K^{-1}
c_g	weight concentration of the compressor oil before throttle, kg kg^{-1}
h, Δh	enthalpy, enthalpy of mixing, kJ kg^{-1}
m	mass, kg
Δm	quantity of non-evaporated from RWF refrigerant, %
P	pressure, kPa
P_0	pressure in evaporator, kPa
q_0	specific refrigerating effect, kJ kg^{-1}
R	universal gas constant, kJ mol^{-1} K^{-1}
T	temperature, K
v	specific volume, m^3 kg^{-1}
w	weight concentration, kg kg^{-1}
W	compression isentropic work, kJ kg^{-1}
X	vapor quality, kg kg^{-1}

Greek symbols

α_R	Riedel's criterion
ε	coefficient of performance (COP)
λ	actual volumetric effect
μ	molecular weight, kg mol^{-1}

Subscripts and superscripts

C	property under critical conditions
CON	property under condensation conditions
l	liquid phase
mix	property of the refrigerant-oil solution
OIL	property of oil
R	property of the pure refrigerant
RH	regenerative heat exchanger
rlq	remaining liquid quantity in evaporator
RSV	reference state value
S	property of the refrigerant-oil solution under saturation conditions
v	vapor phase
$^-$	property $^-$ is the pseudoproperty

depends upon the quantity and the type of compressor oil, circulating in the system with the refrigerant. The refrigerant and oil mixture is known as *real working fluid* (RWF) in a vapor-compression refrigeration system. The design of the refrigeration system is based on thermophysical, chemical, toxicological and ecological properties of pure refrigerants ASHRAE (1998) and does not take into account the presence of compressor oil the refrigerant. At the same time the presence of the compressor oil admixtures in the refrigerant leads to decrease in the cooling capacity of the system due to decrease in heat transfer coefficient in the evaporator (Zürcher et al., 1998a,b; Kedzierski, 2001, 2003; Lottin et al., 2003). The compressor oil admixtures also increases the compression work. At the same time, the circulation of the compressor oil in the refrigeration system is also important (Lebreton et al., 2001; Andrade et al., 1999) and must be taken into account during the design of refrigeration plant.

In order to design a refrigeration system, the information about the thermophysical properties of a refrigerant oil mixture is imperative. For this purpose, it is necessary to have data on concentration of compressor oil in the working fluid before the throttle and the concentration drops of the RWF in the evaporator as well. Most of the indirect methods of determining the oil concentration in the different parts of refrigeration system are based on the information on RWF thermophysical properties (Andrade et al., 1999). To our knowledge, only a few papers are available in the literature which have considered caloric properties of the RWF and evaluated the effect of admixtures on the efficiency of the compressor system (Meltser, 1969; Hughes et al., 1982; Hewitt et al., 1996; Corr et al., 1996; Medvedev et al., 2004; Youbi-Idrissi et al., 2003, 2004; Zhelezny, 2002; Zhelezny et al., 2004, 2007a,b; Lottin et al., 2003), and the heat transfer (Zürcher et al., 1998a,b; Kedzierski, 2001, 2003). A very good review on this phenomenon has been recently published by Youbi-Idrissi and Bonjour (2008).

The caloric properties of the RWF are not available due to lack of information from manufacturing industries about the composition and molecular structure for the compressor oils. The existing equations of state cannot be directly used for calculation caloric properties of the RWF and correspondingly cannot be applied for development the pressure–enthalpy diagrams for the RWF (Medvedev et al., 2004). In our previous papers (Zhelezny et al., 2003, 2004, 2007a,b; Medvedev et al., 2004; Semenyuk et al., 2008) we proposed to use a theory of thermodynamic similarity in order to predict the solubility, density, pseudocritical parameters for the RWF over wide range of refrigerant concentrations based on limited experimental information. The correlations were successfully applied for the description of the experimental data for the solubility of various RWF (Medvedev et al., 2004; Zhelezny et al., 2007a,b) and then for the calculation of caloric properties the RWF. Based on results obtained the next step was a development of the pressure–enthalpy diagrams for the RWF, suitable for practical application. In this paper we offer the presented results as a demonstration of applicability developed pressure–enthalpy (*P*–*h*) diagrams of RWF for the theoretical evaluation the efficiency of the compressor system.

2. Determination of the enthalpy of real working fluid in an evaporator

It is common knowledge that thermodynamic properties of the RWF substantially differ from properties of ideal liquid solutions. The presence of oil admixtures in refrigerant results in formation of solutions with a strong zeotropic behavior. The oil boiling point usually exceeds 250 °C (Semenyuk et al., 2008; Mermond et al., 1999). This value is significantly lager than value of the boiling temperature for the RWF in the evaporator. Correspondingly, the vapor phase of the RWF consists almost pure refrigerant and the compressor oil admixtures exist only in the liquid phase of the RWF. The