

## EXERGY ANALYSIS ON VAPOUR COMPRESSION REFRIGERATION SYSTEM

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### ABSTRACT

*This article focus on the exegetic investigation on a vapor pressure refrigerating framework. The exegetic relations have been characterized. A scientific model for doing exergy examination has been produced. Then for different evaporator and condenser temperature exergy efficiency is found and the graphs are plotted.*

**KEYWORDS:** COP, Condenser, Exergy Efficiency, Reversible COP & Total Change in Entropy

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### 1. INTRODUCTION

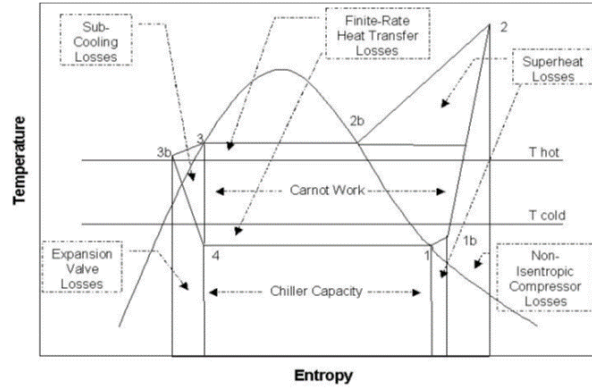
The exergy examination is generally acknowledged as a valuable apparatus in getting the enhanced comprehension of the general execution of any framework and its segments. Exergy examination likewise helps in considering the essential building choices with respect to outline the parameters of a framework. The aim of this paper is to introduce an exergetic analysis method on the vapor compression refrigerating system in order to compare the performance between the COP calculated by the total change in entropy and actual obtained COP.

### 2. LITERATURE REVIEW

Padill et al [1] done the exergy investigation and the effect of direct supplanting of R12 with zeotropic blend R413A. The execution of a local vapor pressure refrigeration framework initially intended to work with R12 was assessed utilizing a reproduced demonstrating. They reasoned that the general vitality and exergy execution of this framework working with R413A is superior to that of R12. Kumar et al [2] determined a technique to complete the exegetic investigation of a vapor pressure refrigeration framework utilizing R11 and R12 as refrigerants. Arora and Kaushik [3] did a definite exergy investigation of a real vapor pressure refrigeration cycle. Dincer [4] declares that ordinary vitality examination, in the light of the principal law of thermodynamics, assesses vitality for the most part on its amount yet investigation that depend on second law considers the nature of vitality as well as amount of vitality.

### 3. METHODOLOGY

#### 3.1 Thermodynamic Derivation based on the Second Law for Chiller



**Figure 1: Reverse Rankine Cycle with Irreversibilities**

The First Law equation that describes the refrigerant-side operation of a chiller is

$$\Delta E = Q_{cond} + Q_{cond}^{leak} - Q_{evap} - Q_{evap}^{leak} - P_{in} + Q_{comp}^{leak} = 0 \quad (1)$$

Where,

$Q_{cond}$  = heat transfer in the condenser, kW

$Q_{cond}^{leak}$  = heat transfer from the condenser piping to the environment, kW

$Q_{evap}$  = heat transfer in the evaporator, kW

$Q_{evap}^{leak}$  = heat transfer from the evaporator piping to the environment, kW

$P_{in}$  = compressor power input, kW

$Q_{comp}^{leak}$  = heat transfer from the compressor to the environment, kW

The Second Law equation is

$$\Delta S = \left( \frac{Q_{cond} + Q_{cond}^{leak}}{T_{cond}^{ref}} \right) - \left( \frac{Q_{evap} + Q_{evap}^{leak}}{T_{evap}^{ref}} \right) - \Delta S_{internal} = 0 \quad (2)$$

