Using Exergy Analysis Methodology to Assess the Heating Efficiency of an Electric Heat Pump

Yongan Ao
Associate Professor
Shenyang Jianzhu University
Shenyang City. P.R. China
hj-aya@sjzu.edu.cn

Lin Duanmu
Associate Prof.
University of Technology.
Dalian City. P.R.China.
Duanmulin@sina.com

Shengqiang Shen
Prof.
Dalian University of
Technology. Dalian City.
P.R.China

Abstract: **T**he authors, using exergy analysis methodology, propose that it should consider not only the COP (coefficient of Performance) value of the electric power heat pump set (EPHPS/or HP set), but also the exergy loss at the heating exchanger of the HP set to assess the heating efficiency of the HP set and reduce the anergy at the heating exchanger of the HP set. Considering the quantity and quality transmission efficiency for the HP set, the authors defined three parameters to show the heating exergy loss and heating exergy efficiency for the HP set, presented an average heating temperature ranges for the heating exchanger with four different refrigerants, in which the HP set runs efficiently. Compared to the COP assessment standard, the authors attained a suitable average heating temperature range for the HP set more accurately. The authors concluded the following: 1) to assess the heating efficiency of a HP set or to define a better temperature range for the heating exchanger of a HP set, people should not only consider the COP value of the set, the characteristics of the refrigerants, but also the exergy loss and exergy efficiency at the heating exchanger; 2) it is not perfect to assess an HP set performance with only one parameter, COP, and 3) we would better improve the room structure and floor shape in order to heat the room well in a low temperature heating system.

Keywords: exergy analysis, exergy loss, COP, HP set, efficiency

1. INTRODUCTION

Because of energy want, all the countries in the world are studying and developing new kind of energy and the techniques of saving energy[1][2]. As the heat pump has the characteristic, high heating efficiency, its coefficient of performance (COP) is more than 1, the scientists and experts in the world are doing their best to improve its property to achieve a better HP set which can be widely used in summer and in winter as well[3][4].

Nowadays, the COP is the basic property that assesses the good or bad of the characteristic of a HP set. But the COP of the set can only show the variation direction of the set with a defined refrigerant under certain conditions[5][6], it can not give the optimum region of the work state for the set, the average heating temperature region for the heating exchanger, and the suitable room structure and floor shape for the building with the low temperature heating system[7]. Exergy analysis methodology, however, considers the quantity and quality equilibrium of the energy[8][9], so we can save the high quality enery in using the HP set in the future. The use and study of the exergy analysis methodology are extensive, especially in abroad,[10][11] the have extend to all kinds of study disciplines and engineering construction regions.

This paper analyzes the heating efficiency of a HP set with the exergy analysis methodology. The method assesses not only the using efficiency of energy quantity, but also the exergy loss of the heating exchanger and the optimum region of the work state at a certain evaporation temperature, and also how to improve the room structure and floor shape in order to heat the room well in a low temperature heating system.

2. EXERGY ANALYSIS METHODOLOGY AND SOME BASIC CONDITIONS

2.1 Exergy Analysis Methodology

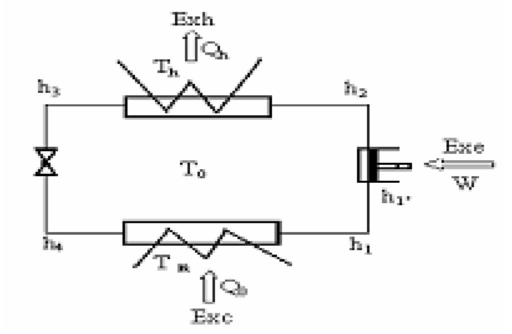

Fig.1 The schematic of the HP set

Exergy analysis includes three basic equilibrium equations, they are: mass equilibrium equation, energy conservation equation, and exergy equilibrium equation[9]. For a HP set (see Fig. 1), we get the following equations:

Energy conservation equation,

$$(h_1\text{-}h_4) + (h_2\text{-}h_{1'}) = (h_2\text{-}h_4)\ldots\ldots \quad (1)$$

