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Research Paper

Investigations of thermal performance of ejection refrigeration system driven by low grade heat

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A B S T R A C T

Buildings represent a very high energy consumption percentage compared to other economy sectors. Technologies dealing with energy savings, reduction of the energy consumption and efficiency improvements are highly desirable. Paper presents the system proposed for the air-conditioning purposes which utilizing the hot water in heat distribution network as a motive heat in summer season. The proposed refrigeration system is equipped with gas ejector. The system is operating with pro-ecological refrigerant R-1234ze(E). The paper presents the results of the experimental investigations. The thermal capacity of the heat source was 100 kW. Water was the heating medium with temperature below 65 °C. Two evaporation temperatures 0 °C and 6 °C typical for low and medium temperature air-conditioning systems were set in the experiments. The operation of the regenerative heat exchanger applied for R-1234ze(E) is analysed for the first time for the case of the ejection systems. The features of operation of the ejection system on the basis both external and internal parameters were analysed. The system achieved *COP* = 0.25 for evaporation temperature 0 °C, and *COP* = 0.40 for 6 °C. It was showed that the internal heat transfer improved *COP* of the system for approximately 10–12%.

1. Introduction

The total demand for heating and cooling in 2012 in EU countries was reported as almost 50% of the total final energy consumed in the EU (1102 Mtoe). Residential, tertiary and industry, are three main sectors which consumes energy for heating and cooling. The households buildings representing the highest share accounted for 45% of final energy heating and cooling consumption, while industry's share is 37% and services' of 18%. [1]. Energy is used in buildings for heating and cooling, hot water, lighting and appliances, and the majority of this energy come from the burning of fossil fuel. Even if the renewable energy is the world's fastest-growing energy source with increase by 2.6%/year; still, the fossil fuels continue to supply more than 75% of world energy use in 2040 [2]. The building sector, therefore, plays a significant role in mitigating the impacts of climate change through reducing the demand; i.e. energy conservation, and by maximising the use of renewable energy [3]. This has increased the need for new energy substitutes and conversion methods to meet an increasing energy demand and pave the way to cost-effective heating and cooling solutions. One of the possibilities of the combine heating and cooling demands is utilisation of the district heat for chilled water production. This can be accomplished by application of sorption or ejector systems. District heat is deliver as a hot water or steam from a central plant to buildings via the underground pipe network. The main purpose for district heat is heating the domestic tap water during summer season. Therefore the temperature of the heating water in the heating system is usually below 70 °C, and in some cases even below 65 °C. Such temperature level makes that absorption system cannot be effectively use as a refrigeration device for air-conditioning. Besides the higher motive operating parameters the sorption systems are much more expensive than ejection systems. As cooling needs is mostly met by electricity usage, the new directives on energy efficiency buildings should offer different cooling efficiency solutions; District Cooling has a major role to play in order to meet the challenges for Europe and provide a robust and environmentally sound framework for future energy solutions [4].

The proposed refrigeration system equipped with gas ejector is presented in Fig. 1. Refrigerant in vapour state is pressurised by mean of ejector instead of mechanical compressor. Therefore, the electrical power consumption is reduced. Also, potential exploitation problems related with mechanical compressors such as, damages of moving parts, oil circulation are also eliminated. New HFO (*hydro-fluoro-olefins*) group refrigerant R-1234zeE was used in the system. Regulation of the European Parliament and the EU Council

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Nomenclature

AC	air-conditioning
COP	coefficient of performance
c_p	specific heat at constant pressure, kJ kg^{-1}K^{-1}
GWP	Global Warming Potential
h	specific enthalpy, kJ kg^{-1}
$\dot{m}$	mass flow rate, kg s^{-1}
p	pressure, MPa
T	temperature, K
t	temperature, °C
Q	thermal capacity, kW
U	mass entrainment ratio, –

Greek symbols

Δ	difference
Π	compression ratio, –

Subscripts

c	condenser
crit	critical
CW	chilled water
e	evaporator, secondary fluid
d	discharge
g	generator, primary fluid
l	liquid
max	maximum
p	pump
R	refrigerant
RHX	regenerative heat exchanger
sat	saturation condition
st	standard
v	vapour
W	water

No. 517/2014 enacted on April 16th, 2014 [5] and analysis of the performance of the system working with different fluids for the ejector system [6] were the basis for the fluid selection. According to this Regulation most of the high *GWP* refrigerants will be forbidden within few years in UE countries. Moreover, domestic and commercial AC units with more than 3 kg of refrigerants of *GWP* > 150 can not be used after 2025. R-1234zeE is a low *GWP* ≈ 6 refrigerant with thermodynamic properties similar to isobutane (natural, but explosive fluid) and R-134a (high *GWP* fluid). The critical parameters of the selected refrigerant are [7]: t_{cr} = 109.36 °C, p_{cr} = 3.6349 MPa and ρ_{cr} = 489.24 kg/m^3.