Where,

$T_{cond}^{ref}$  = Temperature of the Condensing refrigerant, K

$T_{evap}^{ref}$  = Temperature of the Evaporating refrigerant, K

$\Delta S_{internal}$  = Internal Entropy Production, W/K

$$Q_{cond} = \frac{T_{cond}^{ref}}{T_{evap}^{ref}} (Q_{evap} + Q_{evap}^{leak}) + T_{cond}^{ref} \Delta S_{internal} - Q_{cond}^{leak} \quad (3)$$

$$0 = \frac{T_{cond}^{ref}}{T_{evap}^{ref}} (Q_{evap} + Q_{evap}^{leak}) + T_{cond}^{ref} \Delta S_{internal} - Q_{cond}^{leak} + Q_{cond}^{leak} - Q_{evap} - Q_{evap}^{leak} - P_{in} + Q_{comp}^{leak} \quad (4)$$

The  $Q_{cond}^{leak}$  terms cancels out & equation is solved for  $P_{in}$  to obtain:

$$P_{in} = \frac{T_{cond}^{ref}}{T_{evap}^{ref}} (Q_{evap} + Q_{evap}^{leak}) + T_{cond}^{ref} \Delta S_{internal} - Q_{evap} - Q_{evap}^{leak} + Q_{comp}^{leak} \quad (5)$$

By combining  $Q_{evap}$  &  $Q_{evap}^{leak}$  terms, equation becomes:

$$P_{in} = Q_{evap} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + Q_{evap}^{leak} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + Q_{evap}^{ref} + T_{cond}^{ref} \Delta S_{internal} \quad (6)$$

Dividing both sides of the above equation by  $Q_{evap}$  gives:

$$\frac{P_{in}}{Q_{evap}} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{Q_{evap}^{leak}}{Q_{evap}} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + \frac{Q_{evap}^{ref}}{Q_{evap}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} \quad (7)$$

The Coefficient of Performance (COP) of a chiller is defined as:

$$COP = \frac{Q_{evap}}{P_{in}} \quad (8)$$

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} + \frac{Q_{evap}^{leak}}{Q_{evap}} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + \frac{Q_{evap}^{ref}}{Q_{evap}} \quad (9)$$

The  $Q_{evap}^{leak}$  terms in equation (9) can be further combined to yield:

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} + \frac{1}{Q_{evap}} \left[ Q_{evap}^{leak} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + Q_{comp}^{leak} \right] \quad (10)$$

The  $Q_{evap}^{leak}$  term in equation are multiplied by unity in the form of  $\frac{T_{cond}^{ref}}{T_{cond}^{ref}}$  to obtain:

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} + \frac{T_{cond}^{ref}}{Q_{evap}} \left[ \frac{Q_{evap}^{leak}}{T_{cond}^{ref}} \left( \frac{T_{cond}^{ref}}{T_{evap}^{ref}} - 1 \right) + \frac{Q_{comp}^{leak}}{T_{cond}^{ref}} \right] \quad (11)$$

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} + \frac{T_{cond}^{ref}}{Q_{evap}} \left[ \frac{Q_{comp}^{leak}}{T_{cond}^{ref}} + Q_{evap}^{leak} \left( \frac{1}{T_{evap}^{ref}} - \frac{1}{T_{cond}^{ref}} \right) \right] \quad (12)$$

$$\Delta S_{leak} = \frac{Q_{comp}^{leak}}{T_{cond}^{ref}} + Q_{evap}^{leak} \left( \frac{1}{T_{evap}^{ref}} - \frac{1}{T_{cond}^{ref}} \right) \quad (13)$$

$$\left( \frac{1}{COP} \right) = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{internal}}{Q_{evap}} + \frac{T_{cond}^{ref} \Delta S_{leak}}{Q_{evap}} \quad (14)$$

Combining the  $\Delta S$  terms in the below equation

$$\Delta S_{total} = \Delta S_{internal} + \Delta S_{leak} \quad (15)$$

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{total}}{Q_{evap}} \quad (16)$$

