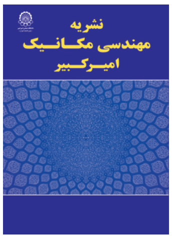

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Thermoeconomic Analysis of a Variable Refrigerant Flow System

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ABSTRACT: Exergy and thermoeconomic analysis is an effective method for determining thermodynamic characteristics and optimizing thermodynamic-economic performance of refrigeration systems. The present study deals with exergy and thermoeconomic analysis of a variable refrigerant flow system with four evaporators used in the dairy industry. A computer code written in EES software was used for system simulation. Impact of three refrigerants, R502, R1234ze and R134a, on thermodynamic-economic parameters of the system was investigated. In addition to calculation of exergy efficiency of refrigeration cycle for three mentioned refrigerants, effect of evaporation and distillation temperature on system exergy degradation and exergy efficiency of was also investigated. Results showed that R1234ze gas can be appropriate alternative for R502 and R134a gases. Also, results show that exergy destruction in compressor in reference temperature from 3.974kW for R134a refrigerant increases to 4.221 kW for refrigerant R502. Exergy destruction in the condenser in second level was calculated for all refrigerants. In thermoeconomic analysis, costs of components of variable refrigerant flow system were investigated and total costs for R134a, R502 and R1234ze refrigerants were studied. It was observed that a lowest cost is related to R502 refrigerant and total annual cost for or R134a and R1234ze refrigerants are in the next ranks.

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1- Introduction

Limitation of energy resources and increasing energy consumption in one hand, and excessive energy consumption by different communities on the other hand, in addition to pollution of the environment and loss of national capital, it has endangered lives of the people. Stoeker and Jones [1] provided a research on variable refrigerant flow systems with application in dairy industry. Xia et al. [2] experimentally studied Variable Refrigerant flow (VRF) system and measured values of pressure and temperature in different places of the cycle. Ansari et al. [3] described performance of R1234yf and R1234ze gases in a simple air-conditioner equipped with a liquid vapour heat exchanger. Babiloni et al. [4] studied new two-evaporator systems with double source. More accurate examination of R1234yf gas by Esbrí et al. [5] showed that it is good replacement for R134a gas according to the energy and exergy analysis results. Although wide studies have been conducted on multi-evaporator variable refrigerant flow systems, low attention has been paid to thermoeconomic performance of multi-evaporator systems. In this study, unlike the past studies, exergy and thermoeconomic analysis is investigated for variable refrigerant flow systems with four evaporators using R1234ze as replacement for R502 and R134a at different evaporator and condenser temperatures.

2- Methodology

A condensing unit related to double or multi-evaporator is used in some refrigeration systems. This type of refrigeration systems are mainly used in commercial systems such as markets, dairy, restaurants, and food industries. Evaporators may have similar or different temperatures depending on different values of cooling loads. If two or more evaporation temperatures are required, pressure reducer valves should be used at the outlet of higher temperature evaporators. Fig. 1 shows a VRF system with four evaporators operating at different temperatures. In this system there is a compressor, separate expansion valves for each evaporator, a condenser and two evaporator pressure regulators. Coefficient of performance of VRF system can be calculated as Eq. (1):

$$COP = \frac{(\dot{Q}_1 + \dot{Q}_2 + \dot{Q}_3 + \dot{Q}_4)}{\dot{W}_{comp}} \tag{1}$$

Total exergy balance equation is written as follows:

$$\dot{E}_{dest} = \dot{E}_{in} - \dot{E}_{out} \tag{2}$$

Thermoeconomics is a method which combines exergy concept with part of economy which belongs to it. Thermoeconomic target function includes costs related to input exergy and system investment costs in monetary unit. Overall calculating Life Cycle Cost (LCC) of system is an appropriate method for heat systems with initial investment and performance and maintenance costs during their life cycle. In engineering economy, time interval for such target is often selected as one year. Annual cost function of total system is as following equation:

$$C_{total} = \begin{bmatrix} \dot{Z}_{comp} + \dot{Z}_{con} + \dot{Z}_{ev1} + \\ \dot{Z}_{ev2} + \dot{Z}_{ev3} + \dot{Z}_{ev4} \end{bmatrix} .CRF + C_{el}.H \begin{bmatrix} \dot{W}_{comp} + \dot{W}_{fan,cond} + \dot{W}_{fan,ev1} \\ + \dot{W}_{fan,ev2} + \dot{W}_{fan,ev3} + \dot{W}_{fan,ev4} \end{bmatrix} \tag{3}$$

