Isı Bilimi ve Tekniği Dergisi, 32, 1, 117-127, 2012
J. of Thermal Science and Technology
©2012 TIBTD Printed in Turkey
ISSN 1300-3615

AN EXPERIMENTAL ANALYSIS OF AIR SOURCE HEAT PUMP WATER HEATER

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(Geliş Tarihi: 04. 08. 2010, Kabul Tarihi: 01. 02. 2011)

Abstract : Heating and cooling are one of the fundamental research area for the engineers. Due to increment of the energy demand and decrement on the sources leads the researchers to develop the recent systems and find out new systems. In the study, performance of a commercial heat pump water heater is studied. The performance of system under various conditions is analyzed with a program prepared in MATLAB 7.3 software by using exergy analysis method. The exergy destruction of the system is calculated by using collected data for each component of the system as well as considering the whole states of entire system. The analyses represents effective conditions and components on the destruction of the performance. It is found that performance of system decreases for low temperature and high humidity ambient conditions.
Keywords: Air source heat pump, Exergy analysis, Experimental analysis, Exergy destruction.

HAVA KAYNAKLI ISI POMPASI SU ISITICISININ DENEYSEL ANALIZI

Özet : Isıtma ve soğutma mühendisler için önemli araştırma alanlarından birisidir. Enerji talebindeki artış ve kaynaklardaki azalma araştırmacıları mevcut sistemlerin geliştirilmesi ve yeni sistemlerin bulunması hususlarında yönlendirmektedir. Bu çalısmada ise, ticari bir ısı pompası su ısıtıcısı çalışılmıştır. Sistemin performansı çesitli ortam koşulları için MATLAB 7.3 yazılımda hazırlanan bir kod ile gerçekleştirilmiştir. Sistemden toplanan sıcaklık ve basınç verilerine kullanılarak sistemin bütünü ve tüm komponentlerinin ayrı ayrı ekserji yıkımı değerleri hesaplanmıştır. Analiz sonuçları sistemin performansı üzerinde etkin koşulları belirtmiştir. Analiz sonuçları, düşük sıcaklık ve yüksek nem çevre koşulları altında sistem performansının azaldığını göstermiştir.
Anahtar kelimeler: Hava kaynaklı ısı pompası, Ekserji analizi, Deneysel analiz, Ekserji yıkımı.

NOMENCLATURE

$\dot{E}_{xd}$	Exergy destruction (kW)
h	specific entahalpy (kj/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat transfer rate(kW)
s	specific entropy(kj/kg.K)
$\dot{W}$	power (kW)

Subscripts

i	inlet
o	outlet

INTRODUCTION

Heating and cooling are the fundamental processes in engineering science. Numerous methods have been searched and applied for the problems which appeared in application. Developing the most effective system is the common purpose for all researches in engineering sciences.

The researches on improvement of the systems are expanded by considering alternative energy sources which is triggered due to diminish in recent energy sources. Air source heat pump water heaters are one of these systems that based on usage of energy in air. Heat pumps that have wide spread usage through out the world and specifically Europe according the laws supporting the substitution with present systems. Usage of Heat pump systems is increased at around 13 % in the last two decades which is rising as an important alternative of heating systems (Brisa, 2009). Hazardous effects of coolant used in system and inefficient usage under poor weather conditions are important deficiencies of heat pumps.

The analysis of the heat pumps has vital importance for the improvement of present systems as well as developing the innovative systems. There have been numerous heat pump performance analyses in literature which are performed from first and second laws of thermodynamics aspects. The researchers who have investigated the performance of systems from energy analysis point of view revealed the results for various refrigerators or heat pumps such as; absorption heat pumps, pulse tube refrigerators, cryocoolers under different conditions. In these studies (Choi et al.2007; Dincer 2003; Feng et al. 2008; Han et al. 2007; Tu et al., 2006; Yao et al. 2004; zhianqiang et al. 2008) the systems are investigated according to different climate conditions, with different coolants, with different components or improved components clear out all of these effects on the performance of system. On the other side some researchers investigated the performance of the system from exergy point of view. Exergy is defined as maximum amount of work which can be produced by the system. Heat pumps, absorption heat pumps, air conditioning systems, ground source heat pumps are investigated with this aspect either numerically or experimentally by several researchers(Alexis 2005; Bonnet et al. 2005; Ceylan 2007; Chen et al. 1998; Chengqin et al. 2002; Esen et al. 2007a; Esen et al. 2007b; Hepbaşlı and Akdemir 2004; Hussain et al. 2004; Lior and Zhuang 2007; Razani et al. 2007; Nikolaidis and Probert 1998; Yang et al. 2005; Yumrutaş et al. 2002; Vidala et al. 2004; Xia et al. 2006)

The researchers analyzed systems by considering exergy method, investigated exergy (availability) of systems for a certain state of process which is typically set as final stage of process and availability of system is investigated for all components by considering the final stage. Although this point of view gives an idea about performance of the components individually by considering final stage of the system which represents the maximum achievable level, it doesn't give an idea about the performance variation during the whole process. Additionally, studies in literature don't contain the experimental studies based on component features under different climates furthermore the exergy destruction rates of individual components during the charging time aren't included in the same studies. Therefore, the performance of either the whole heat pump water heater system or each component is investigated individually from the exergy destruction point of view. The system performance is evaluated under different climates which are obtained with the change of temperature and humidity values to simulate the actual weather conditions that the system is used. The performance of the system is investigated by collecting the values of temperature and pressure from inlet and exit of all each component during charging time. Furthermore the collected values are used for the calculation of exergy destruction of component and entire system by a program prepared by MATLAB 7.3. Analytical studies are performed with the assumption of steady-state steady-flow regime where as experimental studies followed the charging time and data were collected during the transient heating process of water in the tank. By considering the charging time, the component base performance analysis
for an air source heat pump has been a successful contribution to the literature about heating cooling systems.

