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Comparative Analysis on Ejector and Converging Tee-driven Refrigeration Systems

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Abstract

The growing need for thermal comfort has resulted in an increase in refrigeration systems and, as a result, increased electricity demand for these systems. Waste heat-driven devices for refrigeration systems appear to be a potential alternative to traditional compression-based refrigeration technologies for reducing energy consumption. These devices in the refrigeration cycle can be driven by waste heat (free or inexpensive low-temperature energy source) as the primary energy source instead of electricity. This study investigates the ejector-driven and converging Tee-driven refrigeration systems (EDRS & CTDRS) using waste heat, aiming to provide an alternative to traditional VCC. An experimental setup is developed with a 3.6 mm nozzle size of an ejector and a converging tee diameter of 12.7 mm. A comparative experiment was conducted to assess the coefficient of performance (COP). In terms of performance, the EDRS COP outperformed the converging-tee-driven refrigeration cycle. The results showed that the proposed concept is promising to develop an alternative to the traditional refrigeration cycle and heat recovery.

Keywords:Refrigeration; Vapor Compression Cycle; Waste Heat; Ejector; converging Tee;

1. Introduction

Air conditioning is a need for humans in everyday life. Air-conditioning using a large amount of electric power results in a considerable proportion of fossil fuel combustion. Air conditioning and refrigeration systems consume a big part of the electricity used worldwide. There has been a huge growth in air conditioning usage, particularly in southern nations, causing major supply challenges during peak load hours. Furthermore, predictions show a tremendous increase in energy use. Another effect is the rising energy cost. Thus, many alternatives need to be considered to overcome the electricity demand. An ejector is a widely used device for energy conversion [1], [2]. A refrigeration system powered by an ejector has the ability to minimize energy usage and consequently increase performance.

The EDRS is a vapor compression cycle (VCC) modification. Low-grade thermal energy use is considered as an essential kind of energy conversion that is both ecologically friendly and energy-saving. Low-grade thermal energy is an energy resource, and its recovery will improve energy efficiency. The ejector-driven refrigeration system, being a heat-driven device, provides a practical technique for converting low-grade heat into useful cooling. Low-grade heat sources, such as solar collectors [3], industrial processes, and automobiles [4] power the ejector. An ejector compresses refrigerant vapor from the evaporator and discharges it to the condenser rather of pressuring it with a mechanical compressor. The vapor generator, which is heated by a low-temperature heat source generated the motive vapor. An appropriate ejector substantially increases the system's performance.

Many studies have demonstrated that a suitable ejector increases the system's performance. For instance, the authors [5] developed an ejector-driven refrigeration system to overcome the throttling losses. The system performed optimally, with a 5 to 13% greater COP than a typical refrigeration system with a nozzle diameter

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of 2.3 mm and a corresponding ratio of 15.3. The researchers of [6] investigated the variable area ratio on a multi-evaporator refrigeration system. The results indicate that the energy saving increased by 112% by the variable area ratio compared to the traditional refrigeration system. An experimental investigation of the R134a EDRS was conducted by [7]. The outcomes indicate that with the rise in boiler temperature (motive), capacity, COP, and entrainment ratio improved and then reduced. Hence, the motive temperature must be optimized for the set condenser and evaporator temperatures to achieve maximum COP. Our previous study [8] compared the ejector nozzle sizes for an EDRS. The findings revealed that an ejector with a nozzle size of 3.6 mm performed well compared to 1.8 and 5.4mm nozzle sizes. Moreover, compared to the VCC, the refrigeration cycle performed well at below 0ºC. A similar study by Chaiwongsa et al. [9] investigated a motive nozzle's various nozzle outlet diameters for system performance. The ejector-nozzle with an outlet diameter of 2 mm yielded the highest COP.

This study aims to utilize the ejector and converging tee to reduce power consumption and improve the COP of conventional refrigeration systems. An ejector and converging tee with nozzle sizes of 3.6 mm and 12.7 mm are considered, respectively. A comparative analysis is discussed in this study. The present study is subdivided into four sections. The first section provides an introduction, while the second is about methodology. Section 3 contains the results and discussion, and section 4 has the conclusions.

