JOURNAL OF COLLEGE OF EDUCATION
NO.3...............................2017

Performance Improvement of Ground Source Heat Pump System Using Matrix Heat Exchangers

Alaa H. Shneishil
Department of Physics, College of Education, the University of Mustansiriyah,

dralaa@uomustansiriyah.edu.iq

Abstract

The aim of this work is to investigate experimentally the performance improvement of ground source heat pump system (GSHP) by using Matrix Heat Exchangers (HEXs). The experiment is done using one, two in parallel and two in series HEXs. The performance of GSHP with these three cases of HEXs has been investigated by measuring the consumption current, suction pressure and discharge pressure under the influence of fluid mass flow rate, inlet fluid temperature and time of operation. The results show that the system performance is improved when GSHP with series HEXs is used instead of one and two in parallel HEXs and there is also a reduction in consumption current at all load conditions. The consumption current increases with increasing inlet fluid temperature and decreases with increase fluid mass flow rate. Thus for one HEX case when fluid mass flow rate 6.5 L/ min the consumption current various from 10 A for inlet fluid temperature 12 ^{o}C to 13.7 A for inlet fluid temperature 40 ^{o}C. On the other hand, In the case of parallel HEX the consumption current is about 12 A, while it is about 11.5 A for series HEX connection.

Keywords: Ground Source Heat Pump System, Matrix Heat Exchangers

تحسين اداء منظومة مضخة حرارية ذات المصدر الارضي باستخدام مصفوفة مبادلات حرارية

م.د. علاء حسين شنيشل
قسم الفيزياء- كلية التربية- الجامعة المستنصرية

الخلاصة

الهدف من هذا البحث هو التحقق عمليا من تحسين أداء نظام مضخة حرارية ذات المصدر الارضي (GSHP) باستخدام مصفوفة مبادلات حرارية. أجريت التجربة باستخدام مبادل حراري واحد، مبادلان على التوازي ومبادلان على التوالي. تم فحص أداء المنظومة في الحالات الثلاث للمبادل الحراري من خلال قياس التيار المستهلك وضغط المبخر وضغط المكثف تحت تأثير درجة حرارة المائع الداخل ومعدل سرعة تدفق المائع ووقت التشغيل. تشير النتائج إلى أن أداء المنظومة قد تحسن عندما تم استخدام المنظومة مع مبادلات حرارية متوالية بدلا من مبادل واحد ومبادلين على التوازي وهناك أيضا انخفاض في قيمة التيار المستهلك في جميع ظروف الحمل. يزداد التيار المستهلك مع زيادة درجة حرارة الماء الداخلة وينخفض مع زيادة معدل سرعة تدفق المائع. لذا في حالة مبادل حراري واحد عندما يكون معدل سرعة تدفق المائع ٦,٥ لتر / دقيقة فان التيار المستهلك يتغير من A ١٠عندما تكون درجة حرارة الماء الداخلة ^{o}C ١٢ إلى A ١٣,٧ عند درجة حرارة المائع ^{o}C ٤٠. من ناحية أخرى، في حالة مبادلين حراريين بشكل موازي فان التيار المستهلك حوالي A ١٢ ، في حين يبلغ حوالي A ١١,٥ في حالة مبادلين حراريين بشكل توالي.

الكلمات المفتاحية : منظومة مضخة حرارية ذات المصدر الارضي، مصفوفة المبادلات الحرارية

1. Introduction

Thermal systems like heat pumps consume large amount of electric power. So it is need to improve energy efficient heat pump systems [1]. Also energy consumption associated with heat pump systems increase all over across the world in last few years. According to report conducted by RECS (Residential Energy Consumption Survey) in US during 2009, it shows that 62% of Residential homes have heat pump systems. This value is very high as compared to year 1997 which is 48% and in 1978 it is 24% [2]. The conventional heat pump systems seem reasonable as the air temperature in summer is about 40^{o} C. But when the air temperature increase and approaches

50º C or higher, the performance of these systems decrease [3]. Ground source heat pump system (GSHP) is a heat pump system that utilizes the thermal energy stored underground. In cooling mode, the ground represent as a heat sink, and in heating mode as a heat source for GSHP. At certain depth underground, the temperature is nearly-constant which lead to GSHP operates over smaller temperature differences than heat pump system using the air as a thermal energy reservoir (conventional heat pumps). GSHP consequently achieve energy efficiency or coefficient of performance (COP) substantially better than conventional air source heat pump systems [4,5]. They are therefore regarded as to be renewable energy technology. GSHP can be widely used in many applications such as space cooling, heating, domestic hot water as well as a variety of agricultural and industrial applications where massive cooling/heating is needed [6]. Using of matrix heat exchanger (HEX) with GSHP system leads to decrease refrigerant temperature entering the expansion device and increase refrigerating effect in comparison to conventional system. Hence both COP and capacity will be increased [7]. In the face of energy crisis, the climatic changes occur and global warming many researchers have paid much attention on strategies for improving thermal systems and saving energy of GSHP. Ibrahim in 2012 shows that around 37% energy saving by using GSHP [8]. Abeer et al in 2013 indicated that GSHP leads to a 30% energy saving during winter and 15% during summer [9]. Alaa in 2014 study experimentally the performance of GSHP without matrix HEX. He showed that that there is 55% of energy saving in comparison to conventional system [10]. Apostolos et al in 2015 found that significant primary energy saving which is up to 25.4% [11]. Young-Ju et al in 2016 analyzed the energy of GSHP using TRNSYS. As a result, the GSHP total energy consumption was reduced by 46% [12]. This project concentrated to investigate experimentally the effect of using Matrix HEX connected in parallel and in series for improving the performance of GSHP.