2. Previous research on ejection systems

Utilisation of solar energy is the most popular way for driving the ejection refrigeration system. This type of motive energy can be thought as very attractive. Both types of investigations, i.e. experimental and numerical analysis of the ejection system can be found in the literature. In paper [8] authors have tested flow pattern in a variable geometry ejector to achieve the optimum geometry for solar-driven refrigeration system. Such system was also reviewed by Abdulateef et al. [9]. Dynamic hourly simulation of the performance of the solar ejection cooling system with R134a was provided by Tashtoush et al. [10]. Alternative refrigerants from common solvents including acetone, benzene, toluene, and non-flammable synthetic refrigerants from R-236 and R-245 groups have been numerically tested by Gil and Kaspersky [11]. The authors carried out series of simulations of the ejection cooling systems for the generator temperature between 70 and 200 °C. Solar-driven ejection cooling system for crop storage in Mediterranean region was presented in [12]. Authors have presented the theoretical and experimental study of the thermo-pump and the ejection refrigeration system for isobutane, dimethyl ether, trifluoroiodomethane and R-124. Ersoy et al. [13] tested the solar-powered ejection cooling-system operating with refrigerant R-123. Again, solar radiation was used as a motive heat source. Ejector equipped with a spindle in order to control the primary flow in the solar ejection refrigeration system was tested in [14]. Influence of the source temperature and the spindle position on the system performance were tested.

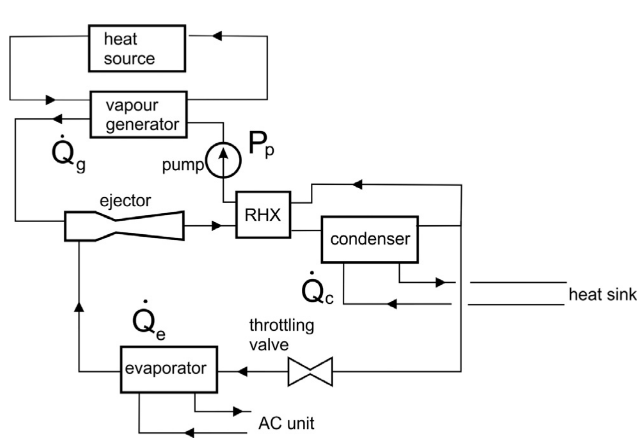

Fig. 1. Schematic of the ejector refrigeration system with internal heat exchanger (RHX).

The most up to date comprehensive state-of-the-art studies dealing with ejection systems were given in [15,16]. The review presented by Besagni et al. [15] was focused on application of the ejector in refrigeration systems. Chen et al. [16] have focused the review on the ejection technology including classic, advance and combined ejection technology. The working principles, working fluid selection and performance evaluation were given. The first experimental investigation of the refrigeration system with gas ejector operating with isobutane was presented by Butrymowicz et al. [17]. Solar energy was used as a motive heat, however, any other renewable sources or waste heat can be used. On the basis of the results presented in [17] we propose to use the ejection refrigeration system for the air-conditioning purposes with utilisation of heat supplied to the building via heating distribution network. The level of the temperature of the hot water (below 65 °C) creates an opportunity for application of ejection devices. It should be pointed out that absorption systems are not suitable for operation with source heat with temperature below 70 °C. In most cases the absorption systems operates with heat source temperature higher than 80 °C. For this reason these devices can not be applied for production of chilled water with reasonable *COP*. Combining the ejection system with district heating network allows to effective use of surplus heat and not require high investment costs in comparison to absorption systems. Papers [18,19] presenting the operation of the absorption systems with heat source temperatures up to 130 °C. The *COP* of discussed system used for AC purposes is 0.14 for chilled fluid temperature 12/8°C and *COP* = 0.17 for temperatures 18/14 °C. The authors have pointed out that using of different pairs of sorbent-refrigerant can lead to lowering of generator temperature. Theoretical analysis of the performance of the ejection sys-