SYSTEM DESCRIPTION

The performance of the heat pump is investigated for different climates which are simulated by climatic chamber by considering the actual climates that the system is used in. The variation of climate is performed by considering north Europe climate which comprises the biggest amount of heat pump system market. The temperature and humidity combinations that had chosen for experiments are assumed as the representative of annual climatic variations of mentioned region. The decided conditions are simulated with climatic chamber shown in Fig. 1.
5 °C,10 °C, 20 °C, 30 °C ambient temperatures are chosen according to the product catalogue and defined climates. Corresponding humidity values are chosen as % 70 -80- 90 which represent the high humid climates and % 40 humid represents the poor humid conditions by considering the limit %65 humid between poor and high weather conditions (Guo et al. 2008).

Figure 1. Climatic chamber used for simulation of ambient conditions.

Heat Pump Used In Experiments

The air source heat pump water heater used in the experiments is a product of a heater and cooler brand which exports all this type of products to Europe. Heat source of the system is air for the water; during the process heat is absorbed at evaporator from air and released at condenser to water. Technical properties of the system are given in Table 1 and the circuit diagram is given in Fig. 1.

Table 1. Technical Properties of Heat Pump Water Heater

Refrigerant:	R 134a
Storage capacity:	300 liter
Max. Water temp.:	55 °C
Compressor:	Danfoss SC15GHH
Power Source:	220V/50Hz
Process range:	5 – 32 °C ambient temperature

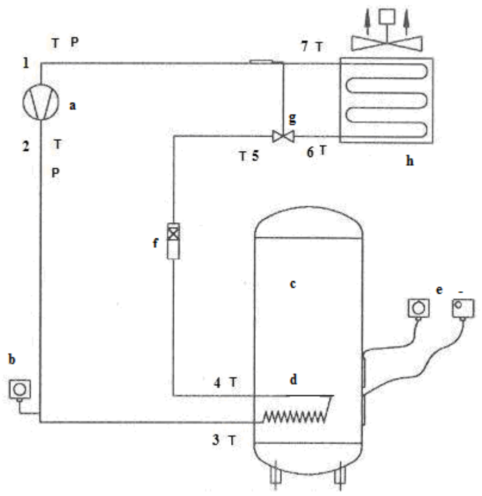

Figure 2. Circuit diagram of Heat Pump System: a-compressor b-high pressure pressostat c-storage tank d condenser e-thermostat f-drier filter e-expansion valve h-evaporator.

During the process of water heating; the refrigerants' temperature and pressure increase in the compression process at the compressor, release the heat at the condenser and the temperature and pressure of it decrease at this stage, in the following step expanded and temperature and pressure reaches to the desired low values of refrigerant which absorbs heat from ambient air at the evaporation process at the evaporator.

Experimental Set Up

For the evaluation of the systems' performance under defined criteria's, temperature and pressure data are collected from inlet and outlet of each component which are also investigated individually. Temperatures at each component's inlet and outlet are measured by thermocouples, pressures are measured just at inlet and outlet of compressor by transmitters and all these measured values are collected by data collector. The points that the data are collected are figured out in Fig. 2 on scheme where T is representing the temperature and P is representing pressure. In Table 2 the used equipments are listed.

Table 2. The equipments used in the experiments.

Pressure transmitter:	Midas, P 0-40 bar, amp. 4 -20 mA,
Thermocouple:	Elimko, K-type, 05 T2K,
transducer:	For transmitter cycle
Flowmeter:	Krohne Enelsan, 10 bar, 0-20 g/s
Data Collector:	Daqpro 5300, 8 channel,
Climatic Chamber:	Angelotti- OP7

The measurements that have been performed by these equipments are listed below:

1) Mass flow rate of the refrigerant is measured by flowmeter
2) The temperatures at the inlet and outlet of components are measured by thermocouples.
3) Pressure at the inlet and outlet of the compressor is measured by transmitter
4) The total and instant power consumption is measured by power suppliers which has the capability about measuring these values.
5) The instant values of temperature and pressure are collected by data collectors.