2. Ground Source Heat Pump System

Shallow geothermal energy sector is continuing to grow at a higher than expected rate: more than 66,000 units are installed worldwide annually. 80 % of these installed units are domestic [13]. GSHP which represent an application of Shallow geothermal energy are divided into three types according to the ASHRAE definition: surface water, ground water source, and ground-coupled heat pump systems. Figure 1 illustrate GSHP system. In this regard, it has received more concern. The utilization of this technology is growing rapidly in Europe, especially in Germany, Switzerland and Austria. Over 140,000 GSHPs have been installed in the USA and more than 30,000 units have been installed in Switzerland [14]. Heat pump system is a device which extract heat from a lower temperature heat source and transferring it to a higher temperature heat sink (air, or other fluid) in order to maintain the heat source temperature below that of the surroundings. Vapor compression systems are the most common refrigeration systems [15, 16]. A condenser is a HEX used to condense a refrigerant from its gaseous to its liquid state by giving up the latent heat from refrigerant to air or other fluid. It have various designs and come in many sizes ranging from rather small to very large industrial-scale units [17]. The use of fluid cooled condenser will definitely increase the heat transfer efficiency and so increase the COP of the heat pump unit [18]. The compressor work of GSHP can be calculated from the thermodynamic work rate of an isentropic process [19]:

$$\dot{W}_t = \frac{\gamma}{\gamma-1}\, \dot{m}_r\, P_{suc}\, v_{suc} \left[\left(\frac{P_{dis}}{P_{suc}}\right)^{\frac{\gamma}{\gamma-1}} - 1\right] \qquad (1)$$

Where γ is the isentropic exponent, $\dot{m}_r$ is the refrigerant mass flow rate, P_{suc} is the suction pressure, P_{dis} is the discharge pressure, v_{suc} is the specific volume at suction state. The magnitude of theoretical power is influenced by the discharge and suction pressures of the system which are different from the evaporating and condensing pressures due to different temperature and mass flow rate of inlet fluid to the condenser. The actual work $(\dot{W})$ can be calculated from theoretical work $(\dot{W}_t)$ by accounting the electrical and mechanical losses $(\dot{W}_{loss})$ and is given by [19]:

$$\dot{W} = \eta . \dot{W}_t + \dot{W}_{loss} \qquad (2)$$

Where η is a constant of proportionality. HEX is a device that transfer the heat from one fluid to another fluid at different temperatures and separated by a heat transfer surface. HEXs are used in more process such as condenser or evaporator in heat pump system. They could be classified in many different ways. A tube-in-tube HEX is one type which consists of one tube placed concentrically inside another tube of larger diameter with appropriate fittings to direct the flow from one section to another section. One fluid flows through the inner tube and other fluid flows through the annular space. They can be arranged in various parallel and series arrangements to meet mean temperature difference and pressure drop requirements [20].

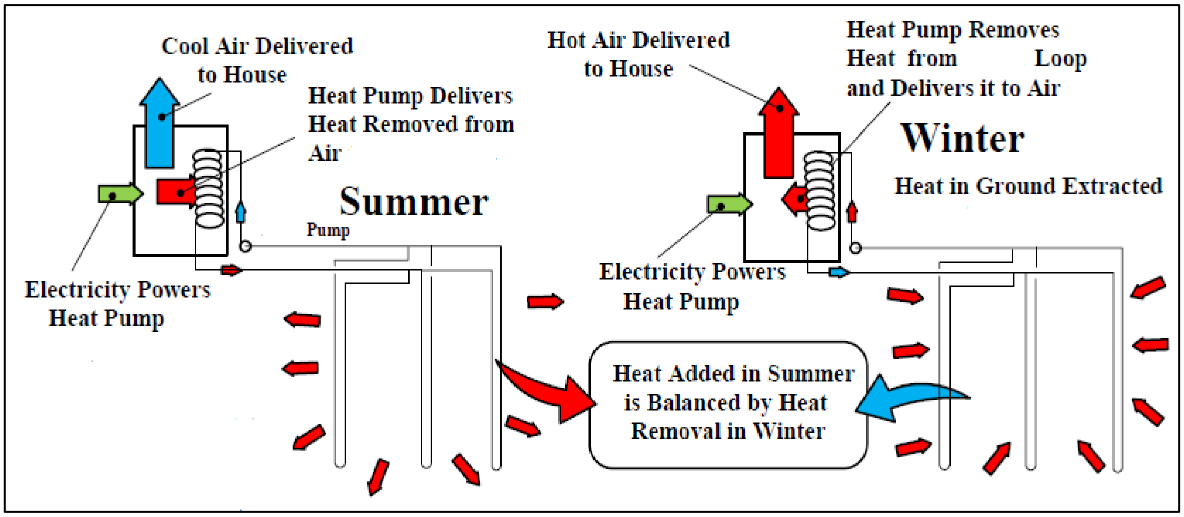

Figure (1): Ground source heat pump system

3. Experimental Part

The experimental setup is a modification of GSHP system. The basic components are all same as that of conventional compression system. GSHP has been used as an experimental setup and the system is modified by adding a matrix HEXs. The flow here is counter flow type as the effectiveness is more when compared with the parallel flow type HEX. There are three cases under study, in the first case one HEX is used as illustrated in figure 2. The second is the parallel case which the inlet fluid flows through the outer side in two ways, one way to the first HEX and the second way to the second HEX, also the outlet fluid has two ways from the two HEXs as shown in figure 3. The third case is the series connection that the inlet fluid to the first HEX and the outlet fluid from the second HEX and the two HEXs connected with each other as shown in figure 4. The consumption current of the GSHP is measured using a digital clap meter. Thermocouples with temperature measuring range (-50 ^{o}C to 80 ^{o}C) and accuracy ±1 ^{o}C are used to measure the fluid temperatures at inlet and outlet of each HEX. The suction and discharge pressure is measured using a pressure gage of two scales which is supplied by Chine. The first scale low pressure ranges from (-30 psi to 250 psi) to read the suction pressure of the compressor, and the other for high pressure ranges from (0 psi to 500 psi) to read the discharge pressure. The flowmeter instrument manufactured by ZYIA Company with a range of 0 to 20 L/min (0 to 5.5 GPM) has been used to measure the fluid mass flow rate through HEX. This instrument connected with pump of about 10 L/min from one side and with the outdoor HEX of the system from the other side.

