

El Hassan, Mouhammad; Assoum, Hassan H.; Bukharin, Nikolay; Abed-Meraim, Kamel; Sakout, Anas

## Article

# Investigation of thermo-physical fluid properties effect on binary fluid ejector performance

Energy Reports

## Provided in Cooperation with:

Elsevier

**Suggested Citation:** El Hassan, Mouhammad; Assoum, Hassan H.; Bukharin, Nikolay; Abed-Meraim, Kamel; Sakout, Anas (2020) : Investigation of thermo-physical fluid properties effect on binary fluid ejector performance, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 287-292,  
<https://doi.org/10.1016/j.egyr.2019.11.076>

This Version is available at:

<https://hdl.handle.net/10419/243891>

### Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

### Terms of use:

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),  
September 20–23, 2019, Okinawa, Japan

# Investigation of thermo-physical fluid properties effect on binary fluid ejector performance

Mouhammad El Hassan<sup>a,b,\*</sup>, Hassan H. Assoum<sup>c</sup>, Nikolay Bukharin<sup>d</sup>,  
Kamel Abed-Meraim<sup>e</sup>, Anas Sakout<sup>e</sup>

<sup>a</sup> Prince Mohammad Bin Fahd University, Mechanical Engineering Department, Al Khobar, Saudi Arabia

<sup>b</sup> University of Alberta, Mechanical Engineering Department, Edmonton, Canada

<sup>c</sup> Beirut Arab University, Mechanical Engineering Department, Tripoli, Lebanon

<sup>d</sup> Southern Alberta Institute of Technology, School of Manufacturing and Automation, Calgary, Canada

<sup>e</sup> Lasie, University of La Rochelle, La Rochelle, France

Received 2 October 2019; accepted 22 November 2019

## Abstract

Supersonic Ejector (SE) is a thermally-driven fluidic compressor that replaces the electro-mechanical compressor in Reverse-Rankine refrigeration/heat pump cycles. These widely used thermal cycles account for billions of kWh of electric energy and produce hundreds of millions of metric tons of atmospheric carbon yearly in North America.

As compared to mechanical compressors, ejectors are simple mechanical devices with no moving parts. It can be configured to provide residential and commercial space heating/cooling and water heating, industrial process heating/cooling, industrial distillation/desalination and drying. Rather than electricity, SE-based systems can make direct use of many forms of thermal energy including solar thermal, waste heat, biogas, or natural gas, depending on emission targets, price, or availability. It is known that the SE systems have a lower thermal efficiency as compared to mechanical compressor because of its lower performance at high compression ratios.

Highly efficient ejector would thus play a critical role in unlocking the wide spread use of renewable energy such as waste heat, solar thermal, and geothermal. Even in the absence of renewable energy, such a device would enable fuel switching from electricity to natural gas, which would save 65 to 75% on energy costs, and relieve the power grid during peak times.

In the present study, Computational Fluid Dynamics (CFD) is used to study the effect of fluids thermo-physical properties including molecular mass, viscosity and specific heat ratio on the performance of an ejector for distillation applications. It is found that molecular mass and specific heat ratio can significantly affect the entrainment ratio of the ejector and consequently the COP of the refrigeration system.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

**Keywords:** Supersonic ejector; Binary fluid ejector; Refrigeration; Heat pumps; Computational Fluid Dynamics; Coefficient of performance

\* Corresponding author at: Prince Mohammad Bin Fahd University, Mechanical Engineering Department, Al Khobar, Saudi Arabia.  
E-mail address: [melhassan@pmu.edu.sa](mailto:melhassan@pmu.edu.sa) (M. El Hassan).