Sample size

The accuracy of the data is also as important as the collected data from the experiments. In literature the several methods has offered and used by numerous researchers such as sample size and uncertainty analysis. Sample size is a statistical approach for the decision of the accurate experimental repetition value which represented by equation 1.

$$n = \frac{z^2 \sigma^2}{d^2} \tag{1}$$

Where

z: 1.96 that is obtained due to the confidence level at 95% which is also the most preferred confidence level in the literature

σ: 3, standard deviation is obtained due to the preliminary studies of the system

d: margin of error at 5% is assumed due to the expectations

According to mentioned equation the sample size is defined as 4 which represents the minimum repetition of the experiments

Uncertainty Analysis

The accuracy of the measured data is as important as the obtained results from experiments. Uncertainty is the measure that is used for the representation of the accuracy of these data. The reasonable uncertainty values can be estimated by considering environmental effects on the measurement. The accuracy of the experimental apparatus can be affected from the failure of the measurement devices which can be prevented with the uncertainty analysis of the system. The uncertainty analysis method of Kleine & McClintock (Coleman&Steele, 1999) which is one of the widely used analysis model, depends on the error rates of the measured parameters which is given below

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right] \tag{2}$$

Where R is the result of a given function in terms of the independent variables and w_R is the uncertainty in the result and w_1, w_2, .., w_n be the uncertainties in the independent variables. The total uncertainties of the measurements are estimated to be 2.2% for the temperatures of water in the storage and refrigerant used by the system, 2.45 % for pressures, 3.0 % for power inputs to the compressor & condenser fan. Uncertainty in reading values of the table is assumed to be 0.2 %.

By considering both sample size and uncertainty analysis the collected data is used by the prepared code for the simulation of the system.

THEORETICAL ANALYSIS

Performance of the air source heat pump system is studied with respect to coefficient of performance and exergy analysis due to the data obtained from experimental analysis of the system. The evaluation of the performance is performed by a program prepared by MATLAB 7.3 software.

During the performance analysis following assumptions have been made;

- System is steady state steady flow
- Kinetic and potential effects are negligible
- The directions of heat transfer to the system and work transfer from the system are positive
- Heat transfer and refrigerant pressure drops in tubing between the components are ignored.
- Air is an ideal gas with constant specific heat
- Power consumption of the fan is neglected when compared with the power consumption of compressor.
- Dead states are the environmental condition under consideration.
- Heat loss through the isolated storage surface is neglected.

Conservation Equations Applied To The System

Conservation of mass

Conservation equation of the mass in each system component is given as

$$\sum \dot{m}_i = \sum \dot{m}_o \tag{3}$$

where $\dot{m}$ is the mass flow rate, and subscripts 'i' represents inlet and 'o' represents outlet.

Conservation of energy

Energy conservation equation is derived according to first law of thermodynamics, in which the net energy transfer is written by considering balance of the net heat, work and mass transfer in and out. The general energy balance equation can be written according to this definition as below;

$$E_i = E_o$$

That can be rewritten by considering the heat work and mass,

$$\dot{Q}_{cv} + \dot{m}_i\left(h_i + \frac{1}{2}V_i^{\,2} + gZ_i\right) = \dot{m}_o\left(h_o + \frac{1}{2}V_o^{\,2} + gZ_o\right) + \dot{W}_{cv} \tag{4}$$

where $\dot{Q}$ is the heat rate, $\dot{W}$ is the power, $\dot{m}$ mass flow rate, h is entalpy, V is speed, g is gravity, Z is height

Second law analysis

The entropy change in a steady state steady flow process is the sum of the entropy generation from the irreversibility's within system boundary, the net entropy transfer through the control volume by heat transfer and entropy change by mass flow across the boundaries.

$$\dot{S}_{gen} = \dot{m}_o s_o - \dot{m}_i s_i - \frac{\dot{Q}_{cv,k}}{T_k} \tag{5}$$

Exergy balance equation

The exergy balance under steady state conditions is expressed generally with the equality of net exergy transfer by heat, work through the control volume boundaries, mass flow and exergy destruction through the boundaries

$$\sum\left(1 - \frac{T_0}{T}\right)\dot{Q}_{cv,k} - \dot{W}_{cv} + \sum \dot{m}_{in}\,\psi_{in} - \sum \dot{m}_{out}\,\psi_{out} = \dot{E}x_d \tag{6}$$

where

$$\psi = (h - h_0) - T_0(s - s_0)$$

Exergy analysis of the system

The energy, mass conservation and exergy balance equations for each component are represented individually in the following part with respect to given equations previously,

For compressor

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_{ref} \tag{7}$$

$$\dot{W}_{comp} = \dot{m}_{ref}\,(h_{2act} - h_1) \tag{8}$$

$$\dot{E}x_{d,comp} = \dot{m}_{ref}\,(\psi_1 - \psi_{2act}) + \dot{W}_{comp} \tag{9}$$

For condenser

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_{ref} \tag{10}$$

$$\dot{Q}_{cond} = \dot{m}_{ref}\,(h_{3act} - h_4) \tag{11}$$

$$Q_{cond} = Q_{water} = \dot{m}_w\,C_{p,w}(T_f - T_i) \tag{12}$$

$$\dot{E}x_{d,cond} = \dot{m}_{ref}\,(\psi_{3act} - \psi_4) - \dot{Q}_w(1 - \frac{T_0}{T_w}) \tag{13}$$