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where C_{el} is electricity costs in terms of \$/kWh, H is hours of operation system during one year and CRF is capital recovery factor. In order to determine investment costs in one year, Capital Recovery Factor (CRF) is used, which is obtained from following equation [25]:

$$CFR = \frac{i\left(1+i\right)^{n}}{\left(1+i\right)^{n}-1} \qquad (4)$$

where i is annual interest rate and n denotes number of system performance years. Economic factors considered in this paper are given in Table 1. Investment cost of expansion valves in target function has been ignored. For estimating investment costs or system equipment purchase cost the following equations are used:

$$\begin{aligned}
\dot{Z}_{comp} &= 9624.2\dot{W}_{comp}^{0.46} \\
\dot{Z}_{cond} &= 1397A_{o,con}^{0.89} + 629.05\dot{W}_{fan,cond}^{0.76} \\
\dot{Z}_{ev1} &= 1397A_{o,ev1}^{0.89} + 629.05W_{fan,ev1}^{0.76} \\
\dot{Z}_{ev2} &= 1397A_{o,ev2}^{0.89} + 629.05W_{fan,ev2}^{0.76} \\
\dot{Z}_{ev3} &= 1397A_{o,ev3}^{0.89} + 629.05W_{fan,ev3}^{0.76} \\
\dot{Z}_{ev4} &= 1397A_{o,ev4}^{0.89} + 629.05W_{fan,ev4}^{0.76}
\end{aligned} \qquad (5)$$

In above equations, $\dot{Z}_{comp}$ ، $\dot{Z}_{ev2}$ ، $\dot{Z}_{ev1}$ ، $\dot{Z}_{con}$ ، $\dot{Z}_{ev3}$ and $\dot{Z}_{ev4}$ denote compressor, condenser, and evaporator purchase cost per dollar unit.

Since surface of heat exchangers and pressure drop are factors which influence total annual system cost, thus designing exchangers is necessary. Respective variable refrigerant flow cycle contains an air condenser and four evaporators of air- cooled compact heat exchanger type. In order to design exchangers, such parameters as pipe diameter, numbers of pipe rows are considered as fixed values. Since two-phase

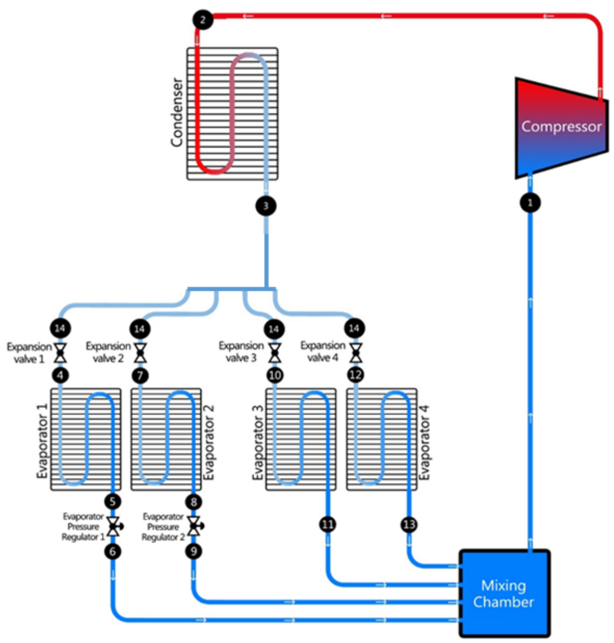

Fig. 1. Schematic of problem

Table 1. Parameters needed for thermoeconomic analysis of variable refrigerant flow cycle