## 1. Introduction

The coefficient of performance (COP) of a BFE refrigeration system can be calculated based on the following equation [1]:

$$COP = \omega f_h \quad (1)$$

where  $\omega$  is the mass entrainment ratio and  $f_h$  is related to the enthalpy ratio of the evaporator and boiler plus pump based on the following equation:

$$f_h = \frac{h_{(v,S)eva}}{h_{(v,P)boi} + \Delta h_{pump}} \quad (2)$$

This COP equation essentially groups all the parameters influencing COP of the system into two categories;  $\omega$  and  $f_h$ .  $\omega$ , is a function of molecular mass, specific heat ratio, dynamic viscosity, thermal conductivity, mass diffusivity, ejector geometry and operating conditions.  $f_h$  is primarily a function of thermodynamic properties of the working fluids such as vaporization enthalpies and heat capacities. Entrainment ratio of the ejector is an important parameter that strongly affects the COP of the system [1–3]. In order to study the effect of thermo-physical properties of primary and secondary fluids on the COP of a BFE system, a CFD model was used to have a better understanding of effects of these properties on the ejector performance. Several RANS-based turbulence models were evaluated in previous studies to investigate the ejector performance. SST (shear stress transport)  $k-\omega$  model was used in El Hassan et al. [1], El Hassan and Bukharin [2], Van and Jan [4] and Kracik and Dvorak [5]. In Bartosiewicz et al. [6],  $k-\omega$  and SST  $k-\omega$  models were compared to  $k-\varepsilon$  model and it was concluded that SST  $k-\omega$  presents a better agreement with the experimental results. In Varga et al. [7], experimental results were used to validate six turbulence models (standard  $k-\varepsilon$ , RNG  $k-\varepsilon$ , realizable  $k-\varepsilon$ , standard  $k-\omega$ , SST  $k-\omega$  and Transition SST) under a relatively wide range of operating conditions. It was also found that the most accurate COP prediction was obtained using the SST  $k-\omega$  model.

In the present paper, the effect of the viscosity, molecular mass and specific heat ratio of primary and secondary fluid on the entrainment ratio of the ejector were studied numerically.

## 2. Methodology

The compressible steady state binary flow simulations in axi-symmetric ejectors were studied using ANSYS FLUENT. More information on the numerical simulations can be found in our earlier papers [1,2]. In this work, the simulations were conducted for distillation application and the secondary fluid is thus considered as water and the operating conditions of the simulations are set based on this application. Considering the optimum conditions for the entrainment ratio,  $f_h$  was calculated for some real primary fluid selected from the thermodynamic NIST database.

## 3. Results

### 3.1. Effect of viscosity of the primary and secondary fluid on the entrainment ratio

In order to investigate the effect of viscosity of Primary fluid on the entrainment ratio for a distillation system, all the operating conditions were set constant, except the viscosity of primary and secondary fluid which was changed for a range of  $7.63 \times 10^{-6}$ – $1.77 \times 10^{-4}$  and  $1.34 \times 10^{-7}$ – $1.34 \times 10^{-5}$  (Pa s) respectively. The molecular weights of the primary and secondary fluids were 250 and 18 g/mol, respectively. The geometrical specifications of the ejector used in this study are as follows:

Jet nozzle throat and exit diameters: 2 mm & 8 mm.

Nozzle exit location (NXP): 35 mm.

Ejector mixing chamber inlet diameter: 29 mm.

Ejector throat diameter: 19 mm.

The CFD results showed that the viscosity does not have significant influence on the entrainment ratio or even on the local flow variables in the ejector. Since viscosity, molecular diffusion and thermal conductivity originate from same physical fundamentals, it is concluded that molecular diffusion and thermal conductivity will have the same negligible effect on the ejector operation and entrainment ratio. This could be related to the fact that the turbulent

fluctuations in the fluid flow in the ejector are much higher than molecular level fluctuations, thus the momentum, mass and heat exchange through the turbulent fluctuations are drastically higher than molecular level exchange for these parameters.

### 3.2. Effect of molecular weight and specific heat ratio on the entrainment ratio

The effect of thermo-physical properties of primary fluid, molecular mass and specific heat ratio, on the entrainment ratio of an ejector was investigated, with the aim of improving the ejector entrainment ratio. The first part of the study will focus on the effect of molecular mass and specific heat ratio of primary fluid on entrainment ratio of a distillation system which the secondary fluid is water. In the second part, the effect of molecular mass and specific heat ratio of secondary fluid on the entrainment ratio will be investigated. The Mach number distribution and velocity fields will be discussed in the next section.