For expansion valve

$$\dot{m}_5 = \dot{m}_6 = \dot{m}_{ref} \tag{14}$$

$$h_5 = h_6 \tag{15}$$

$$\dot{E}x_{d,cond} = \dot{m}_{ref}(\psi_5 - \psi_6) \tag{16}$$

For evaporator

$$\dot{m}_6 = \dot{m}_7 = \dot{m}_{ref} \qquad \dot{m}_8 = \dot{m}_9 = \dot{m}_{air} \tag{17}$$

$$\dot{Q}_{evap} = \dot{m}_{ref}(h_7 - h_6) \tag{18}$$

$$\dot{Q}_{evap} = \dot{Q}_{fan} = \dot{m}_{air} C_{p,air}(T_8 - T_9) \tag{19}$$

$$\dot{E}x_{d,evap} = \dot{m}_{ref}(\psi_6 - \psi_7) + \dot{m}_{air}(\psi_8 - \psi_9) \tag{20}$$

The exergy destruction of each component and the whole system is obtained by the values collected from the tests by a program prepared in MATLAB 7.3 software. The flow chart of the program is given in appendix A.

The exergy analysis of the system is developed by depending on exergy destruction aspect. From this point of view performance of either components or whole system is investigated during the entire charging period which is characterized according to collected values during whole process. By this way, the variation of exergy destruction of the system can be reported for entire states of the refrigerant instead of last state which leads to understand behavior of all components individually during charging time which is defined as the total period that is required for heating entire water inside the storage from 15°C to 55°C. Charging period depends on the ambient conditions which can be satisfied in shorter or longer periods as 5 hours or 13 hours that are corresponding to warm environment (30°C) or cold environment (5°C).

RESULTS AND DISCUSSION

In the study the performance analyses of the air source heat pump water heater is analyzed. System performance evaluation has been performed by considering the north Europe climate in which the system has a wide spread usage. Temperatures as 5°C, 10°C, 20°C, 30°C and humidity's % 40, %70 and %80 are chosen for the simulation of actual ambient conditions.

During the tests, temperature and pressure values at inlet and exit of the components are measured and collected with help of data collector. The exergy analysis of system is performed by a program which is prepared by MATLAB 7.3 software and results are summarized either for each component or for the whole system.

The performance of the system is evaluated according to the decided ambient conditions by considering the charging time which is defined as the total period that is required for heating entire water inside the storage from 15°C to 55°C. Charging period depends on the ambient conditions which can be satisfied in shorter or longer periods as 5 hours or 13 hours that are corresponding to warm environment (30°C) or cold environment (5°C). The performance of the system is defined as the ratio of total amount of heat transfer from air to the water and to the total power consumption for this process which is a common definition for performance evaluation of refrigeration systems and given in equation 20. In figure 3, the performance of the system gets its lowest value at the poor weather conditions and the highest value observed at the highest ambient temperatures as expected due to the nature of the air source system. Additionally, it is clearly seen from the figure that, the high humidity directly affects the performance of the system at low ambient temperatures which is causing frost on evaporator that prevents heat transfer through it.

$$COP = \frac{\dot{Q}}{\dot{W}} \tag{20}$$

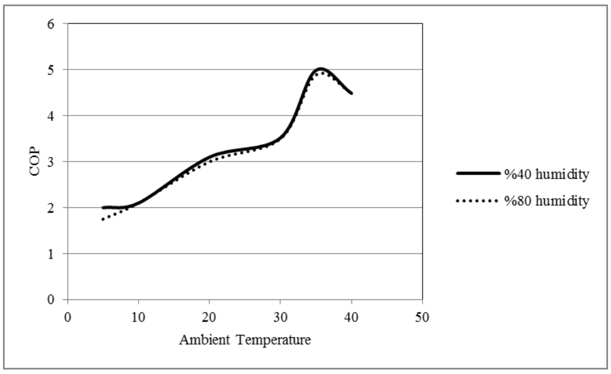

Figure 3. Variation of system performance with respect to the ambient temperature.

Charging time which represents the heat requirement of the system for the water in the storage is changing according to the ambient conditions. Charging time is becoming shorter for the high environmental temperatures on the other hand it is getting longer for the poor conditions which are also summarized in the Tables 3-4. As seen from the tables longest charging time is obtained for lowest ambient temperature and the shortest period is obtained for the warmest ambient condition, additionally it can be noted that, performance of the system is directly proportional with the charging time which corresponds to the power consumption of the system. The highest performance observed for the lower charging times which correspond to less power consumption for heating the same amount of water in the storage. Besides these, it is also seen from the tables that, the charging time is also affected from the humidity ratio; for the highest humidity values the systems' performance getting worse due to frozen conditions occurring at evaporator of system.

The exergy of the system and each component is represented from the exergy destruction point of view according to collected temperature and pressure data by using the prepared program.

Table 3. Charging time for the high humid conditions (80 %)

Temperature(℃)	*Charging time (hour)*
5	13.5
10	11
20	7.5
30	5

Table 4. Charging time for the low humid conditions (40%)

Temperature (℃)	*Charging time (hour)*
5	12
10	11
20	7.5
30	5

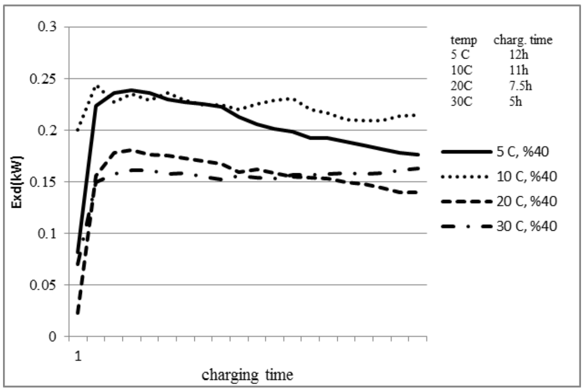

Figure 4. Exergy destruction of compressor for the 40% humidity conditions at different temperatures.

