International Journal of Heat and Mass Transfer 101 (2016) 20–26

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Influence of driving fluid properties on the performance of liquid-driving ejector

Jianbo Tang [a,b], Zhiyi Zhang [c], Luyao Li [a,b], Junjie Wang [a], Jing Liu [a], Yuan Zhou [a,*]

[a] *Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *Tianjin Key Laboratory of Refrigeration Technology, Tianjin University of Commerce, Tianjin 300134, China*

ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 7 April 2016
Accepted 10 April 2016
Available online 25 May 2016

Keywords:
Ejector
Liquid metal
Vacuum
Bernoulli's principle

ABSTRACT

This study focuses on the influence of driving fluid properties on the mass transfer process of ejector apparatus. A liquid-actuated ejector system is firstly designed and three experimental cases working with different kinds of driving fluids, i.e., gallium-based liquid metal, aqueous NaI solution and water, are successively investigated. The results show that the ejector system working with liquid metal has high-vacuum ejecting capacity and good temperature stability. With a system power consumption of about 50 W, the liquid metal driving ejector obtains a no-entrainment vacuum pressure of 33 Pa which is three orders of magnitudes lower than that of the water driving case. When the gas-suction pressure exceeds 40 kPa, NaI solution driving case reveals the highest entrainment. The reasons for the differences in the ejector performance are later discussed. Based on the experimental results and theoretical analyses, the method of using high density, low viscosity and low vapor pressure working fluid to improve ejector performance is proposed. Other than conventional methods which focus on optimizing the geometrical design and operating parameters of ejectors, the method discussed here puts forward a new perspective to improve ejector performance. Moreover, the ejector system working with liquid metal demonstrates its advantages such as compact system design, oil-free vacuum pumping as well as high temperature operation.

1. Introduction

An ejector is a simple-structure device that provides multiple capacities such as vacuum-pumping, compressing, transporting, mixing. It has been widely used in the fields of refrigeration, food industry, as well as chemical, biochemical and medical processes ever since its invention [1–3]. The utilization history of ejector witnesses its continuous evolutions and enormous efforts have been made to improve the performance of different types of ejectors [4]. The performance of the ejector is sensitive to its geometrical design, operating parameters and driving fluid properties. The first two factors are extensively investigated while few studies have been focused on the driving fluid properties [5–8]. As for liquid-driving ejectors, water, as an abundant and easy-handling candidate, is used in most cases [9–11]. Among the few examples that can be found in the open literature, Elgozali et al. [12] studied the effect of viscosity and surface tension on performance of liquid ejector by adding polymeric thickener, sucrose and alcoholic foam breaker to water. Power et al. [13] and Haak et al. [14] reported experimental studies on high-density mercury vapor jet pumps in 1958 and 1959, respectively. Studies on ejector refrigeration cycles and ejector-absorption cycles encounter a variety of driving fluids such as vaporized halocarbon compound (CFC, HCFCs and HFCs), water, ammonia–water solution, and LiBr–water solution. However, thermodynamic properties (enthalpy, entropy, specific heat, etc.) of the driving fluids which have significant influence on the refrigeration performance are of general interest while others are usually neglected [2,4]. Transport properties (density, viscosity and vapor pressure, etc.) have strong effects on the momentum transfer and mixing process of the ejector and should be considered as prior factors when designing an ejector system or choosing operating parameters. Besides, by simply replacing conventional driving fluids with candidates which offer more desirable transport properties may significantly improve the ejecting performance.

Theoretically, driving fluids with high density, low viscosity and low vapor pressure would be ideal candidates. Liquid metal and inorganic salt solution represent two common types of high density, low vapor pressure fluids. Novel functional material GaInSn

---

* Corresponding author.
E-mail address: zhouyuan@mail.ipc.ac.cn (Y. Zhou).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.04.028
0017-9310/

(eutectic gallium–indium–tin) is a nontoxic room-temperature liquid metal which offers many advantages such as ultra-high density and ultra-low vapor pressure while still exhibits good fluidity [15]. Recent years have witnessed its emergence in many unique applications [16–19]. Adding inorganic salt to water is an easy way to create a solution with higher density and lower vapor pressure. In this study, three kinds of driving fluids, namely liquid metal, aqueous solution and water were firstly prepared with their transport properties measured for comparison purpose. The details related to GaInSn handling and oxidation prevention have been described in our previous work [20]. Excellent solubility, good temperature stability and material compatibility are the main reasons for us to choose NaI aqueous solution among all the other inorganic salt solutions that have been tested. The performance of the ejector system working with different driving fluids is later compared in order to study the influence of driving fluid properties on the system performance.

2. Experimental setups and procedures

The properties of the driving fluids vary with temperature change. So after the driving fluids are prepared, separate experiments are carried out to measure their saturated pressure and viscosity under different temperatures. The density of each fluid may also change from temperature to temperature. Since temperature-induced density change is relatively small compared to the density difference between different kinds of fluids, this kind of density change is not considered in this study. As shown in Fig. 1(a), for saturated pressure measurement, a partially filled stainless steel sample fluid container is firstly vacuumed by an auxiliary vacuum pump. The check valve is turned off thereafter so that the container becomes airtight. Then the container is put into a water bath for temperature control. Capillary viscometer is used for viscosity measurement. The setups are illustrated in Fig. 1(b) and the method can be found in Ref. [21].