The exergy equilibrium equation of the HP set system[9],

$$Exe + Exc = Exh + Exl \ldots\ldots\ldots\ldots \quad (2)$$

The heating exergy efficiency of the HP set system,

$$\eta_{ex1} = Exh/Exe \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The heating exergy loss rate in the HP heating system

$$\eta_{ex2} = Exl'/(Exe + Exc)\ldots\ldots \quad (4)$$

The average temperature of the heating exchanger is Th(variable) and the indoor air temperature is remained at 18ºC, the room's exergy efficiency,

$$\eta_{ex3} = Ex_{18}/Exh \quad \ldots\ldots \quad (5)$$

where, $h_{1'}$, h_2, h_4, h_1, h_3, the enthalpy of the inlet and outlet of the compressor, the enthalpy of the inlet and outlet of the evaporator, and the enthalpy of the outlet of the condenser, separately, the unit, kJ/kg; *Exe*, *Exc*, *Exh*, the exergy of the compressor, evaporator, condenser (or heating exchanger), separately, the unit, kw; *Exl* and *Exl'*, the exergy loss of the HP set and the exergy loss of the heating exchanger, the unit, kw; η_{ex1}, η_{ex2}, η_{ex3}, the heating exergy efficiency of the HP set, the exergy loss rate of the heating system, and the room exergy efficiency when the indoor air temperature is 18ºC and the average temperature of the heating exchanger is *Th*, separately; Ex_{18} is the room exergy when the indoor air temperature keeps at the temperature 18ºC.

2.2 The Basic Conditions

The temperature at the equilibrium steady state of the exergy in the paper is 0℃. The evaporation temperature keeps at 5℃ and the average temperature of the lower heat source surface (or the surface of the evaporator) is 10ºC.

3. RESULTS AND ANALYSIS

3.1 The Optimum Range of the Heating Temperature

Choose four kinds of refrigerants (the R600, R21, R113, R22) and calculate the heating exergy efficiency of the HP set (η_{ex1}), the exergy loss rate of the heating system (η_{ex2}), and the room exergy efficiency (η_{ex3}) under the conditions of the same evaporation temperature and same average temperature of the lower heat source with the variation average temperature of the heating exchanger (*Th*). Fig.2 is the values of η_{ex1}, η_{ex2}, η_{ex3} for R600, Fig.3 for R21, Fig.4 for R113, and Fig.5 for R22.

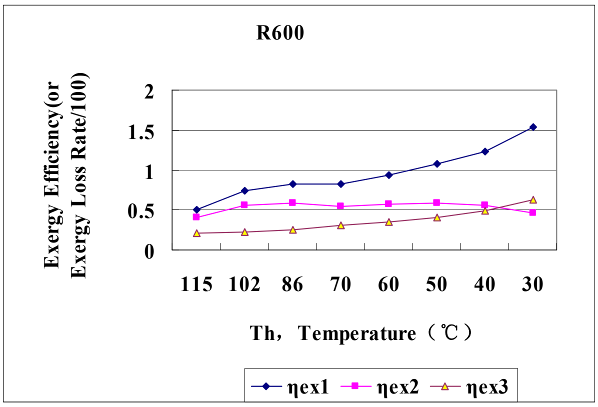

Fig.2. The η_{ex1}, η_{ex2}, η_{ex3} for R600

From Fig.2 to Fig.5, we can find that when the average heating temperature decreases, the η_{ex1} (the heating exergy efficiency of the HP set) increases sharply, the trend of the η_{ex2} (the exergy loss rate of the heating system) drops, and the η_{ex3} (the room exergy efficiency) increases gradually. And all the curve lines of η_{ex2}, η_{ex3} for each refrigerant have intersection points when the average heating temperature *Th* is around at the temperature of 40ºC. If lower the temperature *Th* further, the heating exergy loss of the HP set drops quickly, and the room exergy efficiency rises highly. We call the intersection point the highest average heating temperature. The highest point indicates that when the evaporation temperature is constant, only if the average heating temperature *Th* is lower than the point, transmitting the same amount of the heat, the HP set reduces the waste of high quality energy, and the work state or the *Th* range at this condition is called the optimum heating temperature range.