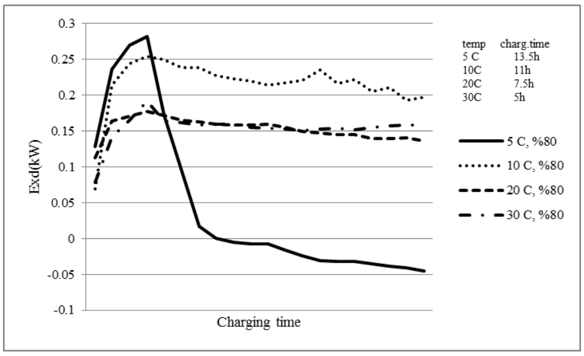

Figure 5. Exergy destruction of compressor for the 80% humidity conditions at different temperatures.

In the figures, the variation of systems' exergy destruction is given according to various ambient temperatures which are representing different climates during charging time for either each component or entire system. Various charging times corresponding to different climates noted out in a chart in each figure to remind the difference between each process.

The Figures 4-7 represents the exergy destruction at condenser and compressor for humid climate (%80) and dry climate (%40) for four different ambient temperatures (5°C, 10°C, 20°C, 30°C). The destruction values are decreasing during charging times which get its highest value at the beginning of the process at the compressor where the destruction decreases at the remaining part of the process. On the other hand the

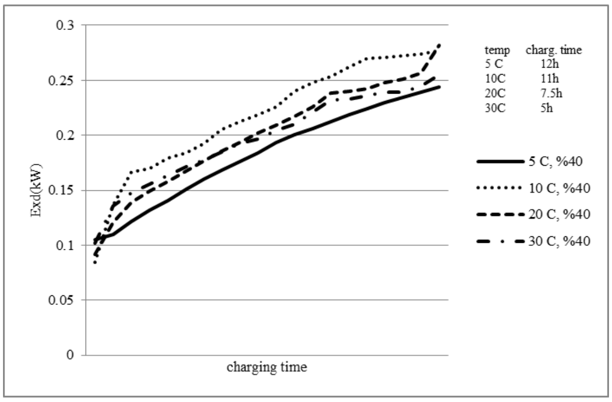

Figure 6. Exergy destruction of condensor for the 40% humidity conditions at different temperatures.

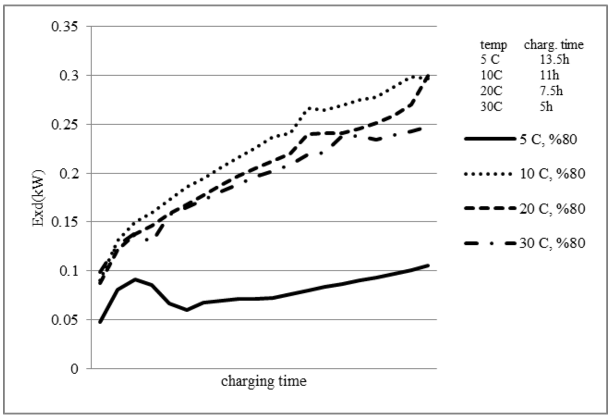

Figure 7. Exergy destruction of condensor for the 80% humidity conditions at different temperatures.

destruction values at condenser increases during the charging time due to the increasing temperature difference between coolant and water. As seen from the figures the lowest values for the destruction is obtained for the poor climates in both components since frozen has began at the evaporator and heat transfer from the heat sources has diminished at the low air temperature and high humidity (5°C - %80).

The various charging times are needed to be reminded as a cautionary note to figure out the exact exergy destruction for each climate which has closer values per unit time. Although the destruction values per unit time in either case is obtained so closer to each other the highest total exergy destruction of the system is obtained for the poor weather condition due to the highest charging time of that condition in both conditions. It is also noted that, due to the temperature and pressure values collected at frost conditions the prepared program is insufficient to calculate the accurate values of exergy destruction but it can give an idea about that conditions

The Figures 8-11 represents the exergy destruction at evaporator and expansion valve for different climates which are obtained with the change of temperature (5°C, 10°C, 20°C, 30°C) and humidity (% 40, %80). As seen from the figures, the exergy destruction values are

Table 5. Total exergy destruction at compressor and condenser during charging time.