To calculate Reversible COP equate  $\Delta S_{total}$  to zero, then we get

$$\left( \frac{1}{COP} \right)_{rev} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} \quad (17)$$

Exergy Efficiency of whole refrigeration system is calculated as ratio of Actual COP by Reversible COP

$$\eta_{exr} = \frac{COP}{COP_{rev}} \quad (18)$$

#### 4. RESULTS & DISCUSSIONS

By keeping the evaporator temperature and refrigerating effect as a constant in each case and varying the condenser temperature change in total entropy, COP, Reversible COP & Exergy Efficiency is found. Following formulas were referred.

$$\Delta S_{total} = \frac{P_{in}}{T_{cond}^{ref}} + Q_{evap} \left( \frac{1}{T_{cond}^{ref}} - \frac{1}{T_{evap}^{ref}} \right) \quad (1)$$

$$\frac{1}{COP} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} + \frac{T_{cond}^{ref} \Delta S_{total}}{Q_{evap}} \quad (2)$$

$$\left( \frac{1}{COP} \right)_{rev} = -1 + \frac{T_{cond}^{ref}}{T_{evap}^{ref}} \quad (3)$$

$$\eta_{exr} = \frac{COP}{COP_{rev}} \quad (4)$$

**Table 1: Variation of COP and Exergy Efficiency with Condenser Temperature for Evaporator Temperature of 278 K**

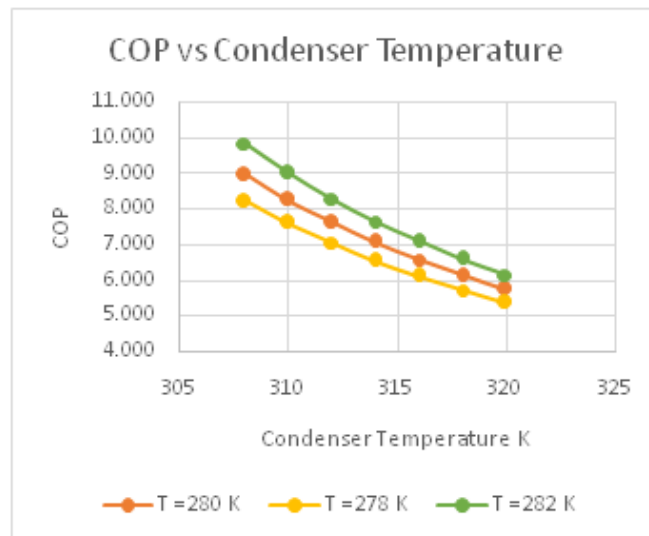
| $T_{evap} = 278 \text{ K}$ |                                 |       |             |                   |              |
|----------------------------|---------------------------------|-------|-------------|-------------------|--------------|
| $T_{cond} \text{ K}$       | $\Delta S_{total} \text{ kW/K}$ | COP   | $COP_{rev}$ | $\eta_{exr} (\%)$ | Obtained COP |
| 308                        | 0.253                           | 7.906 | 9.267       | 88.62             | 8.212        |
| 310                        | 0.292                           | 7.319 | 8.688       | 87.46             | 7.598        |
| 312                        | 0.334                           | 6.797 | 8.176       | 86.16             | 7.045        |
| 314                        | 0.381                           | 6.331 | 7.722       | 84.76             | 6.546        |
| 316                        | 0.432                           | 5.911 | 7.316       | 83.52             | 6.110        |
| 318                        | 0.488                           | 5.529 | 6.950       | 82.15             | 5.709        |
| 320                        | 0.547                           | 5.187 | 6.619       | 80.83             | 5.350        |

