Exergetic analysis of a vapor compression solar refrigeration system

Analyse exergétique d'un système de réfrigération solaire à compression de vapeur

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ABSTRACT. In this article, a detailed Exergy analysis of practical steam compression refrigeration cycle is presented. The computer model has been developed to calculate the performance coefficient, exergy destruction, exergetic efficiency and efficiency defects for R134a and analyze the efficiency of Exergy. Many studies have shown that the compressor occurs most of the energy loss in the gas compression system. The present investigation has been done for evaporator temperature in the range of -10°C to 5°C.

RÉSUMÉ. Dans cet article, une analyse exergétique du cycle pratique de réfrigération à compression de vapeur est détaillée. Le modèle informatique a été développé pour calculer le coefficient de performance, la destruction d'exergie, l'efficacité exergétique et les défauts d'efficacité du R134a et analyser l'efficacité d'Exergie. De nombreuses études ont montré que le compresseur produit la majeure partie de la perte d'énergie dans le système de compression de gaz. La présente étude a été effectuée pour une température d'évaporateur comprise entre -10°C et 5°C.

KEYWORDS. Exergy efficiency, cooling cycle, compression system.

MOTS-CLÉS. Efficacité exergétique, cycle de refroidissement, système de compression.

1. Introduction

Due to the laws of thermodynamics, the atmosphere receives a considerable amount of heat from vapor compression refrigeration systems. This irreversibility is mainly caused by the limited temperature differential between the system and its surroundings during the heat transfer process. Unfortunately, the system's functionality is affected by this irreversibility. So, it is essential to evaluate the loss during each thermodynamic process that makes up the cycle. Energy analysis remains the primary method used for examining thermal systems. The first rule solely deals with the conservation of energy.

Exergy calculations have the potential to provide unexpected and innovative recommendations for enhancements, surpassing what is currently known about materials and energy balances. However, the extent, site, and nature of function deterioration remains undisclosed [1]. Dincer [2] discusses the links between energy and efficiency, energy and the environment, energy and sustainable growth, and information on how to formulate energy policy. Exergy analysis is an effective tool for designing, optimizing and evaluating the efficiency of energy systems. Exergy analysis has established concepts and methods [3-4]. Exergy studies usually aim to determine the peak performance of the system and where the exergy is violated [11].

Exergy analysis of complex systems can be performed by considering each component individually. Find the main locations of energy loss points in possible directions for improvement. Finding the minimum amount of energy required to achieve a specific desired result is a key goal of exergy analysis of energy-consuming systems such as refrigeration, gas liquefaction, and water distillation [5,6]. The exergy analysis of refrigeration and heat pump systems is the subject of numerous studies [7-11]. Based on exergy analysis, Leidenfrost et al. [11] studied the effectiveness of a refrigeration cycle using Freon-12 as a refrigerant. In the heat pump system experimentally studied by Akau and Schoenhals, water is used as heat source and radiator [8]. Kaygusuz and Ayhan [9] reported experimental results for energy analysis of solar assisted heat pump systems. They looked at how different factors affect how well the system works. Furthermore, Torres-Reyes et al. [7,10] performed experimental studies on solar assisted heat exchangers and used exergy analysis to optimize the system. Chen et al. [13] conducted a study on optimizing a multi-stage irreversible combined cooling system.

The main goal of the current study is to evaluate and analyze the exergy and efficiency. Exergy analysis of a country in Kebili, Tunisia using thermodynamic linkages. Finally, it was concluded that exergy analysis is required for vapor compression systems.

2. Exergy analysis for components of the refrigeration system

2.1. *Exergy destruction (ed) in the system components*

Exergy destruction in every element of the cycle is calculated as in line with Eqs. (1) – (5) particular below.[12]

Evaporator

$$ED_e = E_{x4} + Q_e\,(1-T_0/T_r) - E_{x11} = mr\,(h_4 - T_0 s_4) + Q_e\,(1-T_0/T_r) - mr\,(h_{11} - T_0 s_{11}) \quad [1]$$

Compressor

$$ED_{comp} = E_{x1} + W_{comp} - E_{x2} = m_r\,(T_0\,(s_2 - s_1)) \quad [2]$$

Condenser

$$ED_c = E_{x2} - E_{x3} = m_r(h_2 - T_0 s_2) - m_r\,(h_3 - T_0 s_3) \quad [3]$$

Throttle valve

$$ED_t = E_{x33} - E_{x4} = m_r\,(h_{33} - T_0 s_3) - m_r\,(h_4 - T_0 s_4) = m_r\,(T_0\,(s_4 - s_{33})) \quad [4]$$

Liquid vapour heat exchanger

$$ED_{lvhe} = E_{x3} - E_{x33} + E_{x11} - E_{x1} = m_r\,((h_3 - h_{33} + h_{11} - h_1) - T_0\,(s_3 - s_{33} + s_1 - s_{11})) \quad [5]$$

