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Research Paper

# Performance estimation of ejector cycles using ethers and fluorinated ethers as refrigerants

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## HIGHLIGHTS

- The advantages of using ethers and fluorinated ethers as refrigerants were shown.
- Computer software based on the 1-D model of Huang et al. (1999) was prepared.
- The optimal temperature range of primary vapor for each refrigerant was calculated.

## ARTICLE INFO

*Keywords:*
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## ABSTRACT

Computer software, based on the theoretical model of Huang et al. (1999) with thermodynamic properties of selected refrigerants, was prepared. The investigation was focused on alternative refrigerants that belong to the groups of ethers and fluorinated ethers. The main purpose of the paper was to check the possibility of co-operating the above substances with an ejector cooling system powered by a high-temperature heat source. A series of calculations were carried out for the generator temperature from 60 °C to 165 °C, with assumed temperatures of evaporation of 10 °C and condensation of 40 °C. The analysis revealed that there is no single refrigerant that ensures the efficient operation of the system in the whole range of primary vapor temperatures. Each substance has its own maximum entrainment ratio and COP at its individual optimum temperature. The maximum COP values were obtained for dimethyl ether and diethyl ether, and reached 0.30 and 0.25 respectively.

## 1. Introduction

Since the early-90s of the last century, there has been a series of drastic changes in the world of refrigeration and air conditioning. The reason for these changes is the participation of refrigerants released into the atmosphere in both the destruction of stratospheric ozone and the increase in the greenhouse effect. In the mid-1970s it was recognized that chlorofluorocarbons (CFCs) were strong greenhouse gases that could have a substantial impact on climate change as well as being substances that deplete stratospheric ozone levels. Not fully halogenated derivatives of hydrocarbons (HCFCs) and perfluorocarbons (PFCs) were also recognized as harmful substances. Because of the long lifetimes of CFCs, their atmospheric levels continued to increase in the early 1990s, even when their emissions were decreasing [23]. Therefore, in December 1997 under the Kyoto Protocol, all of the above substances were listed as restricted compounds. It then became important to develop new working fluids that have characteristics similar to CFCs, and more importantly, are environmentally benign. CFCs have been replaced by non-ozone depleting substances – hydrofluorocarbons (HFCs). However, over the last two decades, the atmospheric levels of these less-depleting (HCFCs) and non-depleting (HFCs) substitutes have grown rapidly. Although the proposed replacements were characterized by zero ODP, the GWP and residence time in the atmosphere of these substances in some cases were much higher than for primary refrigerants and therefore the use of HFC refrigerants also became problematic. Nowadays, the use of EU Regulation 517/2014 [18] will force drastic changes in refrigeration and air conditioning systems, as most of the currently used refrigerants (R134a, R404A and R410A) will not fulfill the requirements for the GWP parameters. Various substances have emerged to replace HFCs. However, due to their different physicochemical properties, it is still unclear which alternative refrigerants will be used in the near future.

Currently, both theoretical and experimental research concerning the working performance of ejector systems with new and environmentally safe refrigerants are being conducted. Environmentally friendly substances, especially natural ones, are characterized by both a

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**Nomenclature**

| | |
|---|---|
| $A$ | area ($m^2$) |
| $c_p$ | specific heat ($kJ\,kg^{-1}\,K^{-1}$) |
| $C_r$ | compression ratio (dimensionless) |
| $h$ | specific enthalpy ($kJ\,kg^{-1}$) |
| $P$ | pressure (kPa) |
| $Q$ | heat rejected or supplied (W) |
| $s$ | specific entropy ($kJ\,kg^{-1}\,K^{-1}$) |
| $T$ | temperature (°C) |

*Greek symbols*

| | |
|---|---|
| $\gamma$ | heat capacity ratio (dimensionless) |
| $\phi$ | loss coefficient (dimensionless) |
| $\eta$ | isentropic efficiency (dimensionless) |
| $\omega$ | entrainment ratio (dimensionless) |