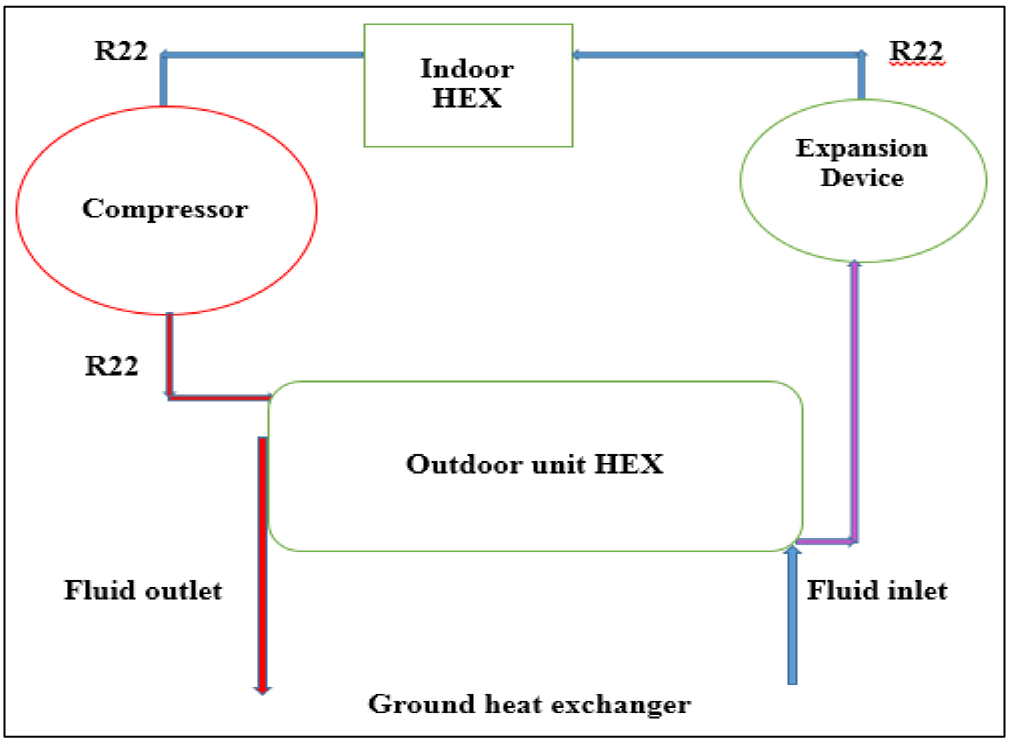

Figure (2): Diagram of experimental set up of GSHP with one HEX

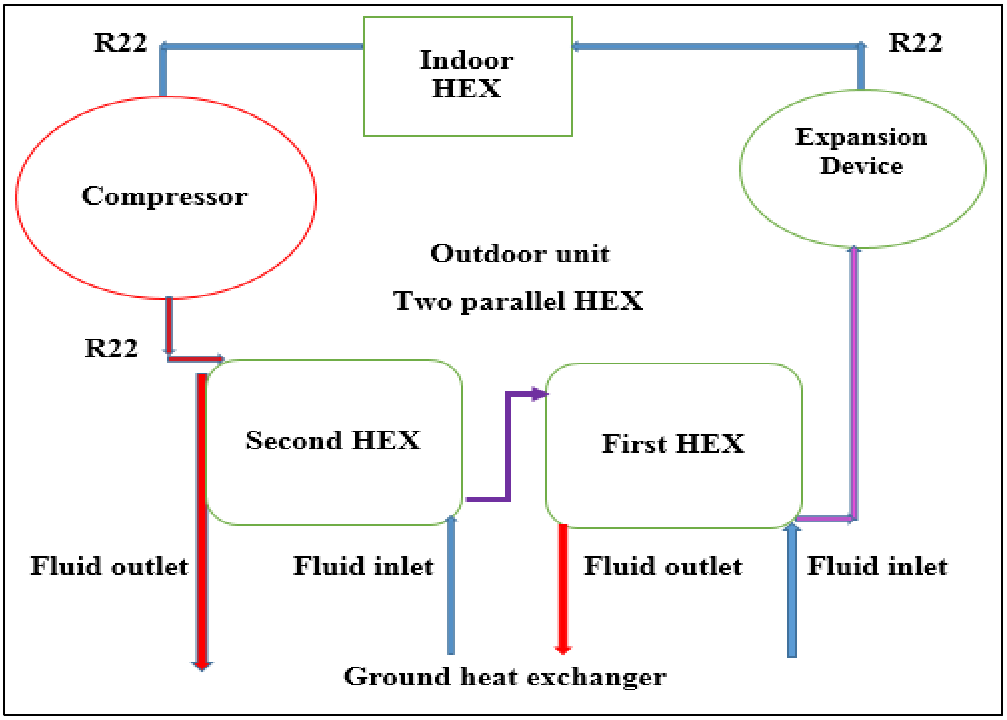

Figure (3): Diagram of experimental set up of GSHP with two parallel HEX connection