2. Materials and Methods

A heat-driven ejector and converging tee may be used to power a refrigeration system instead of or in addition to a compressor. The ejector and the converging tee have no moving parts, are cost-effective, have high reliability, have simple construction, and have minimal installation and operating expenses. Furthermore, both the ejector and converging tee have two intake ports, a motive, and a suction port, as well as one discharge port, allowing the primary high-pressure stream to hold the secondary low-pressure stream. Two streams are mixed in an ejector, discharged at a predetermined intermediate pressure, and actuated by fluid energy rather than electricity.

Both devices (ejector and converging tee) operate on low-grade thermal energy generated by waste heat. Second, the second level of compression is known to exist in order to lower the energy required by the input of a mechanical compressor. Furthermore, these devices serve as a pump to transport refrigerant via the refrigerant circulation channel. The efficiency of the ejector and converging tee directly influences the effectiveness of the refrigeration system. According to the working conditions, the ejector and converging tee have the maximum entertainment ratio, continuously allowing the system to operate optimally.

Table 1. Test conditions of ejector and converging tee

Cycle	Diameter (mm)	Motive Ref. State	Eva. Inlet Temp (ºC)	Cooling water temp. (ºC)
Converging tee system	12.7	Liquid	5	35
			10	
Ejector refrigerant system	5.4		15	
			20	

The proposed refrigeration system uses an ejector and a converging nozzle to investigate the system's energy consumption and COP. The refrigeration systems' key parts are the expansion valve, receiver, condenser, ejector or converging tee, generator, evaporator, accumulator, and compressor. A system's performance relies on the working fluid's thermal characteristics. Thus, R134a refrigerant is employed as a working fluid, while waste heat is used as a primary fluid for the ejector and converging tee motive. In order to circulate the condensing water and waste heat (in the form of hot water) to the generator, two circulation pumps are employed. Table 1 displays the test conditions for the ejector and converging tee-driven refrigeration systems.