#### 3.2.1. Effect of molecular weight and specific heat ratio of the primary fluid ( $M_p$ and $\gamma_p$ ) on the entrainment ratio

Table 1 shows the typical operating conditions for a water distillation system considered in this study.

**Table 1.** Typical operating conditions for a water distillation system.

System Component	T [C]	P <sub>sat</sub> of water at T [MPa]
Boiler (primary fluid)	180	1.0
Evaporator (secondary fluid)	50	0.0122
Condenser (ejector outlet)	55	0.0156

The fluid properties of the primary and secondary fluids were chosen for two sets of temperature and pressure. Tables 2 and 3 show these two sets of operating conditions for which the numerical simulations were conducted. Different values of molecular masses and specific heat ratios were selected for the primary fluid. Figs. 1 and 2 show the effect of molecular mass and specific heat ratio of the primary fluid on the mass and molar entrainment ratio for a BFE, respectively.

**Table 2.** Operating conditions for the CFD simulations. Set 1.

Boundary	T [C]	P <sub>sat</sub> of water at T [MPa]
Primary inlet	180	1.0
Secondary inlet	40	0.0073
Ejector outlet	50	0.0122

**Table 3.** Operating conditions for the CFD simulations. Set 2.

Boundary	T [C]	P <sub>sat</sub> of water at T [MPa]
Primary inlet	174	0.87
Secondary inlet	50	0.0122
Ejector outlet	55	0.0156

It can be seen in Fig. 1 that the mass entrainment ratio decreases with increasing the molecular mass of the primary fluid and the effect of specific heat ratio on the mass entrainment ratio is negligible. The conclusions are different for the molar entrainment ratio.

It is shown in Fig. 2 that the molar entrainment ratio increases with the primary fluid molecular mass and it changes noticeably with the specific heat ratio. The lowest theoretical value of the specific heat ratio is just above 1 and the highest value of this parameter is about 1.67. The molar entrainment ratio is higher for the smaller specific heat ratios. For a specific heat ratio of 1.05, the molar entrainment ratio increases almost twofold if the molecular mass of the primary fluid is greater than 200 g/mol. For distillation application  $M_s$  is constant and equal to 18 for water. The higher values of  $M_p$ , the larger values  $M_p/M_s$  will be. Multiplying these large values by mass entrainment ratio causes the small deviation of graphs for different  $\gamma$  in Fig. 1 looks noticeable in Fig. 2. It is also shown that the molar entrainment ratio increases with  $M_p$ . However, for very large values of  $M_p$ , the secondary mass flow rate becomes close to zero and the molar entrainment ratio decreases.

