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Research Paper

Exergetic interrelation between an heat pump and components

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HIGHLIGHTS

- An air to water heat pump was designed to make an exergetic comparative investigation.
- It is operated with R22 and uses a scroll compressor.
- A detailed exergy analysis is made for components and heat pump system.
- The relation between the exergetic performances of components and heat pump is investigated.

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ABSTRACT

In this study, the relation between the exergetic performance of the heat pump and its components are investigated experimentally by using an air to water heat pump. Moreover, the effects of the working conditions of the components on the exergetic performance of the system are exposed and discussed. An experimental air to water heat pump system was designed and built. The results were evaluated by comparing the components and heat pump according to their performances. 33–45% of the all destructed exergy of the heat pump system comes into existence in the compressor. The contribution of the condenser to the total exergy destruction rate of the heat pump is between 23% and 34%. Contribution of the compressor to the exergy destruction rate of heat pump decreases with an increase in the air temperature and it increases with a decrease in the air mass flow rate. Contribution of the compressor to the exergy destruction rate of heat pump decreases with an increase in the air temperature and it increases with a decrease in the air mass flow rate. In terms of exergetic performance of the heat pump, the importance and priority of the components vary with the heat source thermal conditions.

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1. Introduction

Energy saving and efficiency have become one of the most important issues for energy policies of the governments all over the world. Especially in European countries, using energy more efficiently and decreasing the CO_2 emissions are among the main targets of governments. In the light of these events, most of the countries develop new building regulations or change existing regulations which determine the properties of energy using systems of the buildings. For instance, European Energy Performance of Buildings Directive (EPBD) and some of its suggestions can be thought [1–3]. In this context, energy consumption of heating and cooling systems becomes more important due to the fact that they are the largest energy end use both in the residential and non-residential sector. Thus, many investigations and studies have been made by the researchers to increase the efficiency of the systems and accordingly to decrease the energy consumption of such systems. Moreover, because of the limitedness of the existing energy sources and increase in life standards and environmental sensitiveness, the related researches are being elaborated in the world. One of the systems which offer an efficient energy using possibility for heating and cooling is the heat pump system. It is suitable for using in a large number of applications or sectors like heating, cooling, residential or industrial buildings [4–8]. The use of heat pump system is spreading in the world day by day. For that reason, improving the performance of heat pump systems is very important in order to save the energy and decrease the cost by increasing the efficiency [9].

Energetic and exergetic performance of heat pumps are affected by various parameters and factors. For example, physical properties and thermal specifications of the heat source or sink are the impressive parameters for efficiency and performance. Just like a

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Nomenclature

ED rate	exergy destruction rate (kW)
EE	exergy efficiency
RI	relative irreversibility
$\dot{Q}_{cond}$	heat energy, given to the heating fluid from refrigerant at condenser (kW)
$\dot{Q}_{evap}$	heat energy that taken from the external fluid at evaporator (kW)
$\dot{W}_{comp,elec}$	the electrical energy consumed by compressor (kW)
$\dot{m}$	mass flow rate (kg s^{-1})
$\dot{m}_a$	mass flow rate of air (kg s^{-1})
$\dot{m}_w$	mass flow rate of water (kg s^{-1})
$\dot{m}_r$	mass flow rate of refrigerant (kg s^{-1})
$C_{p,a}$	specific heat of air (kJ kg^{-1} K^{-1})
$C_{p,v}$	specific heat of vapor (kJ kg^{-1} K^{-1})
C_w	specific heat of water (kJ kg^{-1} K^{-1})
T_w	temperature of water (K)
T_a	temperature of air (K)
$T_{w,in}$	temperature of water at the inlet of condenser (K)
$T_{w,out}$	temperature of water at the outlet of condenser (K)
$T_{a,in}$	temperature of air at the inlet of evaporator (K)
$T_{a,out}$	temperature of air at the outlet of evaporator (K)
I	current (A)
U	voltage (V)
$Cos(\phi)$	power factor
$\dot{E}x$	exergy (kW)
ex	specific exergy (kJ kg^{-1})
ex_a	the specific exergy of air (kJ kg^{-1})
ex_r	the specific exergy of refrigerant (kJ kg^{-1})
ex_w	the specific exergy of water (kJ kg^{-1})
ω	specific humidity ratio of air (kg$_{water}$ kg$_{air}^{-1}$)
ω_0	Specific humidity ratio of air at dead state (KG$_{WATER}$ kg$_{air}^{-1}$)
P	pressure (kPa)
P_0	pressure at dead state (kPa)
T	temperature (K)
T_0	temperature at dead state (K)
h	specific enthalpy (kJ kg^{-1})
s	specific entropy (kJ kg^{-1} K^{-1})
h_0	specific enthalpy at dead state (kJ kg^{-1})
h_w	specific enthalpy of water (kJ kg^{-1})
$h_{0,w}$	specific enthalpy of water at dead state (kJ kg^{-1})
s_w	specific entropy of water (kJ kg^{-1} K^{-1})
$s_{0,w}$	specific entropy of water at dead state (kJ kg^{-1} K^{-1})
h_r	specific enthalpy of refrigerant (kJ kg^{-1})
$h_{0,r}$	specific enthalpy of refrigerant at dead state (kJ kg^{-1})
s_r	specific entropy of refrigerant (kJ kg^{-1} K^{-1})
$s_{0,r}$	entropy of refrigerant at dead state (kJ kg^{-1} K^{-1})
$\eta_{ex,cond}$	exergy efficiency of the condenser
$\eta_{ex,evap}$	exergy efficiency of the evaporator
$\eta_{ex,comp}$	exergy efficiency of the compressor
$\eta_{ex,exp}$	exergy efficiency of the expansion valve
$\eta_{ex,HP}$	exergy efficiency of the heat pump
$\dot{E}x_{dest,comp}$	exergy destruction rate of the compressor (kW)
$\dot{E}x_{dest,cond}$	exergy destruction rate of the condenser (kW)
$\dot{E}x_{dest,evap}$	exergy destruction rate of the evaporator (kW)
$\dot{E}x_{dest,exp}$	exergy destruction rate of the expansion valve (kW)
$\dot{E}x_{dest,HP}$	exergy destruction rate of the heat pump (kW)