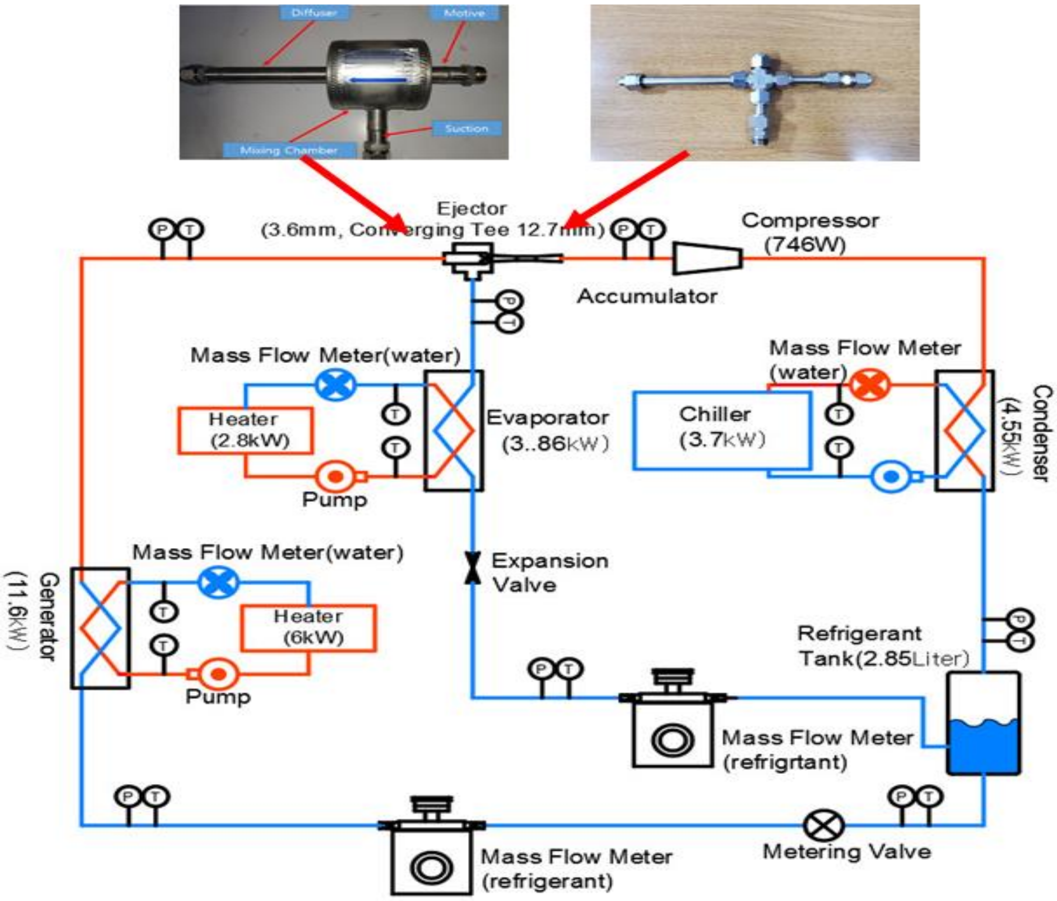

Fig. 1. Schematic diagram of comparison system of ejector and converging tee

Moreover, pressure sensors, T-type thermometers, and refrigerant and water flow meters are used to measure the system's characteristics. A refrigerant receiver is installed at the condenser outlet to ensure that refrigerant flows continuously toward the expansion valve and generator. The primary flow reaches the ejector's motive or converging tee to entertain and compress the secondary refrigerant flow from the evaporator at high temperature and pressure. A heater with an output of 2.8 kW (Rainbow) is employed as the evaporator load. Brazed-plate heat exchangers are both a condenser and an evaporator. As a generator, a brazed-plate heat exchanger is used. Table 2 contains all additional technical characteristics. The refrigeration system schematic diagram for understanding the performance characteristics is depicted in Figure 1.

Table 2. Specification of refrigeration system

Condenser	12.25 kW
Compressor	746 W
Refrigerant tank	2.5 Liter
Expansion valve	Manual
Evaporator	1.93 kW
Generator	11.6 kW
Ejector nozzle size	3.6 mm
Converging Tee pipe size	12.7 mm
Waste heat	80ºC
Refrigerant	R134a

3. Results and Discussion

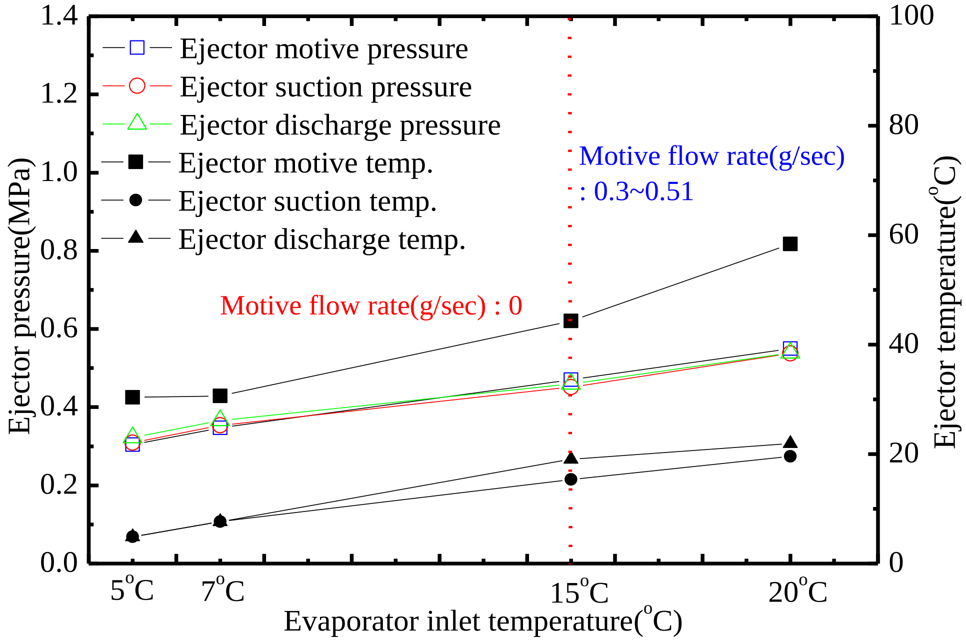

Fig. 2. Variation of ejector discharge pressure and temperature according to evaporator inlet temperature