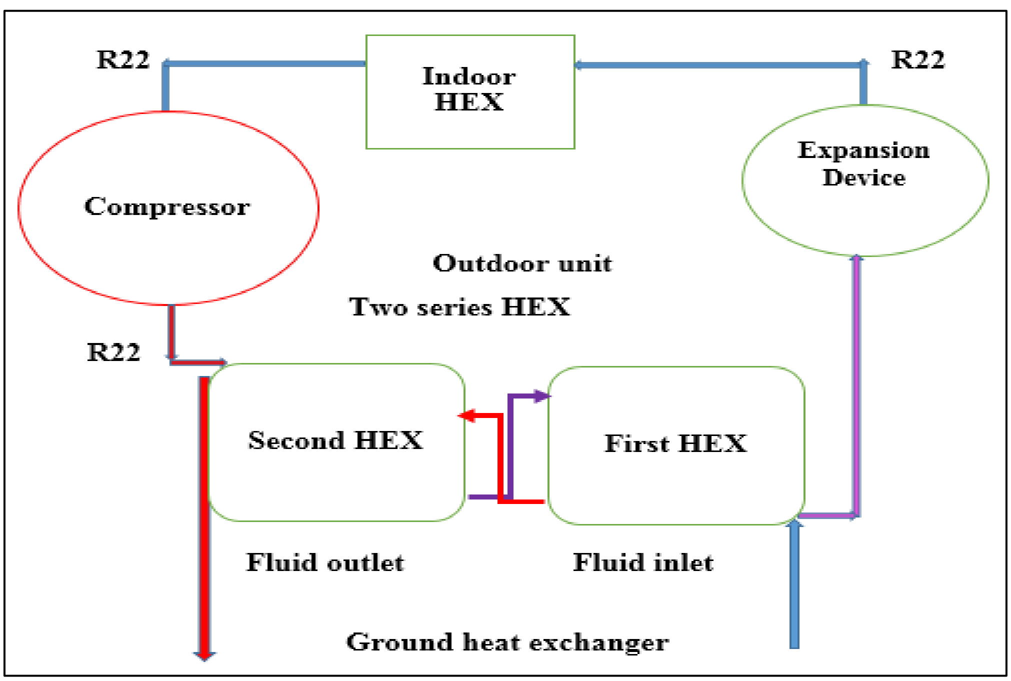

Figure (4): Diagram of experimental set up of GSHP with two series HEX connection

4. Results and Discussion

The performance of GSHP with one HEX illustrates in figures 5 to 11. Therefore, Figure 5 shows the effect of inlet fluid temperature on the consumption current for two values of fluid mass flow rate (9.5 and 6.5 L/min). It is important to mention that, the consumption current increase with increasing input fluid temperature, thus when fluid mass flow rates 9.5 L/ min the consumption current various from 9.6 A for inlet fluid temperature 12 ^{o}C to 13.3 A for inlet fluid temperature 40 ^{o}C, while it various from 10 A to 13.7 A for fluid mass flow rate 6.5 L/ min. It is observed that from figure 6, the suction pressure for different inlet fluid temperatures; It indicates significant suction pressure increases with the increases of inlet fluid temperature for both values of fluid mass flow rate, and it is seen there is a shifting between the values of suction pressure for the two values of fluid mass flow rate in the range of inlet fluid temperature (12^{o}C-26^{o}C), while, they become identical after this range. It can be observed from figure 7, which represents the relationship between the inlet fluid temperature and discharge pressure, that increase of discharge pressure from 130 psi to 250 psi for inlet fluid temperature 12^{o}C to 40^{o}C with fluid mass flow rate 9.5 L/ min, respectively. On the other hand these values are about 154 psi to 266 psi for fluid mass flow rate 6.5 L/ min. The effect of fluid mass flow rate on the consumption current, suction pressure and discharge pressure, respectively at inlet fluid temperature (27) ^{o}C are plotted in figures 8, 9, and 10. It is seen clearly from these figures that decease of all the three values with increasing of mass flow rate. As shown in Figure 8, the consumption current decrease from 15.6 A for mass flow rate 2 (L/ min) to 12.6 A for mass flow rate 6 (L/ min). Figure 9 shows decrease of suction pressure from 56 psi to 50 psi and figure 10 shows decrease of discharge pressure from 285 psi to 215 psi for this rang of mass flow rate. The decreases in consumption current is small in the first part up to (12:45) pm. then it increases to peak value which is (13.3) A, and decreasing sharply to (13) A, at time (2:30) pm, see figure 11.

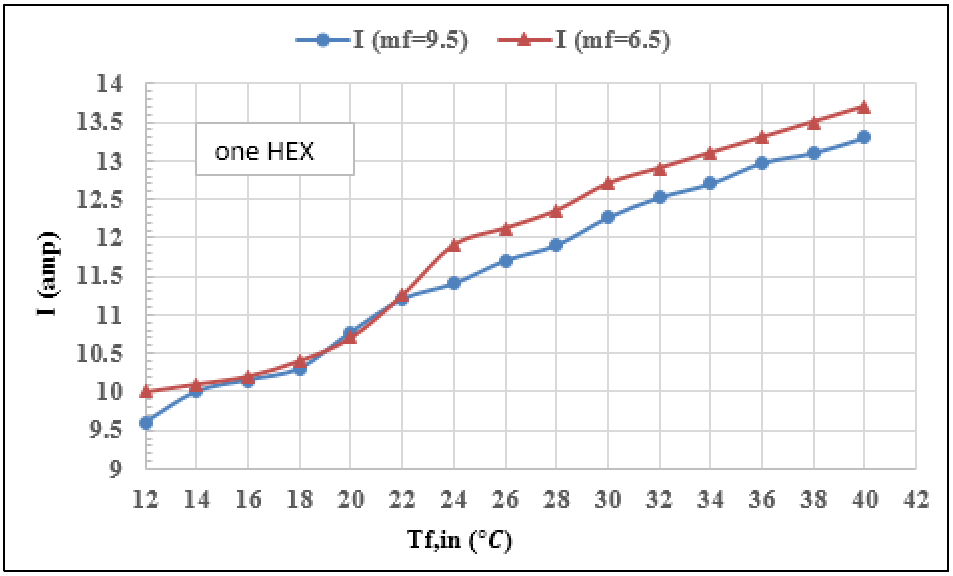

Figure (5): Effect of inlet fluid temperature on the consumption current of GSHP with one HEX