*Subscripts*

| | |
|---|---|
| c | condensing |
| crit | critical |
| e | evaporation |
| g | generating |
| m | mixing |
| N | normal boiling point |
| p | primary flow |
| s | secondary flow (entrained) |
| t | throat |
| COP | coefficient of performance ($=Q_e/Q_g$) |
| GWP | Global Warming Potential |
| IDLH | Immediately Dangerous To Life or Health |
| NOAEL | No Observable Adverse Effect Level |
| ODP | Ozone Depletion Potential |
| PEL-TWA | Permissible Exposure Limit – Time-Weighted Average |
| STEL | Short-Term Exposure Limit |
| TLV-TWA | Threshold Limit Value – Time-Weighted Average |

low GWP and a short atmospheric lifetime (Fig. 1), which is their great advantage when compared to the refrigerants that are currently used. The analysis concerns either natural working fluids, such as carbon dioxide [2,14,27] or hydrocarbons [4,13,17], as well as synthetic refrigerants that are mainly from the group of hydrofluoroolefins (HFO) [8,9,19,26]. The authors of this study also examined the working performance of the ejector cycle for a variety of working fluids. The impact of refrigerants from a group of heavier hydrocarbons [12], as well as organic solvents and selected synthetic refrigerants [10], on the efficiency of the ejector cooling cycle have been examined. It was found that from the group of hydrocarbons, the highest value of COP equal to 0.32 can be obtained for iso-butane. Among the non-flammable synthetic refrigerants, R236fa was the most beneficial, giving a maximum COP = 0.23 ($T_g$ = 95 °C). This value was higher than the one of R141b by up to 21%. It was also found, that it is possible to obtain an entrainment ratio in the range of 0.4–0.5 for refrigerants such as cyclopentane, cyclohexane or acetone if the primary vapor temperature is maintained above 160 °C.

Looking into new refrigerants is an extremely important issue the refrigeration industry is currently facing. More importantly, this issue affects not only large, industrial refrigeration plants, but also the air conditioning systems that are so popular nowadays. In recent years, particular attention has been paid to systems using renewable energy sources. Ejector refrigeration systems have a great potential to be supplied with a renewable or waste heat source, which is why these systems have been given attention in many articles [3,5,21]. A lot of work is focused on the optimal design of the ejectors and also mathematical models to characterize their work [15,20,24,25]. However, one should not forget about their development and should pay attention to refrigerants that can increase the efficiency of the ejector. The aim of the study was to preliminary recognize the possibility of using new refrigerants in ejector cooling cycles. Please note that there is no discussion in literature regarding the issue being raised. To achieve the assumed research goal, the ejector model presented by Huang et al. has been used. The use of this model is justified due to the fact that it is based on real measurement data that was carried out for the R141b refrigerant. The presented 1-D model of the ejector performance at the critical–mode operation allows the analysis carried out for many

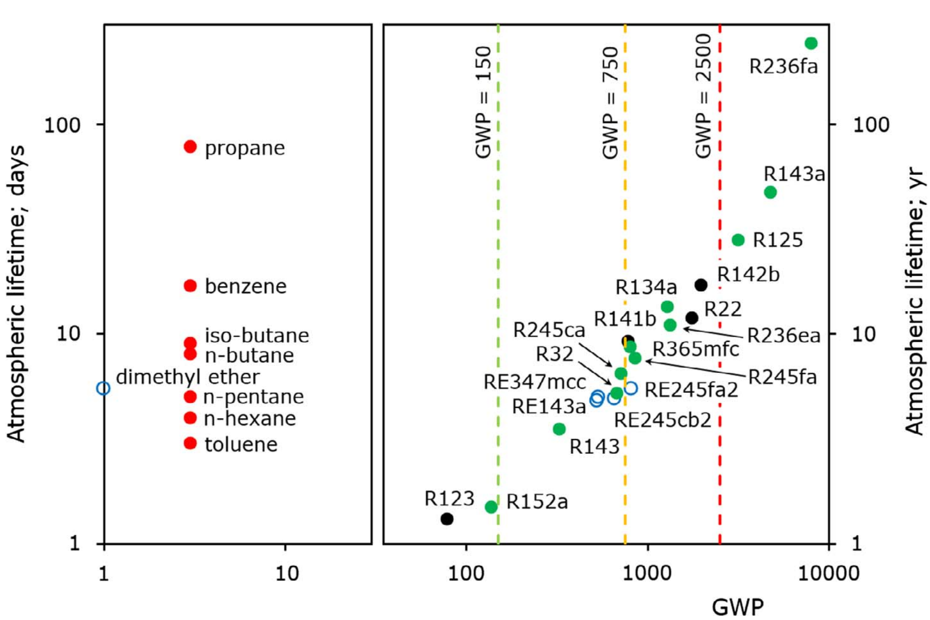


**Fig. 1.** Atmospheric lifetime and GWP for selected refrigerants (based on [6]).