INVESTIGATION OF EXERGY ANALYSIS IN VAPOUR COMPRESSION REFRIGERATION SYSTEM

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"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance)"

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Date: JUNE 2015

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This report is submitted in fulfilment of the requirement for the award of Bachelor Of Degree Of Mechanical Engineering with Honours (Plant & Maintenance)

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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Khas buat

Ayah dan Ibu tersayang

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ABSTRACT

The " Exergy Analysis in Vapour Compression Refrigeration System " project. This project's focus is to investigate on the exergy analysis in vapour compression refrigeration system. Exergy analysis is a thermodynamics method which enables the evaluation and improvement for the refrigeration system in term of performance and efficiency based on the second law of thermodynamics. The main purpose of this final year project is to investigate the exergy loss for each component and to evaluate the heat transfer performance of the vapour compression refrigeration system. For this project, the scopes are to evaluate all the parts in the refrigeration system including evaporator, condenser, compressor and expansion valve, to check the temperature and pressure for each parts using thermometer sensor and pressure gauges, to analyze the collected data in estimating the amount of exergy loss for each components and assessing the second law efficiency through formulated calculation. Using experimental method, a refrigeration system ET412C with vapour compression cycle is used to gain and collect for this project's analysis. The Q_H and W_{In} value increases with the increasing ambient temperature while the Q_L maintains its value steadily. The COP_R is directly proportional with the second law efficiency but inversely proportional with the increasing ambient temperature. Exergy loss for compressor shows a significant increase, expansion valve remains constant, slight decrease and gradually increase in evaporator and gradually decreases in condenser with the increasing of ambient temperature. At 33 degree Celcius, compressor shows the highest exergy loss around 5 W while condenser is lowest at 0.2 W. The result shows the overall exergy loss for the refrigeration system is directly proportional to the increasing ambient temperature. As for this project's conclusion, COP and second law of efficiency are dependent towards the value of exergy loss. Therefore, evaluation of heat transfer performance through exergy analysis is proven effective as the objectives are achieved for this final stage project.

ABSTRAK

Tajuk projek akhir ini ialah “Analisa exergi untuk setiap komponen di dalam system penyejukan gas mampat.” Fokus projek ini adalah untuk menyiasat analisa exergi untuk system penyejukan gas mampat. Analisa exergi adalah kaedah termodinamik bagi membolehkan penilaian dan pembaharuan kepada sistem penyejukan dari segi prestasi dan kecekapan berdasarkan hukum kedua kecekapan termodinamik. Tujuan utama projek ini adalah menyiasat exergi musnah bagi setiap komponen dan menilai prestasi pindahan haba dalam sistem penyejukan gas mampat. Skop projek merangkumi penilaian keseluruhan komponen dalam sistem penyejukan termasuklah penyejat, pemeluwap, pemampat dan injap pengembangan, memeriksa suhu dan tekanan setiap komponen menggunakan thermometer dan tolok tekanan, menganalisa data terkumpul untuk anggaran jumlah exergi musnah setiap komponen dan menaksir hukum kedua kecekapan melalui kiraan formula. Melalui kaedah ekperimen, satu sistem penyejukan ET421C dengan kitaran gas mampat digunakan bagi mendapat dan mengumpul data untuk analisa projek ini. Nilai Q_H dan W_{In} bartambah seiring dengan pertambahan suhu sekitar manakala Q_L kekal. COP_R berkadar terus dengan hukum kedua kecekapan tetapi berkadar songsang dengan peningkatan suhu sekitar. Pada 33 darjah Celcius, pemampat mencatat exergi musnah paling tinggi sekitar 5 W manakala paling rendah ialah penyejat pada 0.2 W. Keputusan menunjukkan keseluruhan exergi musnah bagi sistem penyejukan ini adalah berkadar langsung dengan peningkatan suhu sekitar. Sebagai kesimpulan projek ini, COP dan hukum kedua kecekapan adalah bergantungdengan nilai exergi musnah. Sesungguhnya, penilaian prestasi pindahan haba melalui analisa exergi terbukti berkesan dalam membantu mencapai objektif untuk projek semester akhir ini.