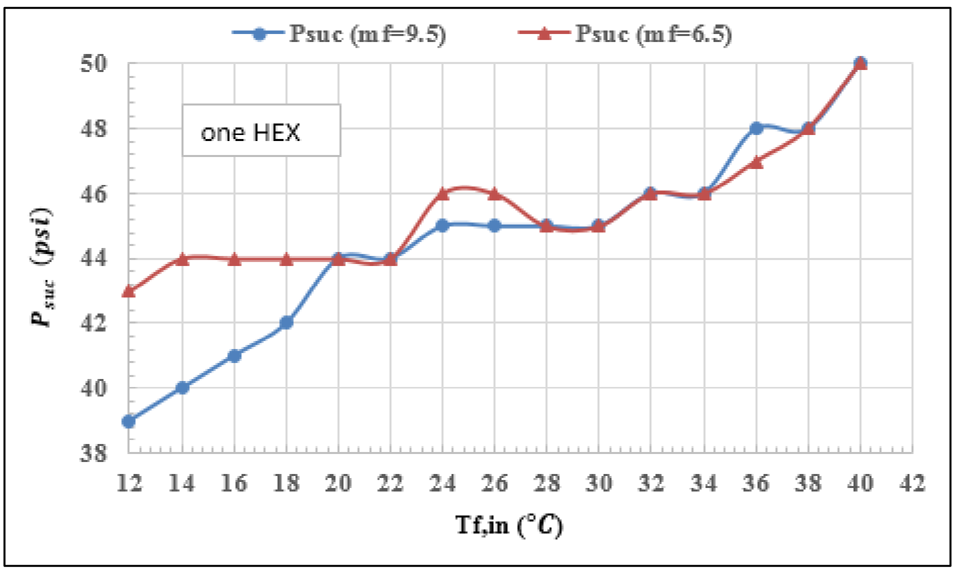

Figure (6): Effect of inlet fluid temperature on the suction pressure of GSHP with one HEX

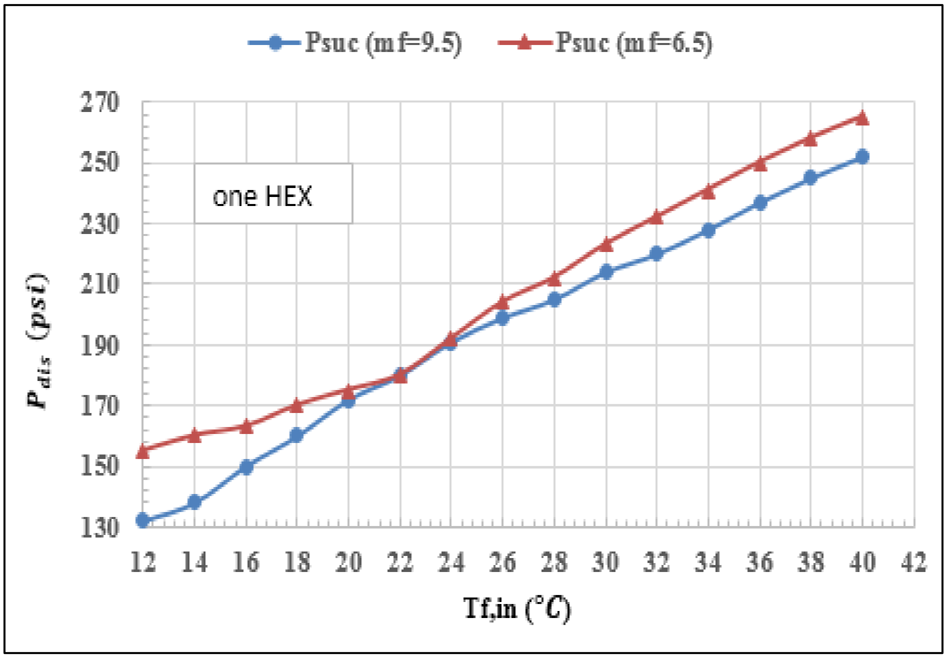

Figure (7): Effect of inlet fluid temperature on the discharge pressure of GSHP with one HEX

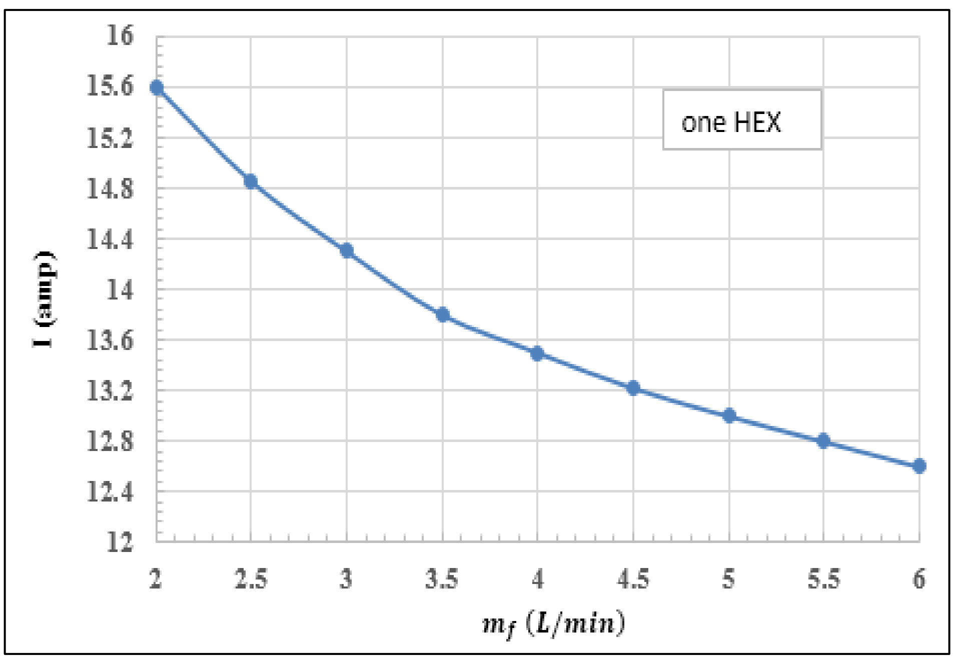

Figure (8): Effect of fluid mass flow rate on the consumption current of GSHP with one HEX