**Table 2: Variation of COP and Exergy Efficiency with Condenser Temperature for Evaporator Temperature of 280 K**

| $T_{evap} = 280 \text{ K}$ |                                 |       |             |                   |              |
|----------------------------|---------------------------------|-------|-------------|-------------------|--------------|
| $T_{cond} \text{ K}$       | $\Delta S_{total} \text{ kW/K}$ | COP   | $COP_{rev}$ | $\eta_{exr} (\%)$ | Obtained COP |
| 308                        | 0.223                           | 8.593 | 10.00       | 89.67             | 8.967        |
| 310                        | 0.259                           | 7.922 | 9.333       | 88.50             | 8.260        |
| 312                        | 0.298                           | 7.33  | 8.750       | 87.18             | 7.628        |
| 314                        | 0.341                           | 6.805 | 8.235       | 85.75             | 7.062        |
| 316                        | 0.389                           | 6.336 | 7.778       | 84.51             | 6.573        |
| 318                        | 0.442                           | 5.911 | 7.368       | 83.12             | 6.125        |
| 320                        | 0.497                           | 5.534 | 7.000       | 81.79             | 5.725        |

**Table 3: Variation of COP and Exergy Efficiency with Condenser Temperature for Evaporator Temperature of 282 K**

| $T_{evap} = 282 \text{ K}$ |                                 |       |             |                   |              |
|----------------------------|---------------------------------|-------|-------------|-------------------|--------------|
| $T_{cond} \text{ K}$       | $\Delta S_{total} \text{ kW/K}$ | COP   | $COP_{rev}$ | $\eta_{exr} (\%)$ | Obtained COP |
| 308                        | 0.193                           | 9.404 | 10.85       | 90.74             | 9.842        |
| 310                        | 0.225                           | 8.627 | 10.07       | 89.54             | 9.018        |
| 312                        | 0.262                           | 7.949 | 9.400       | 88.19             | 8.290        |
| 314                        | 0.302                           | 7.352 | 8.813       | 86.74             | 7.644        |
| 316                        | 0.345                           | 6.823 | 8.294       | 85.48             | 7.090        |
| 318                        | 0.395                           | 6.347 | 7.833       | 84.08             | 6.586        |
| 320                        | 0.446                           | 5.926 | 7.421       | 82.75             | 6.141        |