Parameter	Symbol	Value
Number of operation hours per year	$H\left(\text{hr/year}\right)$	6750
Number of system performance years	$n\left(\text{year}\right)$	15
Annual interest rate	$i\left(\%\right)$	0.14
Capital recovery factor	CRF	0.1628
Electricity price	$C_{el}\left(\$/\text{kWh}\right)$	0.07

heat transfer coefficients are a function of the refrigerant's quality, the exchangers are designed in a range of 0.1, which assumes constant two-phase heat transfer coefficients in this interval. Finally, the required area for each designed exchanger in this interval is obtained from:

$$A_o = \frac{\dot{Q}}{U_0 \Delta T_{LMTD}} \qquad (4)$$

In this equation, U_0 is total heat transfer coefficient based on external surface of exchanger, which is obtained from following equation:

$$U_0 = \left(\frac{A_o}{A_i}\frac{1}{hi} + A_o R_w + \frac{1}{h_o}\right) \qquad (5)$$

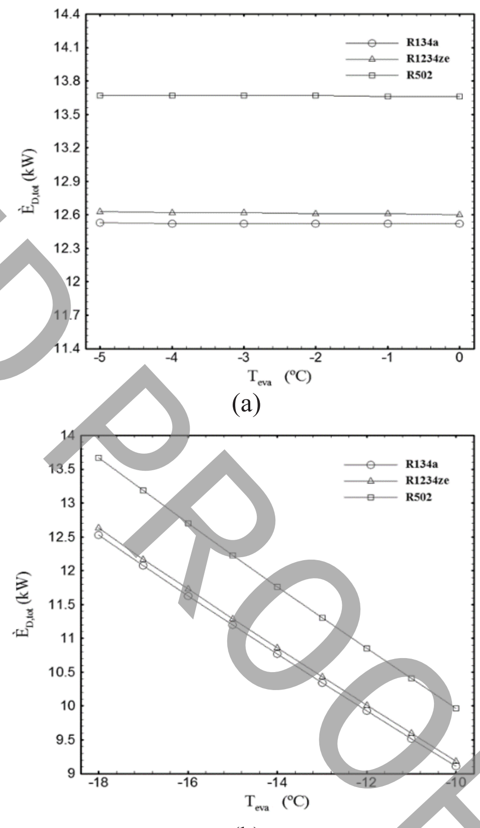

Fig. 1. Total exergy destruction rate versus evaporator temperature for R134a-R502-R1234ze refrigerants (a)for Evaporators 1, 2 (b) for Evaporators 3, 4.

3- Results and Discussion

A theoretical study was provided based on exergy analysis of variable refrigerant flow system with four evaporators in order to investigate evaporation and condensation temperature effect on exergy destruction of system components. Fig. 1 indicates exergy destruction in variable refrigerant flow system with four evaporators for R134a and R502 and R1234ze refrigerants. The condensation temperature has been kept constant at 40 degrees Celsius. The most important factor affecting exergy destruction rate in evaporators is increase in entropy. As the evaporator temperature rises, the entropy flow in the evaporators decreases for the desired refrigerant. Therefore, with increasing evaporation temperature, the exergy destruction in the evaporator is also reduced. The most obvious finding from the exergy analysis is that the lowest rate of exergy destruction is obtained using R134a refrigerant, while the highest rate of exergy destruction is the result of using R502 refrigerant. However, it is clear from the above description that R1234ze can be an appropriate alternative for R134a refrigerant.

4- Conclusions

In this paper, thermoeconomic analysis on variable refrigerant flow system with four evaporators was done. Design of heat exchangers was also provided. Analysis of refrigerants with low global heat such as R1234ze as a replacement for R134a refrigerant in the variable refrigerant flow system was also given. A theoretical study was provided based on exergy analysis of variable refrigerant flow system with four evaporators in order to investigate evaporation and condensation temperature effect on exergy destruction of system components. In thermoeconomic analysis, costs of components of variable refrigerant flow system were investigated and total costs for R134a, R502 and R1234ze refrigerants were studied. It was observed that a lowest cost is related to R502 refrigerant and total annual cost for R1234ze refrigerants is in the next ranks.

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