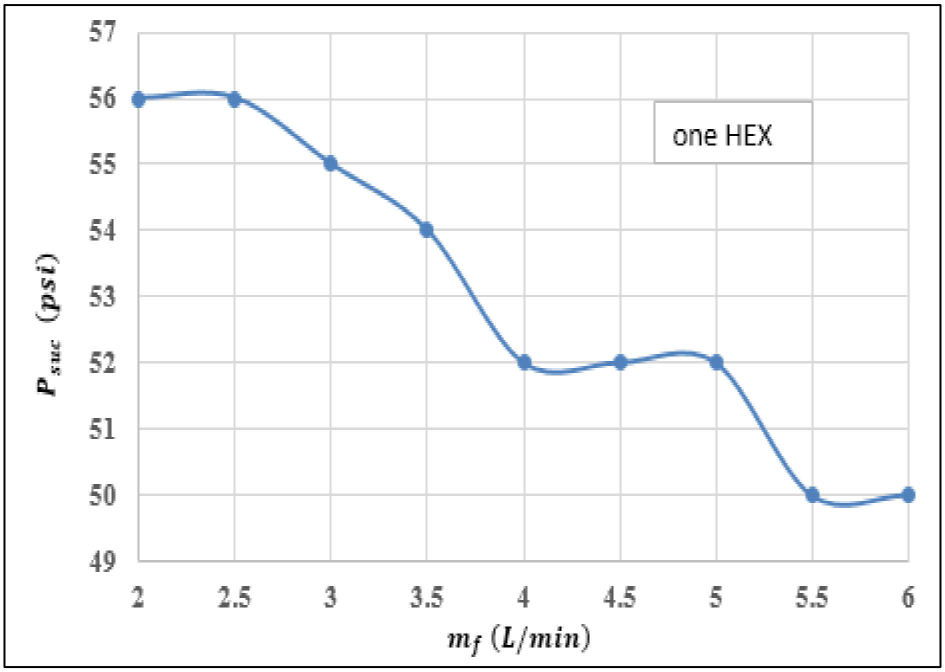

Figure (9): Effect of fluid mass flow rate on the suction pressure of GSHP with one HEX

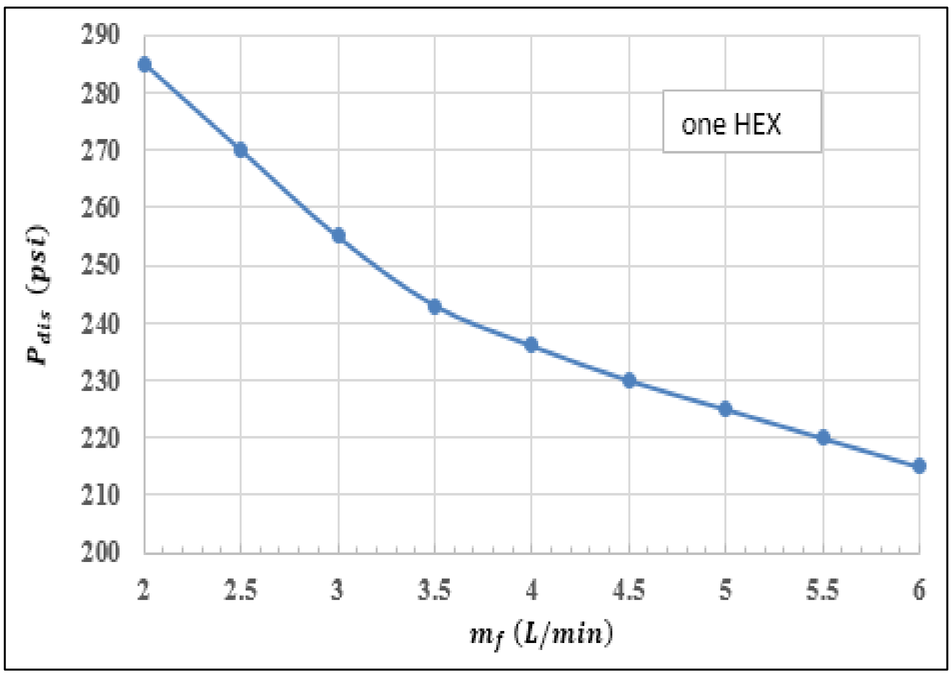

Figure (10): Effect of fluid mass flow rate on the discharge pressure of GSHP with one HEX

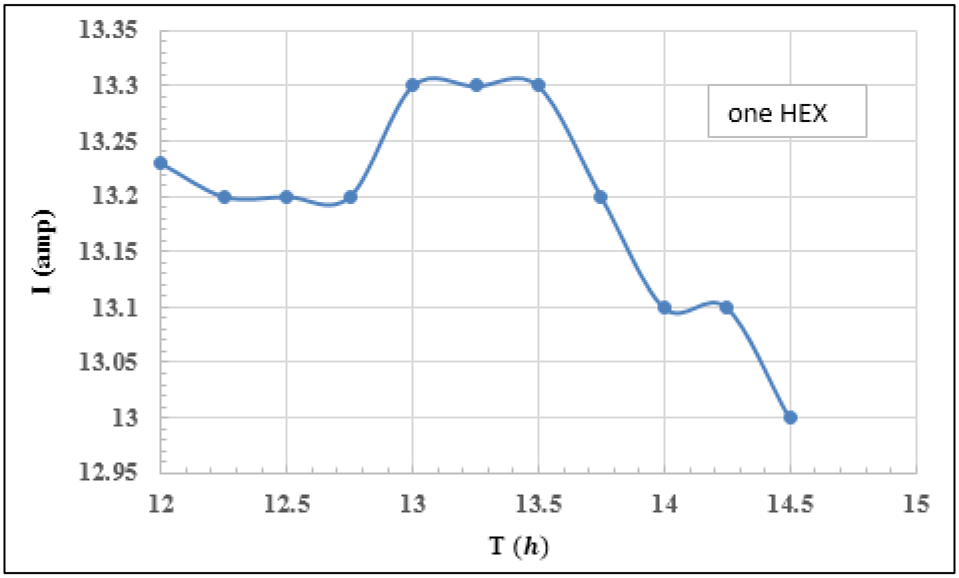

Figure (11): The consumption current of GSHP with one condenser HEX for fluid mass flow rate=4.5 L/s and input fluid temperature=27 °C.