The system arrangements for ejector performance study are shown in Fig. 2. The driving fluid is firstly pumped to a high pumping pressure before it enters the ejector where it draws in nitrogen from the reservoir. Then the two flows interact with each other inside the ejector where they eventually become a liquid–gas mixture. The mixture is later separated due to gravitational difference in the separator. Nitrogen is expelled to the atmosphere while the driving fluid flows back to the pump to complete the ejector loop. Since the driving fluid properties are temperature dependent, a water coil is installed inside the separator for temperature control.

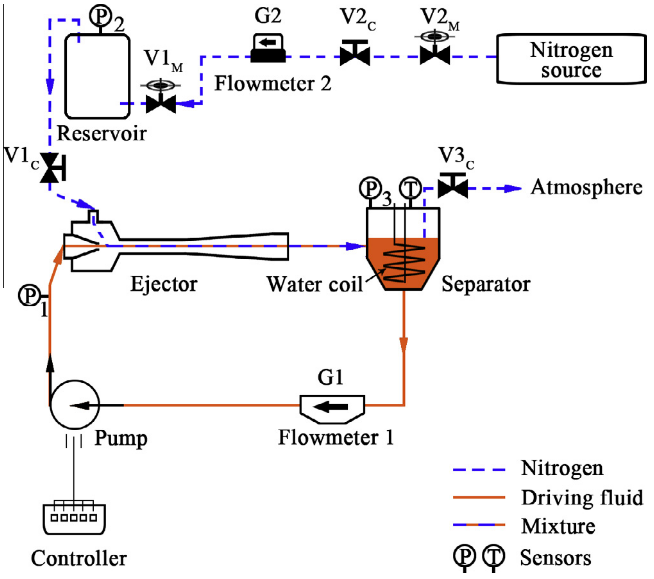

Fig. 2. Schematic drawing of the test rig (not to scale).

The rotation speed ω and electric power input EP of the pump can be controlled with an adjustable controller. The absolute pumping pressure P_P of the driving fluid at the ejector entrance is measured by pressure sensor P_1 (Model number: PX429S15-150A5V, Omega Engineering Inc. Accuracy: ±0.08%). The absolute vacuum pressure inside the reservoir P_V and the absolute discharge pressure at the separator P_D are measured by pressure senor P_2 (Model number: PX429-005A5V, Omega Engineering Inc. Accuracy: ±0.08% and P_3 (Model number: PX429-100A5V, Omega Engineering Inc. Accuracy: ±0.08%), respectively. The mass flow rate of the driving fluid $G1$ is measured by Flowmeter 1 (Model number: DMF-1-3-A, Beijing Sincerity Automatic Equipment Co., Ltd. Accuracy: ±0.2%) and the volume flow rate (standard state) of nitrogen entrainment $G2$ is measured by Flowmeter 2 (Model number: D07-19BM, Beijing Sevenstar Electronics Co., Ltd. Accuracy: ±1%). The temperature of the driving fluid is measured by a sheathed thermocouple (Accuracy: ±0.5 °C) mounted inside the separator.

The vacuum pumping capacity, nitrogen entrainment as well as the pump power consumption are the main parameters that are

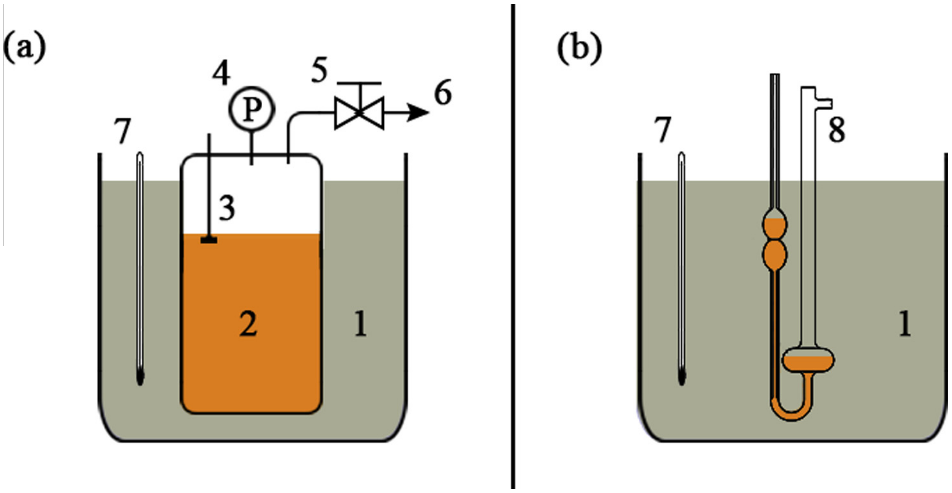

Fig. 1. Schematic drawing of the experimental setups for (a) saturated pressure measurement; (b) kinematic viscosity measurement. 1-Water bath, 2-sample fluid container, 3-thermal couple, 4-pressure sensor, 5-check valve, 6-to vacuum pump, 7-thermometer, 8-capillary viscometer.