An ejector refrigeration system operating characteristics, such as pressure and temperature at the motive against the evaporator inlet temperature, are depicted in Figure 2. In this refrigeration system, an ejector is installed with a nozzle size of 3.6 mm. The pressure and temperature of the ejector motive change with the change of evaporator inlet temperatures such as 5, 7, 10, and 20ºC. As the evaporator's inlet temperature decreased, the ejector motive's pressure and temperature also decreased. As a result, there is no refrigerant flow, as shown in Figure 2. The motive flow rate is 0 g/sec. This phenomenon is because as the refrigerant temperature at the ejector motive and evaporator inlet decreases, the opening degree of the expansion valve and metering valve decreases, resulting in much resistance to the refrigerant flow.

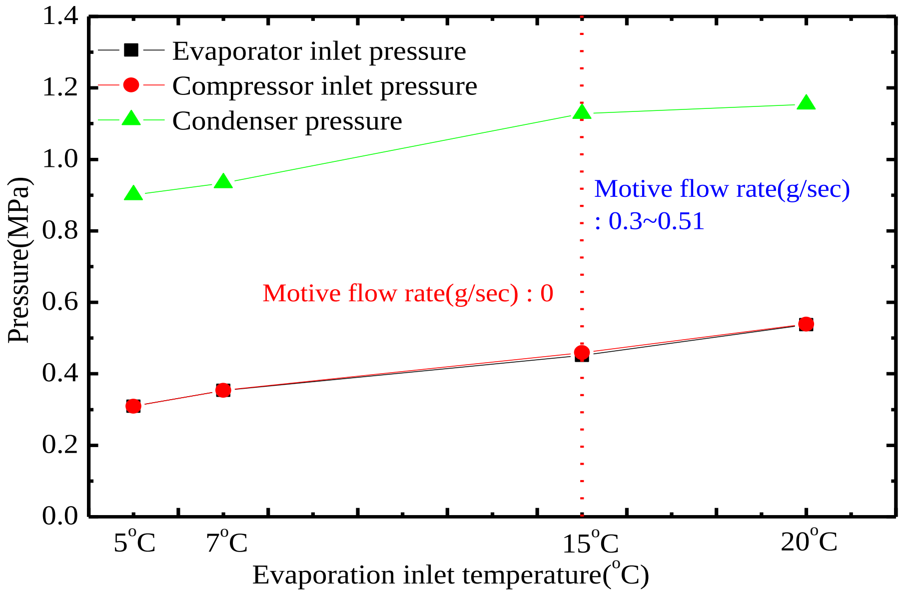

Fig. 3. Variation of the evaporator, compressor, motive, and condenser pressure according to evaporator inlet temperature

At 15 and 20ºC, the refrigerant flow rate is 0.3 to 0.51 g/sec when the refrigerant passes through the generator, and heat exchanges between the hot water and refrigerant. So, the pressure discharged from the generator goes higher before entering the ejector. On the other hand, the pressure discharged from the ejector did not change significantly. This phenomenon is believed to be because of the refrigerant temperature at the ejector inlet increases. The pressure of the refrigerant discharged from the ejector is further affected by the refrigerant flow rate in the ejector. The change in ejector motive temperature due to the generator was not affected at 5ºC and 7ºC temperatures of the evaporator inlet. So, the ejector temperature discharged was 4.9 ºC and 7.6 ºC. However, at 15 ºC and 20 ºC evaporator temperatures, where the mass flow rate of the refrigerant at the ejector motive is 0.3 to 0.51 g/sec, the refrigerant temperature of the ejector motive was 44 ºC and 58 ºC by exchanging the heat through a generator. So, the ejector discharged temperature was 19 ºC and 21 ºC at the evaporator inlet temperature of 15ºC and 20ºC.