	Total exergy destruction compressor (kW)		**Total exergy destruction condenser(kW)**	
Temp./humi.	40%	80%	40%	80%
30	0.75	0.74	0.875	0.75
20	1.125	1.12	1.3125	1.425
10	2.2	2.475	1.925	2.09
5	2.58	N/A	2.1	1.05

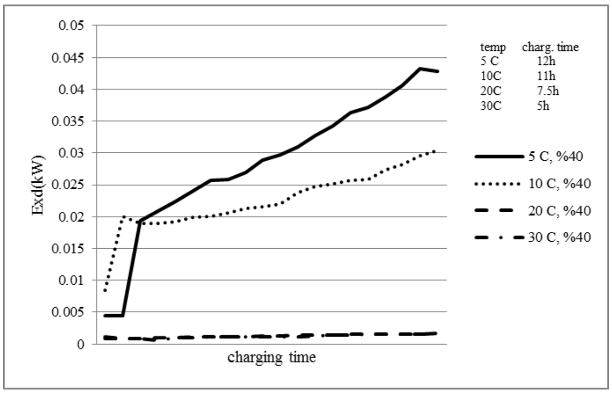

Figure 8. Exergy destruction of expansion valve for the 40% humidity conditions at different temperatures.

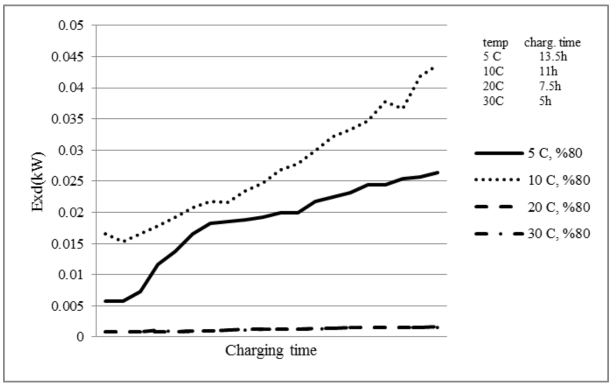

Figure 9. Exergy destruction of expansion valve for the 80% humidity conditions at different temperatures.

decreasing during the charging time in all ambient conditions due to the decrement of temperature differencebetween refrigerant and air. The highest exergy destruction value is obtained for the lowest ambient conditions among various environments as 0.16 kW. While the variation of exergy destruction is segregated from each other in poor humid condition, it is hard to segregate them in high humid condition due to the variation of exergy destruction at 5 °C because of the deposited frost on that device that prevents heat transfer through it. On the other hand the exergy destruction through the expansion valve is also summarized with figures (Fig 8-9) at which it is seen that the destruction at that component is very small when compared with the other components. The highest value is obtained for the lower temperatures of the ambient and the exergy destruction per unit time at the highest values are closer to each other during the charging time. Besides this, as in the compressor and condenser process, it is necessary to point out the charging time variation for each ambient condition to clear out the exact exergy destruction values for each condition which are given in table 1 and 2. The total exergy destruction of expansion valve and evaporator is summarized in table 6. As in the previous table, it is seen that the highest total exergy destruction is obtained at poor weather conditions where the charging time is longer while the total exergy is lower in good whether conditions even they have higher exergy destruction rates per unit time. It is clearly given for both components in Table 6.

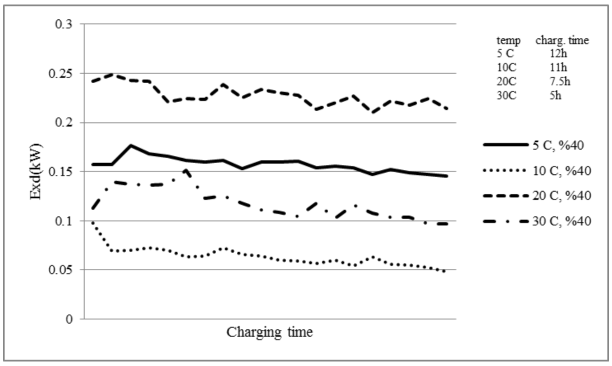

Figure 10. Exergy destruction of evaporator for the 40% humidity conditions at different temperatures.

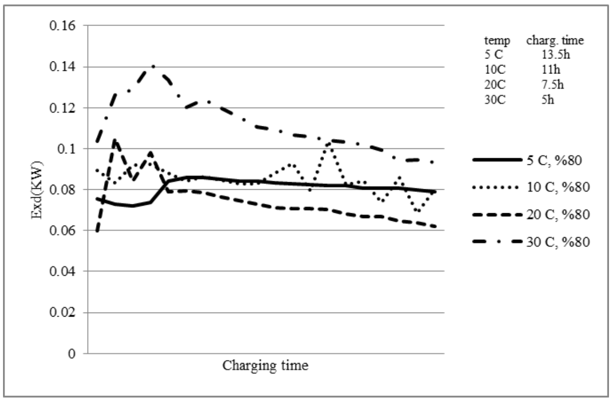

Figure 11. Exergy destruction of evaporator for the 80 % humidity conditions.

