Investigating the effect of various working fluids in cascade refrigeration cycle integrated with thermal desalination system

Mostafa Mokhtari[a], Mohammad Mehdi Keshtkar[a*], Abdollah Abbasloo[b]

[a] Department of Mechanical Engineering, Islamic Azad University, Kerman Branch, Kerman, Iran
[b] Department of Chemical Engineering, Islamic Azad University, Kerman Branch, Kerman, Iran

ABSTRACT

Regarding the energy and potable water crisis and many environmental problems due to the use of fossil fuels, it is necessary to utilize the waste heat of industrial equipment to produce potable water without using another energy source. The cascade refrigeration cycle is one of the widely used industrial equipment, which has valuable waste heat at a high temperature. In this research, the mentioned waste energy is used as an independent energy source to produce potable water in the thermal desalination system. The present work combines a three-effect distillation desalination system with a cascade refrigeration cycle. Along with comparing the 28 working fluid pairs, a scoring method was used to determine the best working fluid pair due to the different scenarios and priorities. The results showed that the lowest power consumption of compressors belongs to R600-R717 working fluid pair. Moreover, the highest mass flow rate of produced potable water, the lowest occupied space and the lowest related investment cost happen when R744-R600A is considered. Using the scoring method, it was determined that when all indicators are considered for selecting the working fluid pair, even in different scenarios with different priorities, the best choice is R600-R717.

KEYWORDS

Cascade system, Thermal desalination system, Wasted energy, Potable water.

[*] Corresponding Author: Email: mkeshtkar54@yahoo.com

1. Introduction

Today, the energy and potable water crisis are serious problems in the world. Increasing the quality level of life and population, the need for energy and potable water also increases. In this way, the use of fossil fuels grows to meet the demand of consumers for supplying the required electricity and potable water. Desalination methods used to produce potable water are divided into two general categories: thermal and membrane methods. In cases where the concentration of salt in water is high, membrane methods are less efficient than thermal methods and algae may form over time [1]. Asim et al. [2] presented a combination of the basic organic Rankine cycle (ORC) and SER which is used for air conditioning. In the proposed system, the energy required by the ORC was provided through the heat exchanger installed between the two cycles. In study [3], an integration of SER and ORC was presented. The main goal was to achieve an optimal system from an economic standpoint. The ORC was installed to provide the required power for the compressor in SER. In a similar research, Liang et al. [4] presented a combination of ORC and SER, where the energy of the ORC was supplied through waste energy at a temperature of 170°C. In study [5], a combined cooling, heating, and power system was presented where its energy was provided through solar energy. The system consisted of subsystems such as solar collectors, ORC, ARC, and SER. there is no investigation into the effects of different working fluids (in the DER) on the performance of desalination. This is while, choosing the best couple of working fluids is important, especially, where the generated heat in DER should be transmitted to the other cycle according to the heat exchange between working fluids.

2. Theory

Considering that in the DER, significant heat is rejected to the environment and this waste heat is the result of valuable power consumption in this cycle. Therefore, consuming a valuable and high-cost energy (i.e. power), the heat is generated, which is wasted without any use. According to Figure 1, in the present work, to prevent the aforementioned waste heat and to increase the efficiency of the refrigeration system, the generated heat is utilized to produce steam and run the TED. In this way, the low-temperature compression refrigeration cycle (LTC) absorbs the heat from the cold environment and transfers this heat to the high-temperature compression refrigeration cycle (HTC) through a heat exchanger. In a conventional system, the generated heat in the HTC is rejected by the surrounding through the condenser.

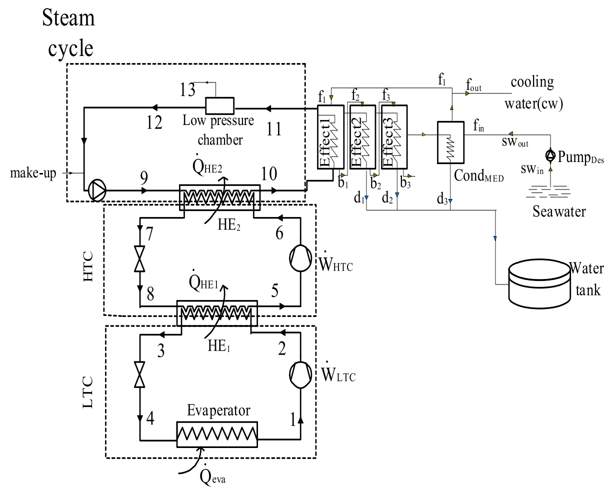

Fig 1. Schematic of the proposed system

To evaluate the proposed system from the energy standpoint, a control volume is considered for each component of the system, and the mass and energy balance equations are extracted according to the input and output streams. The mass and energy balance for the control volume due to the steady state conditions is calculated as [18].