**Figure 2: COP vs Condenser Temperature**

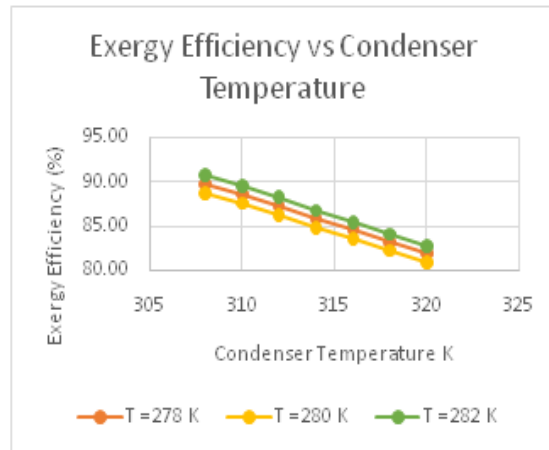


Figure 3: Exergy Efficiency vs Condenser Temperature

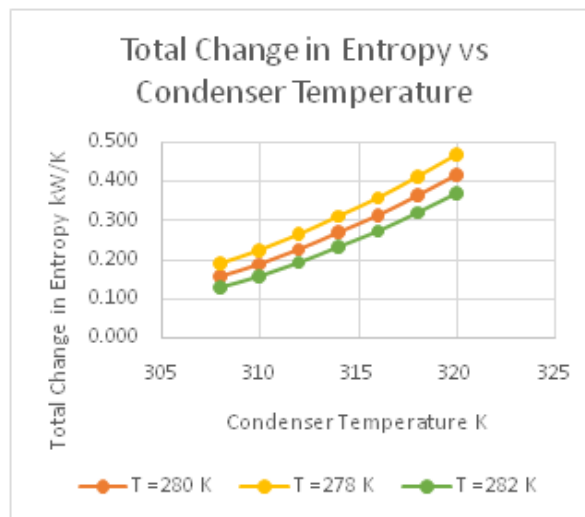


Figure 4: Total Change in Entropy vs Condenser Temperature

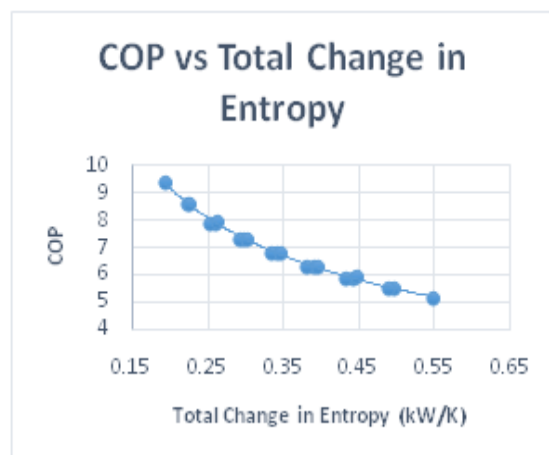


Figure 5: COP vs Total Change in Entropy

At a steady evaporator temperature as the gathering temperature builds, then the entropy of the refrigerant at the bay to the evaporator increments. Since the evaporator enthalpy stays consistent at a steady evaporator temperature, the refrigeration impact diminishes with increment in consolidating temperature as appeared in Figure 2. The refrigeration limit additionally diminishes with increment in gathering temperature as both the mass stream rate and refrigeration impact

diminish. For a constant evaporator temperature as the condenser temperature increases from 308 K to 320 K there is a reduction in COP by 35.6%. And at a constant condenser temperature as the evaporator temperature reduces from 282 K to 278 K the COP is decreased by 14%. The error between COP calculated based on entropy and the actual COP obtained. And the error was around 3-4%.

As the fluid refrigerant goes through the evaporator coil, it persistently ingests warm through the loop dividers which makes the medium cool. Amid this, the refrigerant keeps on bubbling and vanishes. At last the whole refrigerants wind up noticeably dissipated and just vapor refrigerant stays in the evaporator loop. The fluid refrigerant still colder than the medium being cooled, in this manner, the vapor refrigerants keep on absorbing the warmth. Exergy efficiency decreases as the temperature of the evaporator decreases as shown in Figure 3. This can be clarified that if the vanishing temperature builds the warmth exchange between the refrigerant gone into the evaporator tubes and the medium being cooled additionally expands which at last increment the refrigerating impact subsequently the exergy misfortune diminishes Figure 4. The graphs shows that, with the increase in evaporator temperature, the values of COP and exergy efficiency were increased, whereas the total change in entropy (total irreversibility rate) was decreased. It means that an increase in the evaporator temperature affects the system efficiency positively.

With the expansion in condenser temperature, the estimations of COP and exergy effectiveness were diminished, though the aggregate irreversibility rate was expanded (Figure 3 & 4). It is on account of higher the temperature distinction between the encompassing and the segment the higher the exergy loss.

## **5. CONCLUSIONS**

It was found that COP will be maximum when the total change in entropy is minimized (total irreversibility rate) if the refrigeration system capacity is fixed. With the increase in evaporator temperature, the values of COP and exergy efficiency were increased, whereas the total change in entropy (total irreversibility rate) was decreased. At a constant condenser temperature as the evaporator temperature reduces from 282 K to 278 K the COP is decreased by 14%. In the case of condenser temperature result observed was opposite to that of evaporator temperature, i.e. the values of COP and exergy efficiency were decreased, whereas the total irreversibility rate was increased. For a constant evaporator temperature as the condenser temperature increases from 308 K to 320 K there is a reduction in COP by 35.6%. COP calculated based on entropy is in good agreement with the actual COP obtained. And the error was around 3-4%.

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