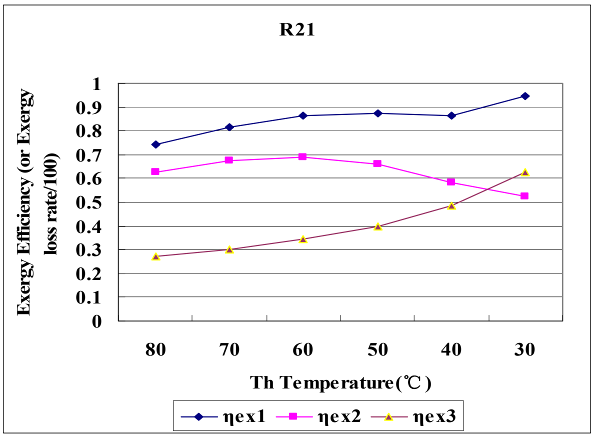

Fig.3 The η_{ex1}, η_{ex2}, η_{ex3} for R21

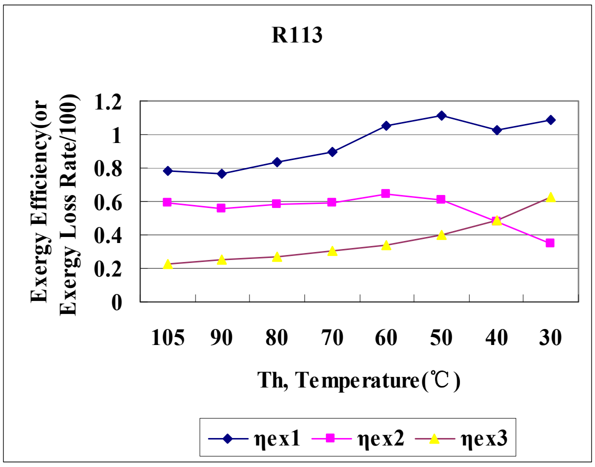

Fig.4 The η_{ex1}, η_{ex2}, η_{ex3} for R113

The intersection point of each kind of refrigerant is also the function of the given evaporation temperature and the assumed standard equilibrium state of the exergy. If the assumptions are different, the intersection point varies with the conditions.

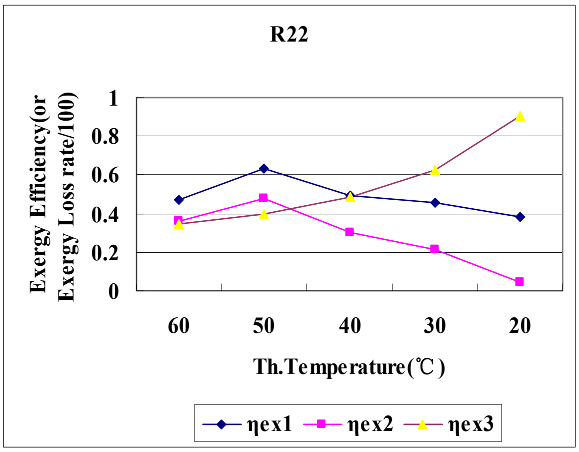

Fig.5 The η_{ex1}, η_{ex2}, η_{ex3} for R22

Comparing the figures from the Fig.2 to the Fig.5, the η_{ex1} of the R600 is the greatest among the four. That is to say when the *Th* is the same the heating exergy efficiency of the HP set with R600 is the highest. Then we can choose R600 as the refrigerant under these certain conditions.

From foregoing discussion we got that the η_{ex1}, η_{ex2}, η_{ex3} three curve lines have the relationship to the properties of the refrigerant, the average heating temperature, the assumed lower source average temperature, and the evaporation temperature. Therefore exergy analysis methodology is a good method considering many synthesis factors and elements to save not only the amount of the energy but also the quality of the energy and present an accurately defined *Th* region in which the HP set runs effectively.

3.2 COPs of The Four Refrigerants

Fig.6 shows the COPs of the four kinds of refrigerants at the constant evaporation temperature and varied condensation temperature. Each curve shows high COP value for the same conditions and the same variation trend as the η_{ex1} curve. Although the COP curve of R600 has the highest COP value when the *Th* drops to less than 50ºC, it could not indicate the optimum temperature region in which the heating efficiency of the running HP set is high, and we could not get the optimum region of condensation temperature for the HP set also.