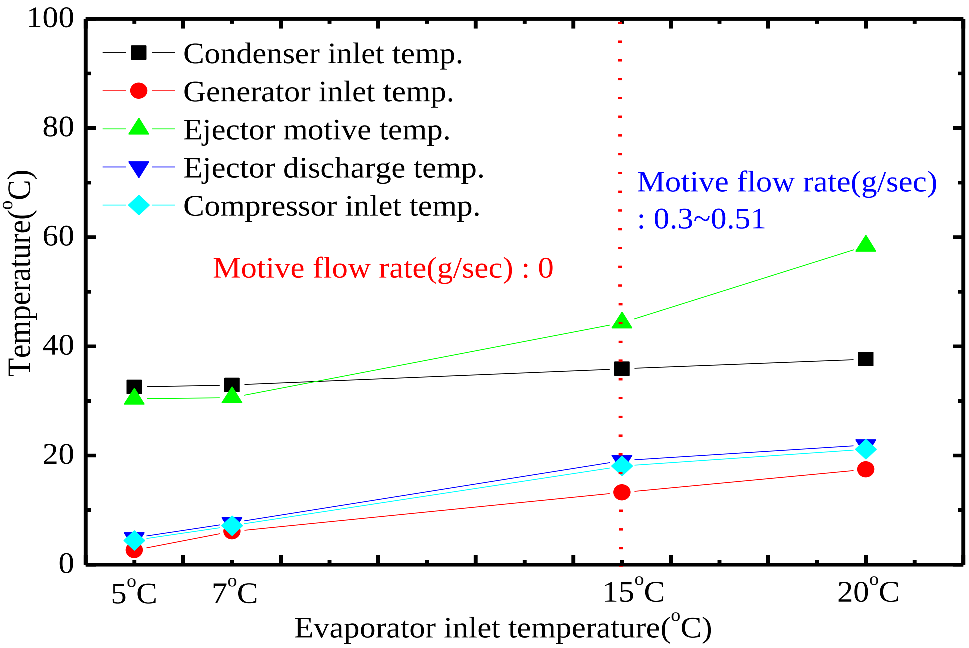

Fig. 4. Variation of the refrigerant temperature of an ejector refrigeration system according to evaporator inlet temperature

Figure 3 shows the inlet pressures of a compressor, condenser, and evaporator versus the evaporator inlet temperature. The results revealed that the refrigerant pressure at the inlet of the compressor and evaporator is almost the same at 5 ºC and 7 ºC, where there is no flow at the ejector motive. However, the compressor inlet pressure is slightly higher at 15 ºC and 20 ºC. This is because of the refrigerant flow rate at the ejector motive. The inlet pressure of the condenser is higher than the inlet pressure of the compressor. It is also depicted that condenser pressure increases with evaporation inlet temperature. Nevertheless, the operation remained stable as the condenser capacity was designed to be larger than the compressor capacity. Figure 4 represents the compressor, condenser, generator, and ejector motive and discharge temperatures against the evaporator inlet temperature. There is a slight difference in ejector discharge and compressor inlet temperatures. The generator inlet temperature is the lowest among others because a metering device is used to maintain the required experimental conditions. Regarding the ejector motive, the temperature remained the same at 5 ºC and 7 ºC because of no refrigerant flow from the motive. Besides, the refrigerant temperature increased at 15 ºC and 20 ºC because of refrigerant flow at the ejector motive.

The refrigerant flow rate (g/sec), power consumption, and cooling capacity versus the evaporator inlet temperature are presented in Figure 5. As shown, there is a slight change in the capacity and power consumption at 5 ºC and 7 ºC, whereas cooling capacity and power consumption increased at 15 ºC and 20 ºC. Although, the increase in cooling capacity trend was higher than the power consumption trend. On the other hand, the ejector motive flow rate remained constant at 5 ºC and 7 ºC, while slightly increasing from 15 ºC to 20 ºC. The generator capacity and COP of an ejector refrigeration system are depicted against the evaporator inlet temperature in Figure 6. There is no change in the generator capacity at 5 ºC and 7 ºC; there is no flow at the ejector motive as well. Nevertheless, the generator capacity is 45.61 and 65.86W at 15 ºC and 20 ºC, respectively. On the other hand, in the COP of the ejector-driven refrigeration system, there is a slight increase from 5 ºC to 7 ºC, after slightly increasing to 15 ºC after that, COP rose dramatically but remained below one on all evaporating inlet temperatures. Although, the COP of the system remained low in the experimental results. The COP can be improved by optimizing capacity and ejector nozzle size. This is one of the solutions to improve the COP.