To compare between the matrix parallel and series condenser HEX connections and to choose the optimum case, it is important to evaluate the performance of the system under the two cases. Therefore the consumption current is plotted against local time for the parallel case in Figure 12 at two values of inlet fluid temperatures (23 °C and 32 °C). It is clear from this figure that the consumption current various from 14.1 A to 13.5 A for inlet fluid temperature 32 °C and from 12 A to 11.7 A for inlet fluid temperature 23 °C. Also to investigate the effect of the inlet fluid temperature on the suction and discharge pressure, it is observed from Figure 13 that the suction pressure stable at about 58 psi and 50 psi for inlet fluid temperature 32 °C and 23 °C, respectively. So, the value of discharge pressure is about 220 psi and 174 psi, respectively as shown in figure 14. On the other hand, figures 15, 16 and 17 illustrate the series connection case. Figure 15 shows the consumption current as a function of time for inlet fluid temperature 25 °C and three values of fluid mass flow rates. It can be seen from this figure that the consumption current various from 11.9 A to 12.5 A, 11.2 A to 11.5 A and 10.5 A to 10.7 A for fluid mass flow rates 7 L/min, 14 L/min and 26 L/min, respectively. Figure 16 indicates that the suction pressure stable at 54 psi for mass flow rate 7 L/s and 48 psi for both mass flow rates 14 L/min and 26 L/min. figure 17 shows that discharge pressure stable at 195 psi, 176 psi and 171 psi for these three values of mass flow rate, respectively.

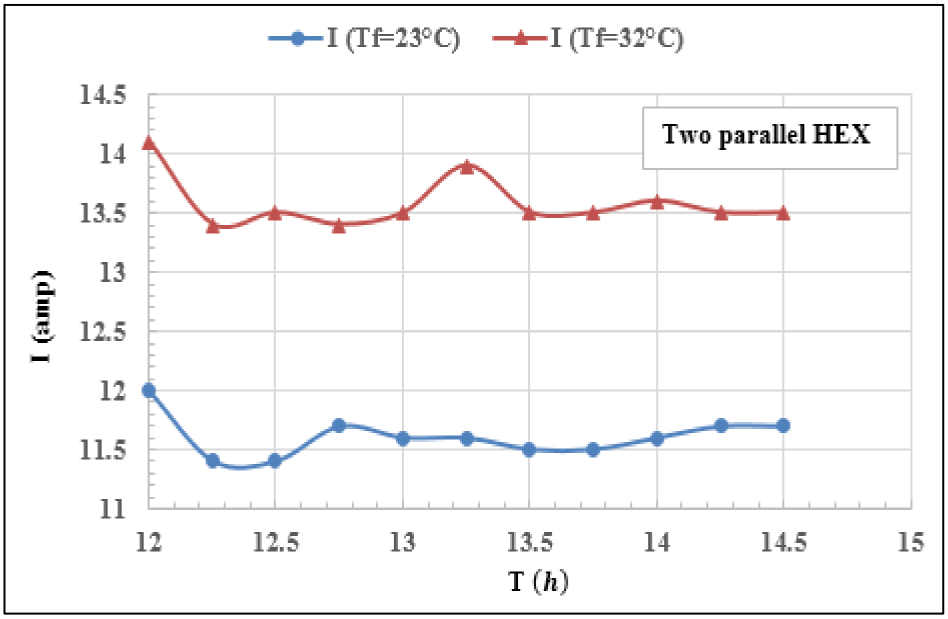

Figure (12): The consumption current of GSHP with two parallel HEX for fluid mass flow rate=6 L/s

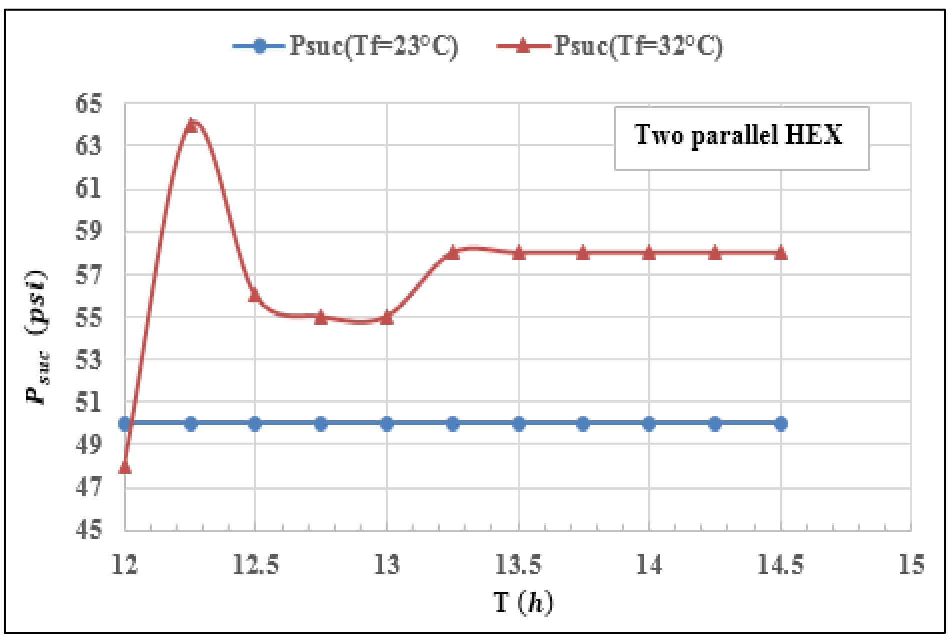

Figure (13): The suction pressure of GSHP with two parallel HEX for fluid mass flow rate=6 L/s