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LIST OF ABBREVIATIONS

h	=	Enthalpy
s	=	Entropy
x	=	Percentage of Moisture/Liquid
P	=	Pressure
T	=	Temperature
Tsat	=	Saturation Temperature
Tsuper	=	Superheat Temperature
T_0	=	Environment Temperature
T_i	=	Air Temperature in Freezer Compartment
T_L	=	Low Temperature Medium
T_H	=	High Temperature Medium
X_{gen}	=	Exergy Generated
X_{dest}	=	Exergy Destroyed
S_{gen}	=	Entropy Generated
Q_L	=	Refrigeration Load
Q_H	=	Heat Generated
W_{In}	=	Power Input
M	=	Mass Flow Rate
COP_R	=	Coefficient of Performance

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CHAPTER 1

INTRODUCTION

1.1 VAPOUR COMPRESSION REFRIGERATION SYSTEM

This final project is to investigate on the exergy analysis in vapour compression refrigeration system. Vapour compression is a type of refrigeration cycle that is widely used in domestic applications such as refrigerators, vehicles and housing air conditioning; commercial applications such as HVAC (heat ventilating air conditioning) systems, large-scale refrigerators, warehouses and storages (chilled and cold); and industrial applications, for examples processing plants, refineries and cooling utility systems. A simple principle of refrigeration system is to reduce the temperature in one region and transfer the heat collected to another region through a medium known as refrigerant. Refrigerant is the medium responsible in absorbing the heat in the targeted area and transfer the heat before disposing them out into the environment (atmosphere). The basic components in a refrigeration system are compressor, expansion valves, condenser and evaporator. Figure 1.1 shows the basic components in the vapour compression system and its process stages.

Vapour compression is one type of cyclic refrigeration where the refrigerant will flow through all the components process in a cycle. In the compressor, the refrigerant enters as vapour in its saturated region and will be compressed at high pressure to the condenser pressure. The high compression will cause the rise of the temperature in the refrigerant and turn into superheated vapour as the refrigerant shift phase into the superheated region. The superheated refrigerant is channeled into the condenser to dispense the heat and lowers its temperature with cooling air or water. The vapour then is cooled and condensed as it flows through the condenser coils. The heat will be released into the surrounding air or circulating water as the superheated vapour is cooled into condensate liquid. The condensate refrigerant will flow and enters the expansion valve. Both temperature and pressure will drop substantially as the refrigerant undergoes throttling effect. The throttling effect causes the refrigerant to experience adiabatic expansion due to reduction of pressure. The expanded refrigerant then flows into the evaporator where the low-temperature refrigerant will evaporates into vapour and absorb heat during the evaporation process. The saturated vapour then leaves the evaporator and completes the cycle as the refrigerant flows back into the compressor.