team work, the performance of the components has an important role on the energetic and exergetic performance of heat pumps. There are many studies and investigations which focus on the performance and working conditions of the components of heat pumps. Most of them focused on the performance of any component like compressor or effect of any component on the whole system's performance. Some of these studies investigate the interaction between the components and the whole system.

For instance, one of them was focused on an optimum system configuring by using a two-stage compression heat pump which uses flash tank cycle. An improved theoretical model was used by the authors with the help of lumped parameter method. The authors analyzed the evaporator and condenser especially [10]. A new Dry-Expansion Evaporator was improved to increase the heat energy gain from the wastewater. It is a Shell-and-Tube type heat exchanger and developed with a de-fouling specification. The performance of the heat exchanger (evaporator) was determined theoretically and experimentally. Then effect of this novel evaporator on the performance of the heat pump was investigated [11]. Shuxue and Guoyuan made a research on air source heat pump which was supported with an ejector and economized vapor injection scroll compressor. They presented the design technique for a heat pump system with ejector (EVIe). Additionally, they abstracted the designing methodology of the heat pump systems with ejector [12]. Another experimental study was made for a direct driven radial compressor, which is used for domestic heat pump systems. This investigation focused on the derivation of the properties and choice for a rational refrigerant. Additionally, the authors studied on a concept prototype with different trade-offs among some important characteristics of research seasonal heat demand, the bearing and rotor dynamics for a stable operation [13]. A heat pump system using a flash-tank coupled with a scroll compressor is compared with a system using a sub-cooler. The heat pump performance was measured experimentally. Using a flash tank on heat pump system is more efficient than the system with a sub-cooler at low air temperatures [14].

A thermodynamically analytical model was developed with vapor injection on the two-stage and a prototype was improved and a testing system was established. The optimum volume ratio of the high-pressure cylinder to the low pressure one was investigated by considering heating and cooling conditions [15]. Four different types of HVAC systems were compared based on heat pump technology at three site locations (Milan, Rome and Palermo). In particular, this study compares the performances of single speed and changeable speed compressor equipment based on heat pump technology [16]. In an experimental investigation, the researchers focused on a small-scale radial compressor according to designing conditions and multi-objective optimization. A prospective method was demonstrated to deal with coupling a rational modeling tool to a multi-objective optimizer. By using the optimizer, it is possible to manage fitting the compressor design into the possible properties, while keeping the good efficiency on a wide operational range [17]. The volume ratio of a two-stage rotary compressor and its effect on air-to-water heat pump with flash tank cycle was investigated. The effect of a two-stage rotary compressor's volume ratio on air to water heat pump was studied experimentally [18]. A novel twin screw compressor was developed by SRM (Svenska Rotor Maskiner) for using in a high temperature heat pump system which uses water as working fluid. This study explores a numerical model for he thermodynamic analysis of compression in twin screw compressors [19].

A study was made on a high temperature heat pump which uses a screw compressor and a screw expander for energy recovery. This study was made in order to determine the thermal cycle and the thermal fluids in terms of their high-temperature (up to 180 °C) potentials without decomposition or using lubricant mechanisms. Then, a screw type compressor was obtained in the mentioned situations. After that, a screw expander was also used as a

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