Table 6. Total exergy destruction at expansion valve and evaporator during charging time

	Total exergy destruction exp. Valve (kW)		**Total exergy destruction evaporator(kW)**	
Temp./humi.	40%	80%	40%	80%
30	0.062	0.065	0.575	0.55
20	0.092	0.096	0.62	0.6
10	0.22	0.302	1.65	0.88
5	0.33	0.135	1.92	1.08

The total exergy destruction is given in the figures 12 and 13 for different ambient conditions which are obtained with the change of temperature (5°C, 10°C, 20°C, 30°C) and humidity (% 40, %80). As seen from the figures lowest exergy destruction value is seen at the highest ambient temperature as 0.4 kW and highest exergy destruction value is obtained for the poor ambient conditions at around 0.6 kW. Besides it is also seen that the exergy destruction values are closer to each

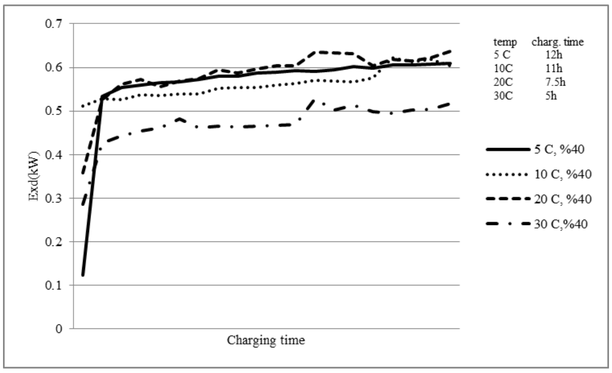

Figure 12. Exergy destruction of entire system for the 40 % humidity conditions at different temperatures.

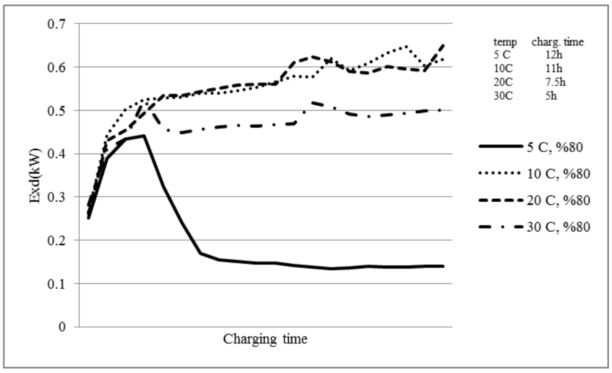

Figure 13. Exergy destruction of entire system for the 80 % humidity conditions at different temperatures.

other during the charging time which is changing in the range of 0.5 kW - 0.65kW. But like for the other figures it is necessary to remind charging time difference which is given in table 1 and 2 to provide to figure out the exact the destruction for each condition. It is also seen from the Figure 13, the deposited frost on evaporator has a serious effect on the performance of the system which is appeared as a dramatic decrement on the destruction value which represents the isolation on the evaporator and proves the system is not processing as expected.

Besides Figure 12-13, the total exergy destruction of the system can be represented by considering the entire destruction of the whole system, through the heating process which are also summarized in the Tables 5-6 for each component individually. Additionally the particular heat requirement of the system for heating the water from 15°C to 55°C is 12.17 kW which is common for each variant ambient condition. Figure 14 (a-d) is summarizing the relation between inlet and outlet energy of the system which are the combination of heat transfer from the air – work done on the system and total exergy destruction of the system – heat released to the water, respectively. The balance for each ambient condition is shown individually on the schemes.

The energy balance of the system is represented in Fig. 14 by considering the exergy destruction rates of the entire system under different environment conditions which are obtained with the change of temperature and

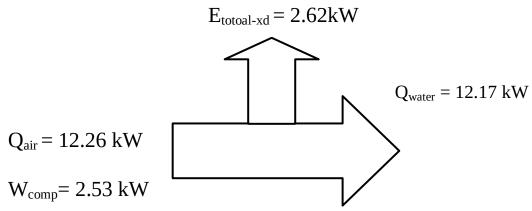

Figure 14 a. Energy balance of the system for 30°C at 40% humidity environment conditions.

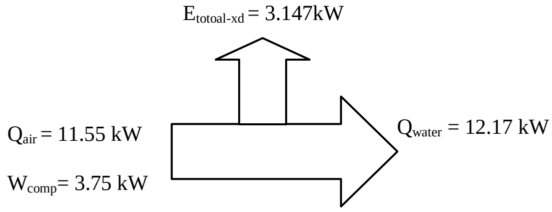

Figure 14 b. Energy balance of the system for 20°C at 40% humidity environment conditions.

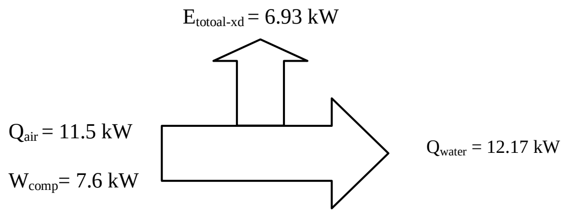

Figure 14 c. Energy balance of the system for 10°C at 40% humidity environment conditions.

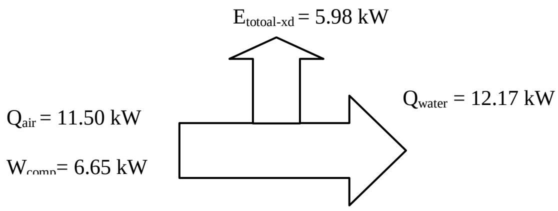

Figure 14 d. Energy balance of the system for 5°C at 40% humidity environment conditions.

humidity. As seen from the schemes, total energy input of the system is obtained from heat transfer from the air and work done by the compressor; these inputs are corresponding for heating of the water inside the storage tank of the system and the destruction appears at the components while the system is in progress which is obtained from the simulation program and summarized in Tables 5-6.