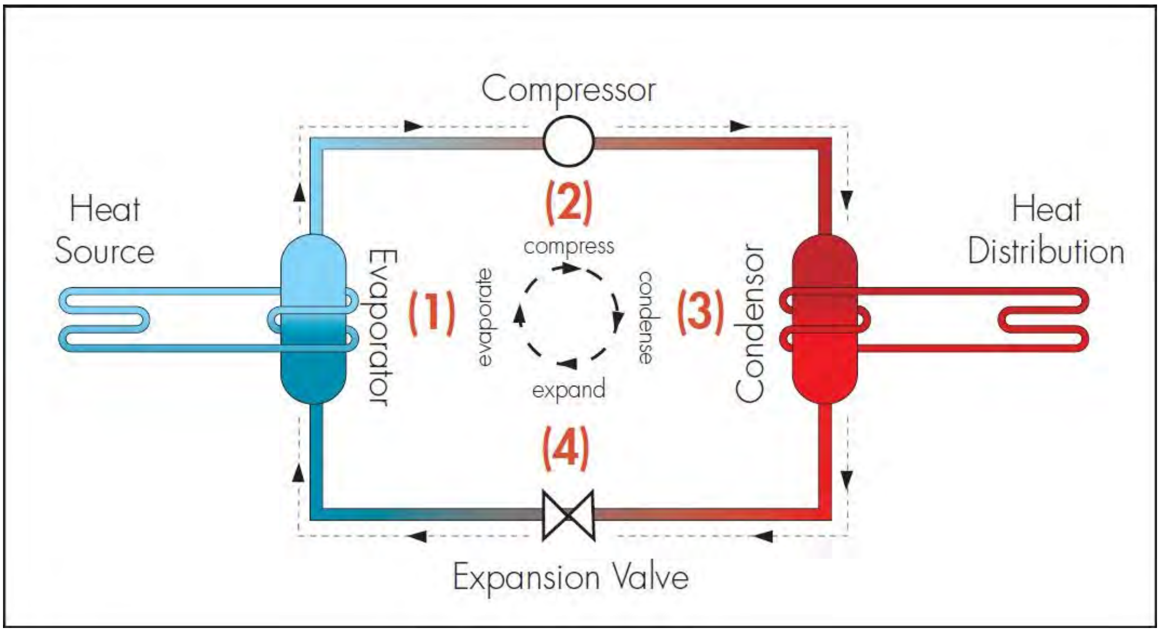

Figure 1.1: Vapour Compression Refrigeration System

(Source: CPD Module, 2008)

1.2 CONCEPT OF EXERGY ANALYSIS

In this project, the refrigeration system and the performance is investigated by applying exergy anaylisis. Exergy is the availability of energy where the system delivers the maximum possible work during its process into the environment equilibrium state. In equilibrium state, the useful potential work is zero (dead state). The first law of thermodynamics stated that energy cannot be destroyed or created and can only be transferred through medium by simply changing from one form into another which explain the conservation of energy principle. Meanwhile the second law of thermodynamics stated that there will always be an increase in the sum of entropies and the decrease in energy level whenever energy is transformed from one form to another form in a natural thermodynamics process. Based on the second law of thermodynamics, exergy analysis is a method in thermodynamics that enable for the refrigeration system to be evaluated and improved in term of its performance efficiency.

Using exergy analysis, the amount of exergy loss can be determined as the exergy loss shows the efficiency of the system. The lower the exergy loss, the higher the efficiency of the system. Exergy loss is the exergy being destroyed during the energy transfer in the thermodynamic process where the energy is actually being released or loss into the environment and therefore is useless towards the system. Exergy analysis is also related to the second law of efficiency in measuring the performance of the system. Engineering and industries practiced exergy analysis to optimize the usage of energy. The assessment in exergy analysis helps in boosting the system’s efficiency by shifting the actual performance nearing the ideal and identifies the thermodynamic losses of each point in the system. As a result, exergy analysis provides valuable information in optimizing the system and further improvement in advancing the system designs.

1.3 FORMULA OF EXERGY ANALYSIS

The exergy analysis includes several formulas to analyze the exergy loss of the system. The refrigeration load, rate of heat rejected and the power input of the system are calculated. Each component of the refrigeration system is also being calculated using specific formula for each of the component in the system. Formulas used are stated as below.

1.3.1 Formula Of Exergy Loss

1.3.1.1 General Formula For Exergy Loss

$$\dot{X}_{gen} = T_0 \dot{S}_{gen} \qquad [1]$$

1.3.1.2 Basic Formula For Refrigeration System

$$\dot{Q}_L = \dot{m}(h_1 - h_4) \qquad [2]$$

$$\dot{Q}_H = \dot{m}(h_2 - h_3) \qquad [3]$$

$$\dot{W}_{in} = \dot{m}(h_2 - h_1) \qquad [4]$$

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{in}} \qquad [5]$$

1.3.1.3 Formula For Exergy Loss For Each Component

$$\dot{X}_{Loss} = T_0 \dot{m}(s_2 - s_1) \quad [6]$$

$$\dot{X}_{Loss} = T_0 \dot{m}(s_4 - s_3) \quad [7]$$

$$\dot{X}_{Loss} = T_0 \left[\dot{m}(s_1 - s_4) - \frac{\dot{Q}_L}{T_L} \right] \quad [8]$$

$$\dot{X}_{Loss} = T_0 \left[\dot{m}(s_3 - s_2) + \frac{\dot{Q}_H}{T_H} \right] \quad [9]$$

The general formula of exergy destroyed is used in this exergy analysis as exergy destroyed indicated the amount of exergy loss in the system. For the refrigeration system, equation (1) represent the refrigeration load of the evaporator and equation (2) represent the heat rate being rejected from the condenser. Meanwhile the power input in the compressor is represented by equation (3) and equation (4) represented the coefficient of performance of the system. The refrigeration load will determine the evaporator performance in the system. For the exergy loss for compressor, expansion valve, evaporator and condenser will be determined using the exergy loss formulas of equation (5), (6), (7) and (8).

