Available online at www.sciencedirect.com

ScienceDirect

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

Lubricity evaluation of oil–refrigerant mixtures with R134a and R290

*Kasper Górny *, Arkadiusz Stachowiak, Przemysław Tyczewski, Wiesław Zwierzycki*

Poznan University of Technology, Institute of Machines and Motor Vehicles, Piotrowo Street 3, 60-965 Poznan, Poland

ARTICLE INFO

Article history:
Received 4 January 2016
Received in revised form 6 June 2016
Accepted 8 June 2016
Available online 11 June 2016

Keywords:
Lubricity
Boundary lubrication
Oil–refrigerant mixture
Propane

ABSTRACT

The article presents an assessment method of lubricity properties of oils for refrigeration compressors in a mixture with a refrigerant. The assessment has been based on sample wear volume in the block-on-ring node under the conditions similar to the operation of the compressor following an extensive standstill.

The authors assessed the lubricity properties of the following mixtures POE/R134a and MO/R290 (three different oils for each group).

In all the analyzed cases it was found that the sample wear after the tests in the oil–refrigerant mixture is significantly (2–32 times) higher than for the oil itself. The test results also showed significant differences in the lubricity properties of oils, which are substitutes in operating conditions. Therefore, the only valid method of assessing lubricity properties of oils for refrigerating compressors are studies on the mixtures of these oils with a refrigerant in the conditions similar to the real operation.

Évaluation de la lubricité des mélanges d’huile et des frigorigènes R134a et R290

Mots clés : Lubricité ; Lubrification limite ; Mélange huile-frigorigène ; Propane

1. Introduction

The problems with lubrication in refrigeration compressors are usually caused by the presence of the oil–refrigerant mixture in the friction nodes. The presence of a refrigerant in the oil degrades its lubricity properties (Akram et al., 2013; Ciantar et al., 1999; Fukui et al., 2000; Nunez et al., 2010). The refrigerant should form a mixture with the lubricating oil in the full range of temperatures and operating pressures. Satisfying this criterion allows for the return of oil from the system to the refrigeration compressor. Simultaneously, the oil does not accumulate in heat exchangers. Most mechanical damage to reciprocating refrigeration compressors is caused by improper lubrication of the sliding nodes due to insufficient amount of oil (oil accumulates in the system) or by the

* *Corresponding author.* Poznan University of Technology, Institute of Machines and Motor Vehicles, Piotrowo Street 3, 60-965 Poznan, Poland. Tel.: +48 61 665 2236; Fax: +48 61 665 2736.

E-mail address: kasper.gorny@put.poznan.pl (K. Górny).

http://dx.doi.org/10.1016/j.ijrefrig.2016.06.011

Nomenclature

p_s refrigerant pressure in the test chamber
r counter sample radius (the ring) [mm]
s sample width (the block's) [mm]
τ_t wear tests duration time
τ_m oil–refrigerant mixture formation time
V sample wear volume [mm^3]
x width trace of sample wear [mm]

Abbreviations
HC hydrocarbons
HFC hydrofluorocarbons
MO mineral oils
POE polyester oils
PVE polyvinylethers

absorption of the refrigerant in the oil. The important issue is therefore the assessment of lubricity properties under operating conditions (in the mixture with a refrigerant).

In most cases, the refrigeration compressor oil should demonstrate its solvability with a refrigerant in a full range of temperatures and pressures occurring in refrigeration systems. The general recommendations for the refrigerants currently in use are to apply mineral oils for natural refrigerants such as hydrocarbons (HC) and ammonia, and to use synthetic polyester oils (POE) or polyvinyl ethers (PVE) for the refrigerants from the group of hydrofluorocarbons (HFC) and their mixtures with hydrocarbons (HFC+HC). It is also recommended that polyalphaolefins or polyester oils be used with refrigerants from the HC group. In general, for the HC group of refrigerants one recommends the application of oils of higher viscosity than for the refrigerants from the HFC group.

While selecting oil for the refrigeration compressors one often uses viscosity as the function of temperature and pressure (Daniel plot). On the basis of these correlations, one can infer the state of the oil–refrigerant mixture at different points of the refrigeration system. This is essential for enabling the return of oil to the refrigeration compressor and proper functioning of the refrigeration appliances. With the help of Daniel plots the lubricating properties of the oil–refrigerant mixtures can be evaluated in the sense of viscosity under occurring conditions. However, the effect of additives cannot be identified.