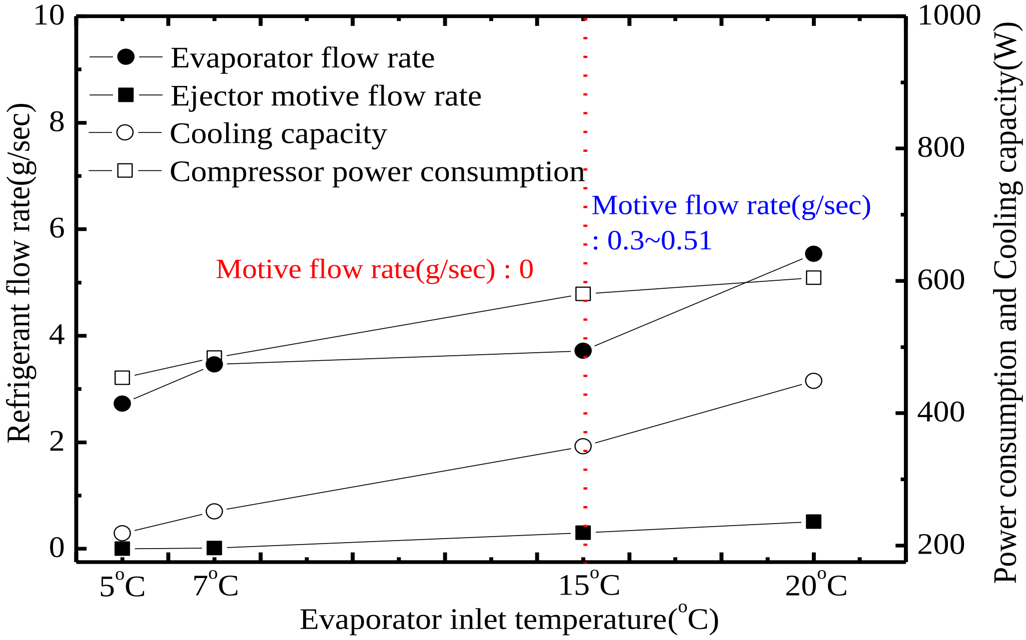

Fig. 5. Variation cooling capacity and compressor power consumption according to evaporator inlet temperature and ejector motive flow rate