The mass flow rate is known as$\dot{m}$, in unit kg/s. As the flow rate of refrigerant R134-a is in L/hr is converted into kg/s. $\dot{Q}_L$ is the refrigeration load of the evaporator and $\dot{Q}_H$ is the heat rate rejected from the condenser, in unit kW. Enthalpy value is presented as h, in unit kJ/kg and the entropy value is presented as S, in unit kJ/kg .K . These values are obtain through temperature records for each point in the system and calculated by referring the refrigerant R134-a table.

1.4 PROBLEM STATEMENT

Since the refrigerant in the system flows has turbulence and uncertainty, it is difficult to know the exact flow rate of the refrigerant in the system. Inaccurate in determining the flow rate will divert the final result from the actual data. The refrigerant pressure at each point in the refrigeration system is hard to find due to limited number of pressure gauges.

The actual performance of components will always be lower than the ideal performance. Hence, the estimation (calculation) of the performance of condenser and compressor will be influenced by the data analysis due to uncertainty in determining the real efficiencies of these components.

1.5 OBJECTIVE

The objectives for this final year project are shown below:

1. To investigate exergy loss for each equipment in vapour compression refrigeration system.
2. To evaluate heat transfer performance in vapour compression refrigeration system.

1.6 SCOPES

For this final year project, the scopes are as shown below:

1. Evaluates all the parts in the vapour compression refrigeration system.
2. Main parts are evaporator, condenser, compressor and expansion valve.
3. To check the temperature and pressure for each parts using thermometer and pressure gauges.
4. Analyze the collected data to estimate the amount of exergy loss for each parts and assessing the second law efficiency through formulated calculation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

This project is focused in studying the performance of the vapour compression refrigeration system. The improvement of the system is also studied to boost the performance of the refrigeration system.

2.1.1 Vapour Compression Refrigeration System

As known before, vapour compression is one of a cyclic refrigeration system where refrigerants flows into four different processes in a cycle. Other types of refrigeration cycle are vapour adsorption cycle and gas cycle. Besides this type of refrigeration system, there are non-cyclic refrigeration, thermoelectric refrigeration and magnetic refrigeration. Non-cyclic refrigeration is a system using ice melting or subliming dry ice for its cooling process. Thermoelectric refrigeration uses the Peltier effect in creating heat flux between two types of different material (semiconductor) for its thermoelectric cooling. Magnetic refrigeration is a cooling technology through adiabatic demagnetizing based on magnetocaloric effect where a heat sink is created using strong magnetic field to develop a force in aligning various magnetic dipoles and position these degrees of freedom in the refrigerant into a lower state of entropy (cooling). Other methods of refrigeration are air cycle machine in aircraft, vortex tube in spot cooling and thermoacoustic refrigeration using sound wave in pressurized gas.

Focusing in vapour compression cycle, a study has been done in the performance characteristic of vapour compression refrigeration system under real transient conditions in the journal (Dabas et.al, 2011). The performance of a simple system, the vapour compression refrigeration cycle will deteriorates in actual conditions due to irreversibility thermodynamic process in the internal and external system, plus further due to transient conditions in evaporator and condenser. In the system, mainly the compressor will experiences internal irreversibility losses, where entropy increases due to friction. In the condenser and evaporator, these heat exchangers will have external irreversibility losses due to due to finite rate of heat exchange against finite value of temperature difference and heat capacities. By increasing the temperature difference between external fluid and refrigerant across evaporator and condenser, the heat transfer in evaporator and condenser will increase, plus the cooling capacity of system will be greater. This study on the characteristics of performance is done on the vapour compression refrigeration system when working under transient conditions. Differ from steady state conditions, the system working under transient conditions cannot be theoretically optimized due to continuous fall of temperature of external fluid over evaporator. The temperature differences continuously to decrease causing reduction of heat transfer over the evaporator tubes which will deteriorate the performance of the refrigeration system. When the differences temperature of refrigerant and external fluid over evaporator is too low for sustaining a reasonable amount of heat transfer and evaporation rate in evaporator, the cooling process of the system will stop. This includes investigating the behavior of the system due to the effect using various length difference of capillary tube in refrigeration system where the pressure of the evaporator and the condenser are determined by the length of the capillary tube. Which concludes that, a shorter capillary tube will produce higher COP but faster reaching the limiting condition while increasing the length of capillary tube delays the limiting condition but gives lesser COP. Refrigeration system must be designed and balanced in each components more accurately via simulation for optimization of its performance in real life transient conditions.