The selection of oil for the refrigeration compressor is determined by the type of refrigerant and operating conditions (the range of pressure and temperature). Among the presently used refrigerants, the ones that have a destructive impact on the ozone layer have virtually been phased out. Also, the refrigerants with a high global warming potential are currently being eliminated. Still commonly used refrigerants are hydrofluorocarbons (HFC), such as R134a. The future efforts, however, are aimed at a gradual replacement of these refrigerants with natural substances which have a negligible impact on climate change. The perspective refrigerants include hydrocarbons (HC), for instance R290 (Calm, 2008). The replacement of refrigerants with the more ecological ones triggers the need for the selection of an appropriate compressor oil.

Lubricity (tribological) properties of mixtures of lubricating oils with refrigerants have been evaluated by using various research methods. Tests have been carried out on different types of model friction nodes due to the use of standard samples, time acceleration and low costs of research as compared to testing real objects in the form of refrigeration compressors.

One of the first appliances for wear tests in the mixture of lubricating oils and refrigerants was the Falex machine. Huttenlocher (1969) used it for wear tests in the mixture of mineral oils with R12. In turn, Kitaichi et al. (1990) used the Falex machine to test a variety of oils, mainly synthetic, in the mixture with R134a. In these tests the mixture was formed by passing the refrigerant through oil. A significant limitation of implementing standard machines for wear tests was inaccurate modeling of typical conditions occurring in the real refrigeration compressors. Typically, it led to testing mixtures at the atmospheric pressure wherein the amount of the refrigerant is much lower than at the pressure existing in the compressor. In addition, there was the risk of penetration of other gases from the environment to the examined mixtures.

The possibility for wear tests in the oil–refrigerant mixture at a pressure higher than the atmospheric one was allowed due to a modernized Falex machine by Sanvordenker and Gram (1974) and Sanvordenker (1984). The friction node was enclosed in a properly sealed chamber, which enabled the implementation of excess pressure during wear tests. In order to form the oil–refrigerant mixture, a small amount of a refrigerant was supplied to the test chamber above the oil contained there.

The research at higher pressures of a refrigerant was presented by Komatsuzaki et al. (1987, 1991). They used the four-ball apparatus. However, the range of pressures applied by them did not correspond to the values that could occur in the majority the existing refrigeration compressors at that time. The four-ball apparatus was also used by, inter alia, Khan et al. (2005). Junk (2010) performed wear tests in the oil/refrigerant mixture using a modified Almen–Wieland machine. The frictional matching used in these tests corresponds to the greatest extent to the actual geometry of the slide bearings due to the distributed aerial contact. Other authors, however, used friction nodes that enabled achieving measurable wear in a relatively short test duration.

Recently, the most frequent test stations have been of the pin-on-disc (Akram et al., 2014; Garland and Hadfield, 2005; Hong-Gyu et al., 2009; Mishra and Polycarpou, 2011; Na et al., 1997; Sariibrahimoglu et al., 2010; Yoon et al., 1996) and block-on-ring (Birol and Birol, 2008; Cannaday and Polycarpou, 2005; De Mello et al., 2009; Hadfield and Garland, 2005; Ikeda et al., 2004; Mizuhara et al., 1994; Muraki et al., 1996; Sheiretov et al., 1995; Suha et al., 2006; Takesue and Tominaga, 1998; Tanaka et al., 2014). A number of these studies have concerned the mixture of oils and agents from the HFC group (mainly R134a) (Garland and Hadfield, 2005; Mishra and Polycarpou, 2011; Muraki et al., 1996; Na et al., 1997; Takesue and Tominaga, 1998; Yoon et al., 1996). On the other hand, rarely have studies addressed the mixtures with the agents of the HC group (mainly R600a isobutene) (Birol and Birol, 2008; Garland and Hadfield, 2005; Sariibrahimoglu et al., 2010). Individual researchers produced the oil–refrigerant mixture in a different way. Mostly, a continuous supply of the refrigerant at a constant pressure was