2.2. *Total exergy destruction*

The overall exergy destruction withinside the machine is the sum of exergy destruction in distinctive additives of the machine and is given by:

$$\sum ED_i = ED_e + ED_{comp} + ED_c + ED_t + ED_{Ivhe} \quad [6]$$

2.3. *Thermal exergy loss*

Thermal exergy loss rate in a component is given by

$$EL_i = Q_i\,(1 - T_0/T_i) \quad [7]$$

where Ti is the temperature at the ith component's boundary and Qi is the heat discarded by that component. In order to account for the rate of heat exergy loss, Eq.

$$ED_i + EL_i = \sum(mex)_{in} - \sum(mex)_{out} + [\sum(Q(1-T_0/T)in] \pm \sum W \quad [8]$$

2.4. *Exergy efficiency*

ηex =exergy in product / exergy of fuel=EP/EF [9]

Product in a vapour compression refrigeration system is the energy of the heat transferred from the cooling area to the evaporator at temperature Tr,

$$EP = Qe|(1-T0/Tr)| \quad [10]$$

and real compressor work input, W_{comp}, is fuel energy. Exergetic efficacity is therefore determined by

$$\eta ex = \frac{|Qe(1-\frac{T0}{Tr})|}{Wcomp} = \frac{COPvcr}{COPrr} \quad [11]$$

where COPrr is the coefficient of performance of the reversible refrigerator working between T0 and Tr and COPvcr is the coefficient of performance of the vapour compression cycle.

2.5. *Exergy destruction ratio (EDR)*

EDR is the ratio of total exergy destruction in the system to exergy in the product and it is given by (12). EDR is related to the exergetic efficiency by Eq. (13).

$$EDR = \frac{EDtotal}{EP} = \frac{COPrr}{COPvcr} - 1 = \frac{1}{\eta ex} - 1 \quad [12]$$

$$\eta ex = 1/1+EDR \quad [13]$$

2.6. *Efficiency defect*

Efficiency defect is determined by dividing the amount of energy consumed by each component by the amount of energy needed to maintain the process (in this case, the electrical power provided to the compressor) [14].

$$\delta i = \frac{\sum EDi + \sum ELi}{Wcomp} \quad [14]$$

where i stands for particular component. The efficiency defects of the components are linked t exergetic efficiency of the whole plant by means of the following relation:

$$\eta ex = (1-\sum i \delta i) \quad [15]$$

3. Results and discussion

A computational model is developed for carrying out the energy and exergy analysis of the system using Engineering Equation Solver software.

Fig. 1 shows the effect of evaporator temperature on EDR and exergy efficiency. As the evaporator temperature increases, the exergy efficiency increases and decreases based on two parameters (see equation [11]).

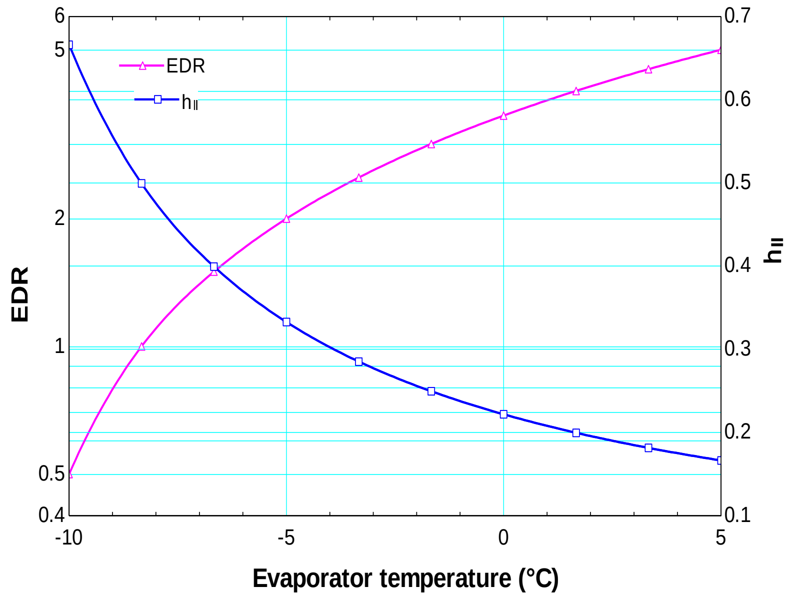

Figure 1. *Variation of EDR and exergy efficiency vs evaporator temperature.*

4. Conclusion

An extensive exergy analysis of R134a in a real vapour compression cycle is given in this communication. Following is a summary of the analysis's findings.

– The COP increase with the increase in the evaporator temperature.

– The exergetic efficiency decrease as the evaporator temperature rises.

– The evaporator temperature is increased from -10°C to 5°C.

To increase energy savings and lessen environmental impacts, more study is required to determine the best refrigerant with the highest performance coefficient and energy efficiency.

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