$$\sum \dot{m}_i = \sum \dot{m}_o \tag{1}$$

$$\sum_k \dot{Q}_k + \sum_i^N (\dot{m}_i h_i)_k = \dot{W}_k + \sum_o^N (\dot{m}_o h_o)_k \tag{2}$$

Considering the above equation, the energy balance for the components of the DER is determined based on the following equations. The stream enters the evaporator in the liquid phase and leaves it in the saturated vapor phase. The heat transfer rate of the evaporator is obtained as

$$\dot{Q}_{eva} = \dot{m}_1 (h_1 - h_4) \tag{3}$$

Next, the saturated vapor enters the compressor. As a result, its temperature and pressure increase. The power consumption is determined as

$$\dot{W}_{comp,LTC} = \dot{m}_1 (h_2 - h_1) \tag{4}$$

After leaving the compressor, the stream passes through the heat exchanger and transfers its heat to another stream that flows in the heat exchanger.

$$\dot{Q}_{HE1} = \dot{m}_2 (h_2 - h_3) = \dot{m}_5 (h_5 - h_8) \tag{5}$$

3. Results and Discussions

It should be noted that the detailed investigation of the integrated system with various types of thermal desalination was carried out in reference [17] from the energy and economic perspectives; Therefore, in the present work, the energy and economic analysis of the integrated system is not considered. However, in the previous study, the effects of various working fluids in DER were not investigated, then, in the present work, the effects of different working fluid couples (WFC) are investigated from the energy and economic perspectives. Accordingly, five indicators are examined for various WFC, which include the mass flow rate of steam produced to run the desalination system, the power consumption of all compressors, the mass flow rate of potable water produced, the total space occupied by the desalination plant, and the total cost imposed on the system due to the change of WFC. First, the above-mentioned indicators are analyzed for different WFCs, and then, the best WFC is selected by using a scoring method. It should be explained that in the following tables, the WFs in the rows represent the WF of LTC. This is while the WFs listed in the first column represent the operating fluid of HTC. Some of the working fluids that are in the LTC have not been investigated in the HTC, this is because the thermodynamic properties of those working fluids do not match with the design conditions. Before examining the effects of the various WFCs, the energy analysis results for the integrated system are reported based on R744-R717 WFC. For this purpose, it is necessary to determine the thermodynamic properties of all points mentioned in Figure 1. The results related to the changes in the COP of the proposed system compared to the changes in the pressure ratio in compressor 1 are shown in Figure 2. Along with the increase in the pressure ratio, the power consumption of the compressor and the output temperature of the compressor increases. Increasing the temperature in the compressor is considered as an advantage, because with the increase in the output temperature of compressor 1, the temperature of the HTC increases, which ultimately causes the production of more steam and potable water. On the other hand, the cooling production capacity is also constant. The results presented in the figure indicate that along with the increase in the pressure ratio in compressor 1, the COP decreases. This issue indicates that although the mass flow rate of the potable water produced develops with the increase in the pressure ratio of compressor 1, this development is less significant than the increase in the consumed power of compressor 1.

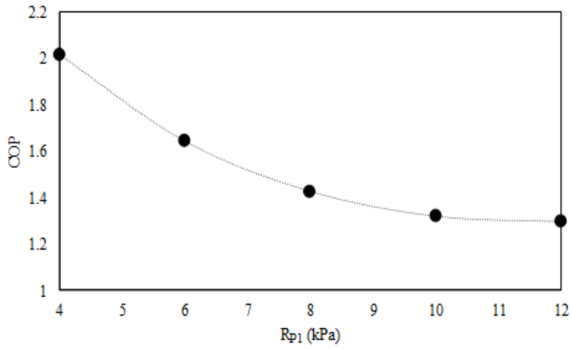

Fig 2. Changes in COP of the presented system due to the changes in the pressure ratio of the LTC compressor.

4. Conclusion

In this article, according to the generated heat in DER, which was wasted into the surrounding without any use, the required steam in a three-effect distillation desalination system was provided to produce potable water. In this way, the waste heat from DER is absorbed through the steam production cycle, and after producing steam at a temperature of 100 ℃, it supplies the required heat for the thermal desalination cycle. Moreover, the changes in the mass flow rates of produced steam, consumed power of the compressors, produced potable water, occupied space of the presented system, and related investment costs were investigated and compared where the WFC changes in DER

5. References

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