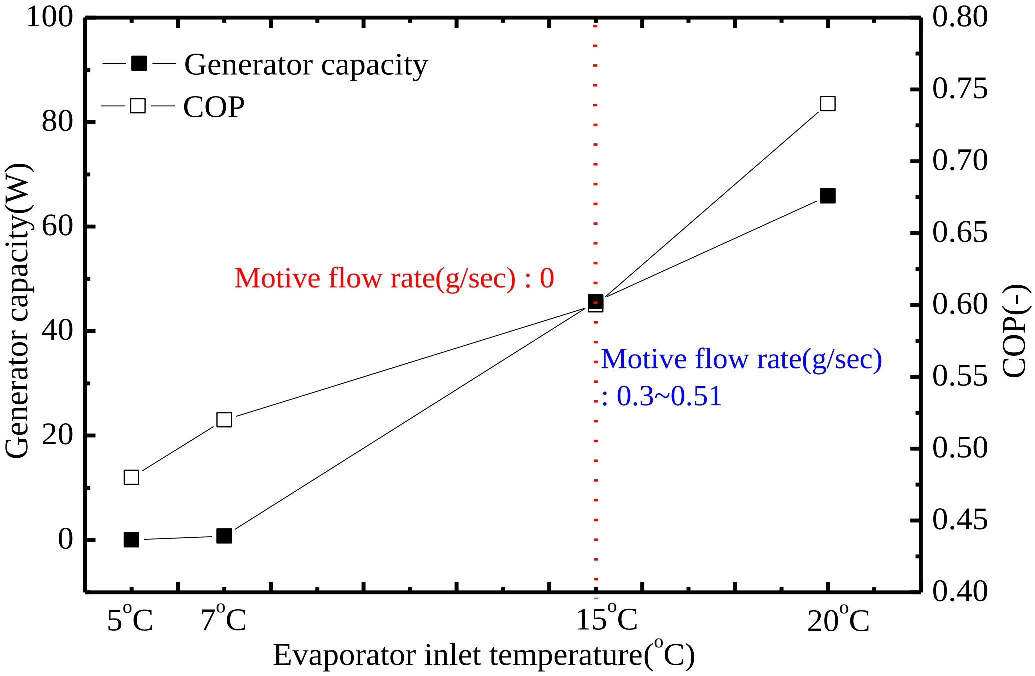

Fig. 6. Variation of generator capacity and COP according to evaporator inlet temperature

A comparative experiment was conducted on the operation and performance characteristics of the refrigeration system installed with the ejector and converging tee to confirm the ejector's effectiveness. A comparison of the ejector and converging tee discharge temperature and pressure is presented in Figure 7. As shown, the ejector discharge pressure is dominant on all temperatures 5 ºC, 10 ºC, 15 ºC, and 20 ºC. On the other hand, in terms of ejector and converging tee discharge temperatures, the ejector discharge temperature is higher on all temperatures, such as 5 ºC, 10 ºC, 15 ºC, and 20 ºC, indicating the domination of ejector-driven refrigeration systems over converging-tee-driven refrigeration system. The cause of this phenomenon is that in the converging tee, only the refrigerant is mixed inside, and in the case of the ejector, refrigerant is sucked from the evaporator outlet and mixed inside. The refrigerant temperature rises and leaves the ejector diffuser with intermediate pressure.

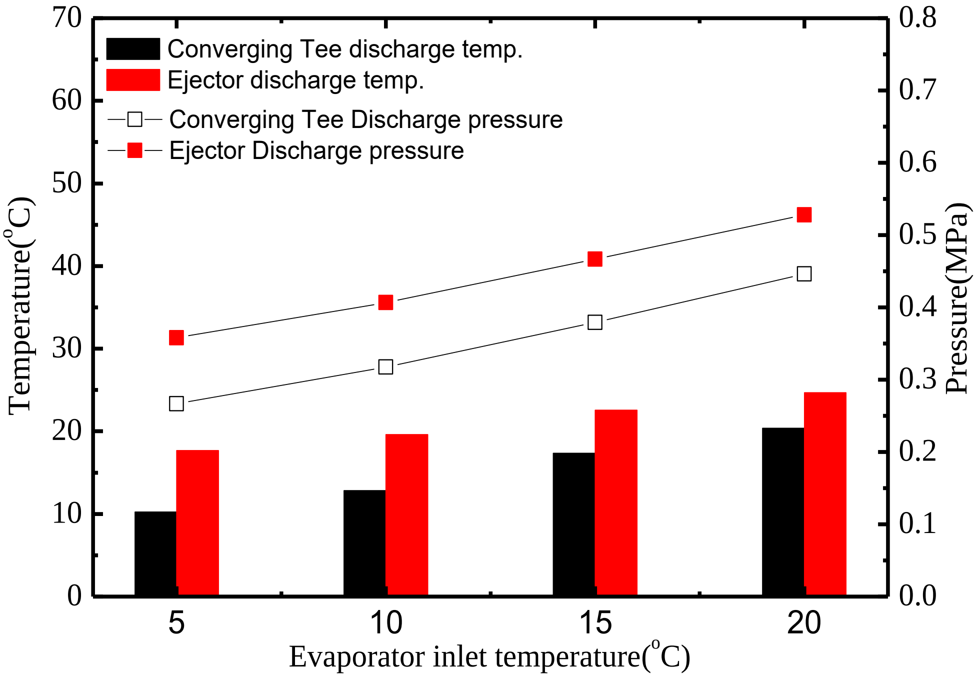

Fig. 7. Variation of discharge temperature and discharge pressure in an ejector and converging tee