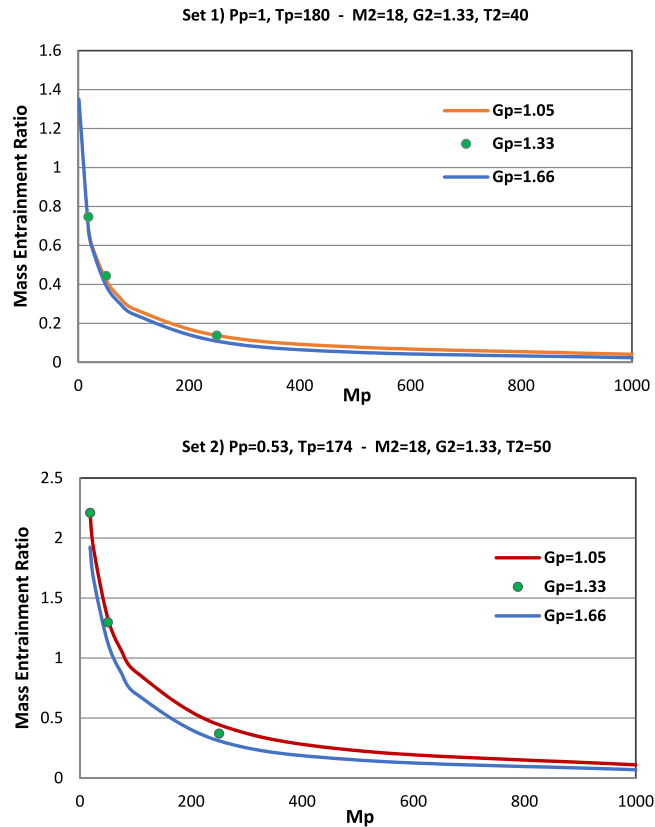


Fig. 1. Effect of molar mass and specific heat ratio of primary fluid on mass entrainment ratio.

### 3.2.2. Effect of molecular weight and specific heat ratio of the secondary fluid ( $M_s$ and $\gamma_s$ ) on the entrainment ratio

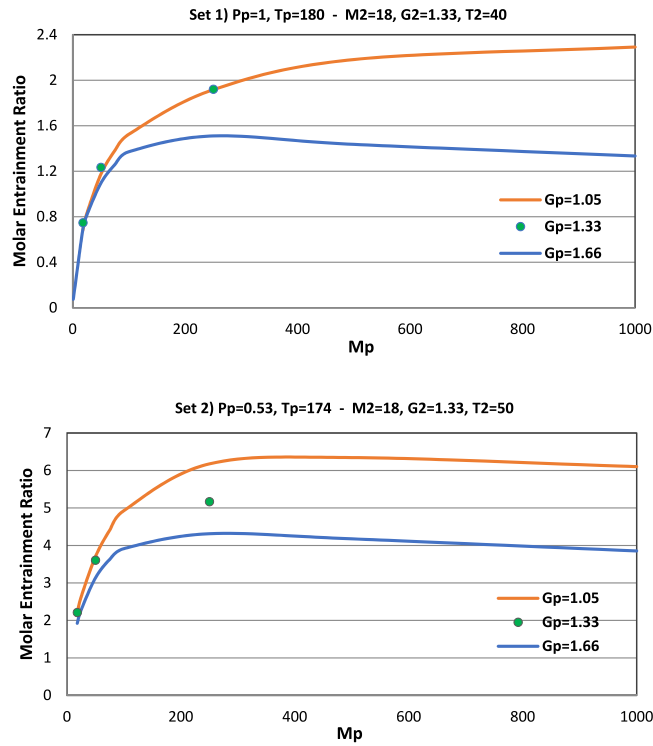
In order to study the effect of secondary fluid properties on the entrainment ratio, two sets of operating conditions were chosen for  $M_p = 100$  and  $500$  g/mol. These operating conditions correspond to different values of molecular mass and specific heat ratios of secondary fluid.

The mass flow rates of primary and secondary fluids for different operating conditions are numerically calculated using a first order solver. Figs. 3 and 4 show the effect of molecular mass and specific heat ratio of the secondary fluid on the mass and molar entrainment ratio respectively. It can be seen from these figures that the mass entrainment ratio increases with molecular mass of the secondary fluid. However, the molar entrainment ratio decreases when increasing  $M_s$ . The specific heat ratio of secondary fluid does not have a strong effect on the mass and molar entrainment ratio and its effect becomes negligible for large values of molecular mass of primary fluid.