The heat transfer rate absorbed by the ambient air were found by considering the air flow rate and the temperature difference measured at three different positions taken in front and the back of the evaporator. Increment of the destruction value with worsening ambient conditions during the process is obvious from the schemes which is also depending on the charging time.

CONCLUSION

In this study, the performance of either the whole heat pump water heater system or each component is investigated individually from the exergy destruction point of view. The system performance is evaluated under different climates which are obtained with the change of temperature and humidity values as; 5, 10, 20, 30 and 40%, 70% and % 80 respectively to simulate the actual weather conditions that the system is used. The performance of the system is investigated by collecting the values of temperature and pressure from inlet and exit of each component during charging time and in the following step the collected values are used for the calculation of exergy destruction either for each component or entire system by a program prepared by MATLAB 7.3.

The experiments show that, performance of entire system is directly proportional with environment conditions. While the highest ambient condition which is obtained with 30°C and 80% humidity percentages is providing highest performance value, the poor weather which is obtained with 5°C and % 80 humidity percentages causes the performance of the system to diminish. Furthermore the results of exergy destruction during charging time, represents that the highest destruction is observed in the compressor and the lowest value is obtained at expansion valve besides this, the variation of the exergy destruction during charging time can be figured out. As it is seen, while the exergy destruction of compressor gets its highest value at the beginning of the charging time, the decrement is appeared at the proceeding process. The condensers' exergy destruction value represents a continuous increment during charging time while exergy destruction is decreasing at evaporation.

Unlike previous studies, this study representing the exergy destruction during entire process to understand accurate performance of all components in details by performing numerous experiments at various climates simulation as a first time for this system. Furthermore, the performance analysis by considering the charging time for each component is a contribution to the literature of analytical and experimental researches of heat pumps.

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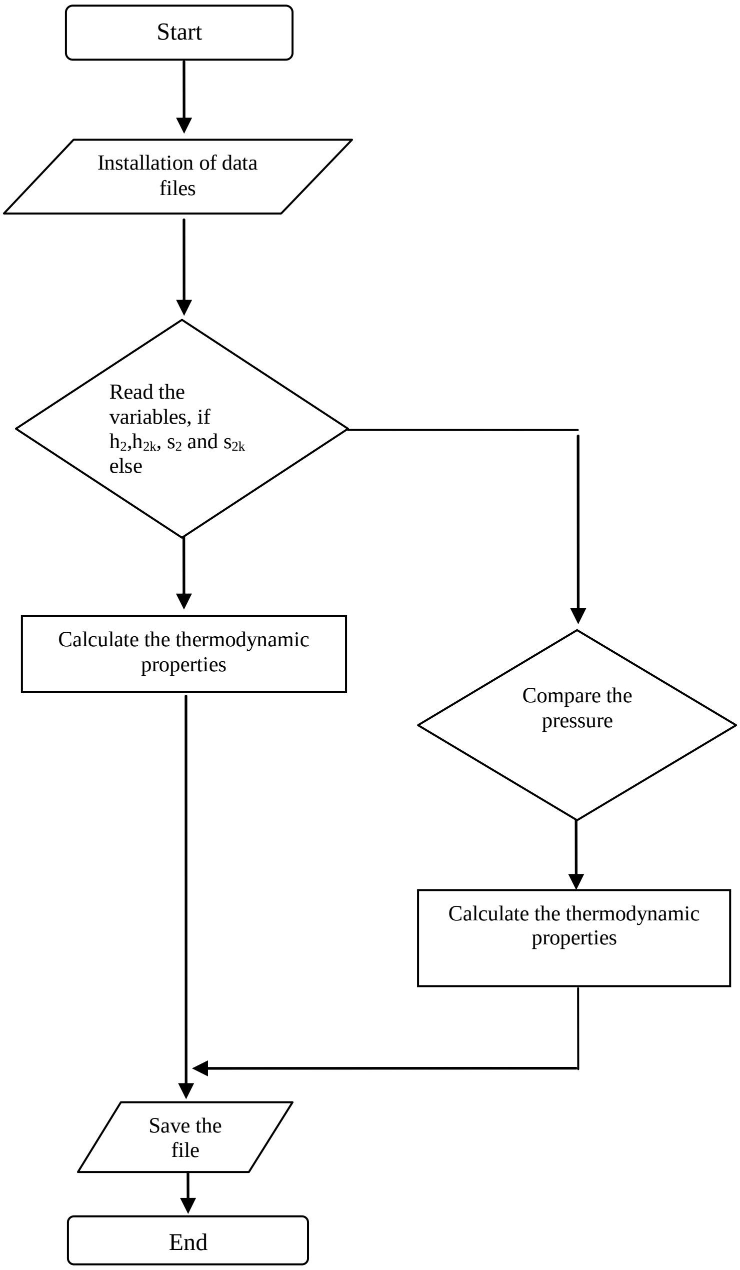
Appendix A


Start
Installation of data files
Read the variables, if h_2,h_{2k}, s_2 and s_{2k} else
Calculate the thermodynamic properties
Compare the pressure
Calculate the thermodynamic properties
Save the file
End