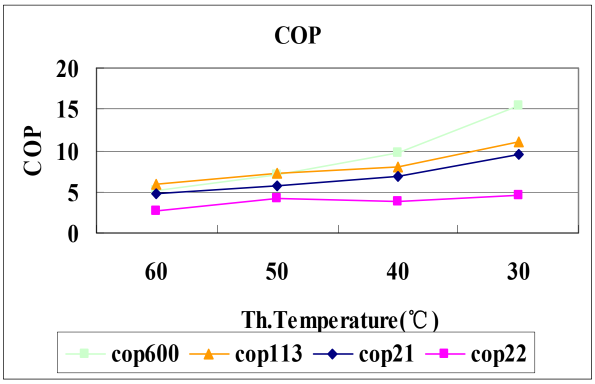

Fig.6 COPs for four refrigerants

3.3 The Relationship Between The Heating Exergy Loss And The *Th*

From the Fig.7, we find that when the indoor air temperature is constant the heating exergy loss for the heating exchanger rises higher gradually with the *Th* dropping lower. So lowering the average heating temperature *Th* of the heating exchanger, we can save some high quality useful energy in heating system of the HP set.

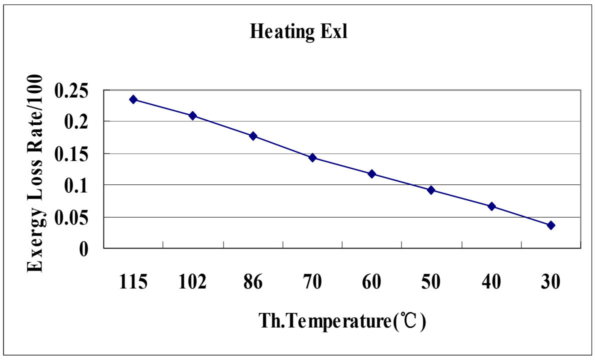

Fig.7 The heating exergy loss and the *Th*

3.4 Room Structure Change

According to the foregoing discussion, we should use lower heating temperature in the heating system of the HP set in order to save more amount of energy in quantity and quality. Hence, most heating experts currently advocate the low temperature heating style to ease the tension the energy source. But some questions along with the style we should consider, such as changing the room structure to meet the need of supplying same amount of heat (as before) in a given room. For example, to keep the indoor air temperature at 18ºC in the given room in which the heating transfer coefficient (*K*) is known and constant, we need to increase the surface area (*A*) of the heat exchanger according to the equation of the heat (*Qh*) ($Qh=K{\cdot}A{\bullet}\Delta t$, where Δt is the difference between the indoor air temperature and the surface average temperature of the heating exchanger). And because most heat transfer processes in the low temperature heating style are natural convection and in the turbulent region, in which the heat convection coefficient in the horizontal plane with the heated surface on the top is greater than the plane placed in the vertical, that means the heating effectiveness of the heating exchanger placed in the horizontal than in the vertical in low temperature heating system. So we would better put the temperature heating exchanger (or cooling) on the floor (or the ceiling) in construction.

If we keep the room volume constant and place the heating pipe on the floor, we should increase the floor area in order to satisfy the requirement of needing large area for low temperature heating system and then reduce the room height. And then if the floor area keeps constant, for saving construction materials such as heating pipe, we suggest design the floor square shape.

4. CONCLUSION

(1) To check the heating efficiency of a running HP set, determine the regions for condensation temperature and for heating average surface temperature of the heating exchanger in certain conditions, we should consider COP value of the HP set, the characteristics of the refrigerant, and the heating exergy loss and the heat exergy efficiency in the HP set.

(2) With exergy analysis methodology that integrates more factors and elements affected the HP set heating efficiency, we present three curve lines of η_{ex1}, η_{ex2}, η_{ex3} that make people possible to assess the heating efficiency of a HP set and choose the suitable working state of a HP set easily.

(3) Using COP as only one standard to assess the effectiveness and performance of a HP set has disadvantage

(4) Determining the average heating temperature

point affects indirectly the height of the room, the floor shape, and the room structure. And we suggest lower the height of a room and make the floor shape square when the floor area keeps constant.

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