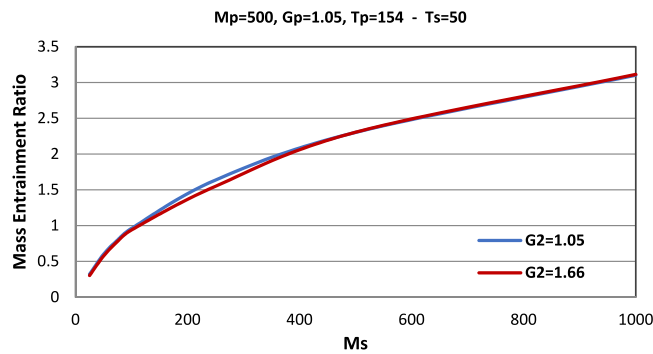
## 4. Conclusion

The influence of the thermo-physical properties of the primary and secondary fluids was investigated numerically using CFD modelling. It was found that the entrainment ratio,  $\omega$ , is mostly a function of molecular mass, specific heat ratio, ejector geometry and the operating conditions. It was also found that the dynamic viscosity, thermal conductivity and mass diffusivity do not have a noticeable influence on the entrainment ratio.

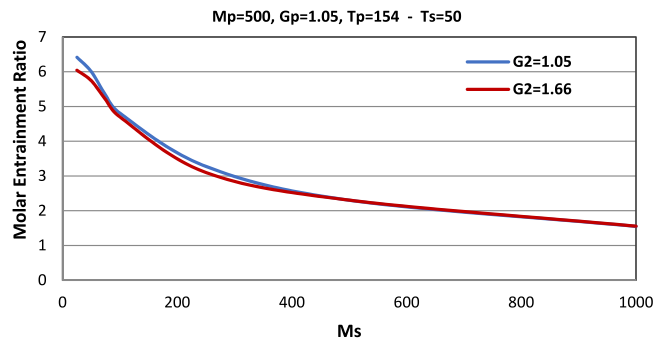
For a distillation system, the mass entrainment ratio decreases with increasing molecular mass of primary fluid and does not change much with the variation of specific heat ratio. The effect of specific heat ratio on the molar entrainment ratio is more noticeable and the values are almost double for  $\gamma_p = 1.05$  as compared to  $\gamma_p = 1.66$  for primary molecular mass greater than  $200$  g/mol.



**Fig. 2.** Effect of molar mass and specific heat ratio of primary fluid on molar entrainment ratio.



**Fig. 3.** Effect of molecular mass and specific heat ratio of secondary fluid on mass entrainment ratio.



**Fig. 4.** Effect of molecular mass and specific heat ratio of secondary fluid on molar entrainment ratio.

The effect of secondary fluid properties on the entrainment ratio was also investigated. The mass entrainment ratio increases with the molecular mass of secondary fluid but the molar entrainment ratio decreases. The specific heat ratio of the secondary fluid does not have a noticeable effect on either the mass and molar entrainment ratios, especially for the large values of molecular mass of primary fluid.

Further investigation regarding the selection of high performance binary fluid combinations for distillation application is being conducted and would be presented in future work.

## References

- [1] El Hassan M, Gubanov A, May W, Martinuzzi R. Numerical investigation of the flow dynamics of a supersonic fluid ejector. In: International conference on heat transfer and fluid flow. Prague, Czech Republic; August 11–12, 2014.
- [2] El Hassan M, Bukharin N. Numerical investigation of the flow dynamics inside single fluid and binary fluid ejectors. *J Phys Conf Ser* 2019;1276(1). 012012.
- [3] Cizungu K, Mani A, Groll M. Performance comparison of vapour jet refrigeration system with environment friendly working fluids. *Appl Therm Eng* 2001;21(5):585–98.
- [4] Van Vu N, Jan K. CFD simulation of ejector: is it worth to use real gas models. *EPJ Web Conf* 2018;180:02075.
- [5] Kracik J, Dvorak V. Preliminary study of the primary nozzle position of a supersonic air ejector with a constant-area mixing chamber. *EPJ Web Conf* 2017;143:02056.
- [6] Bartosiewicz Y, Aidoun Z, Desevaux P, Mercadier Y. CFD-experiments integration in the evaluation of six turbulence models for supersonic ejector modeling. In: Integrating CFD and experiments conference. Glasgow, UK; 2003.
- [7] Varga S, Soares J, Armando R, Oliveira C. On the selection of a turbulence model for the simulation of steam ejectors using CFD. *Int J Low-Carbon Technol* 2017;12(3):233–43.