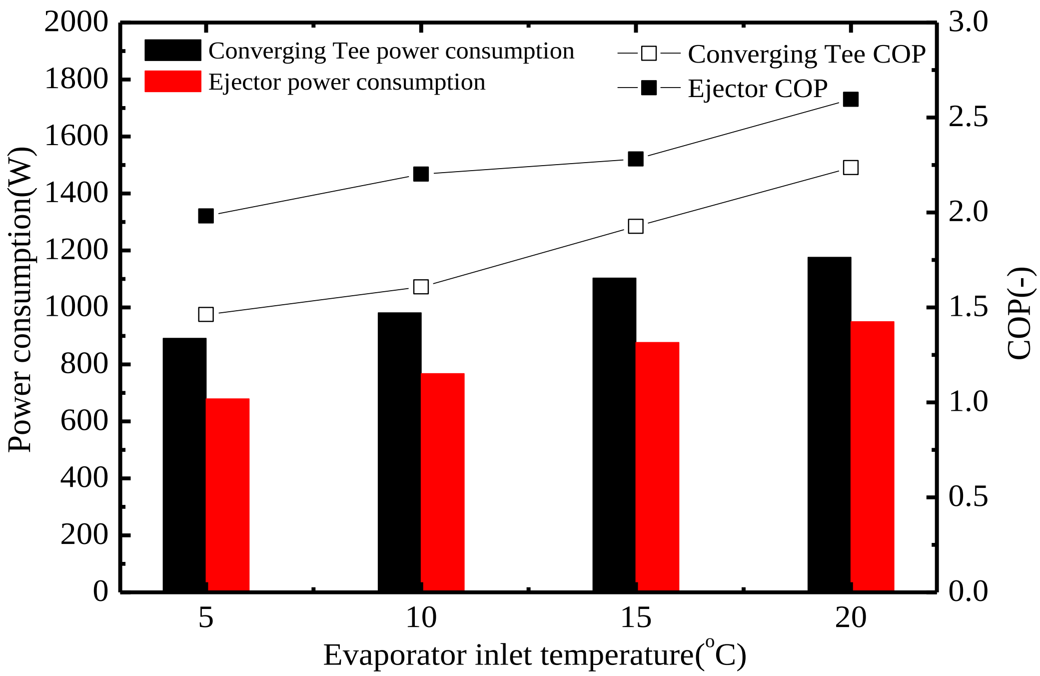

Fig. 8. Variation of power consumption and COP in an ejector refrigeration system and converging tee

Figure 8 shows the power consumption and COP of the ejector-driven and converging tee-driven refrigeration systems according to the evaporator inlet temperature. As a result of the comparative analysis, it is found that the power consumption of the CTDRS was higher than the ejector-driven refrigeration system in all cases of temperature. This is because of the high pressure and temperature in the ejector-driven refrigeration system, causing the compressor to do less work. Regarding COP, the ejector-driven refrigeration system COP is higher than the converging tee-driven refrigeration system. For instance, at 20 ºC, the converging tee-driven refrigeration system COP is 2.25, and the EDRS COP is 2.65 showing the higher COP of the ejector-driven refrigeration system. It is evident that when the ejector-driven refrigeration system power consumption is low, the COP will be higher.

4. Conclusions

A vapor compression cycle-driven refrigeration cycle integrated with an ejector and converging tee is investigated in this study. This study has two goals: to minimize power use in order to achieve energy savings which will result in cost savings and to use waste heat as a renewable energy source. Thus, a comparative analysis has been conducted to identify the results of both cycles. The ejector nozzle & converging tee diameter sizes were 3.6 mm and 12.7 mm. In terms of power consumption, the ejector refrigeration system showed less power consumption against the evaporator inlet temperature in comparison to the converging tee refrigeration system. In terms of COP, the results revealed that the ejector-driven refrigeration system COP is better than the converging tee refrigeration system COP.

Acknowledgments

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