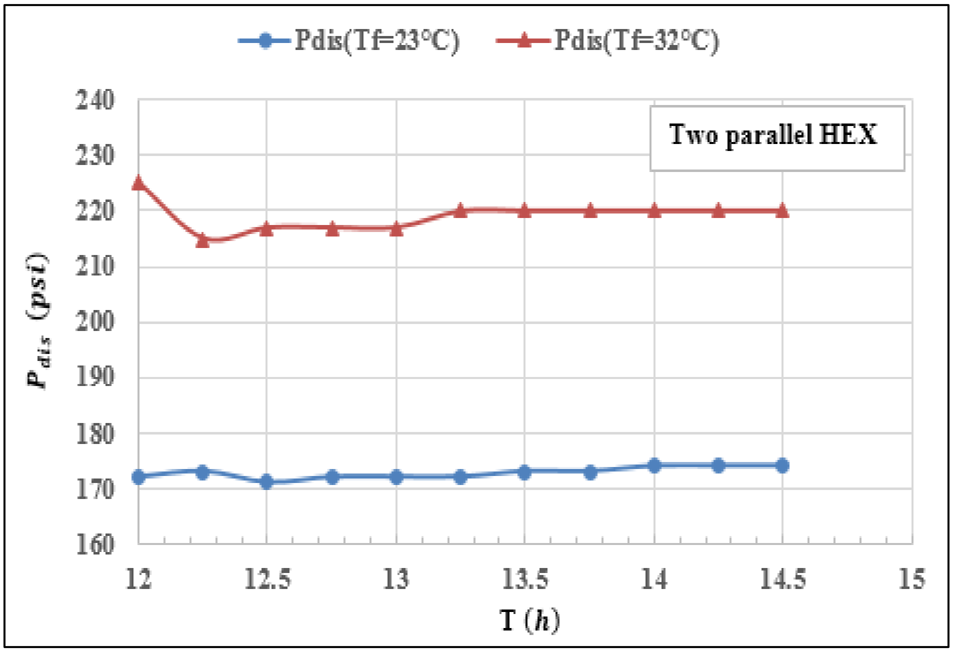

Figure (14): The discharge pressure of GSHP with two parallel HEX for fluid mass flow rate=6 L/s

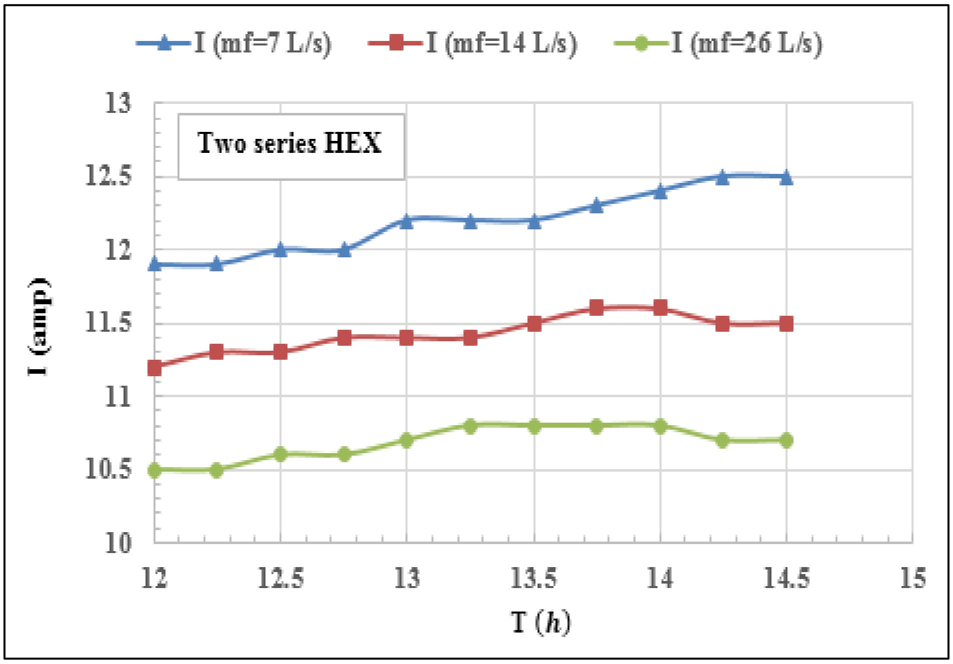

Figure (15): The consumption current of GSHP with two series HEX for input fluid temperature=25 ^{o}C

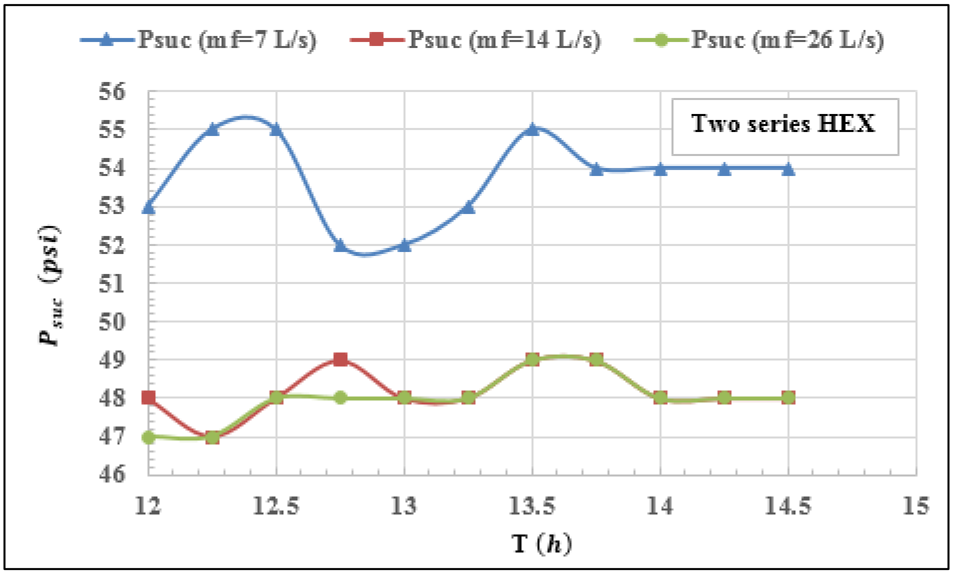

Figure (16): The suction pressure of GSHP with two series HEX for input fluid temperature=25 ^{o}C

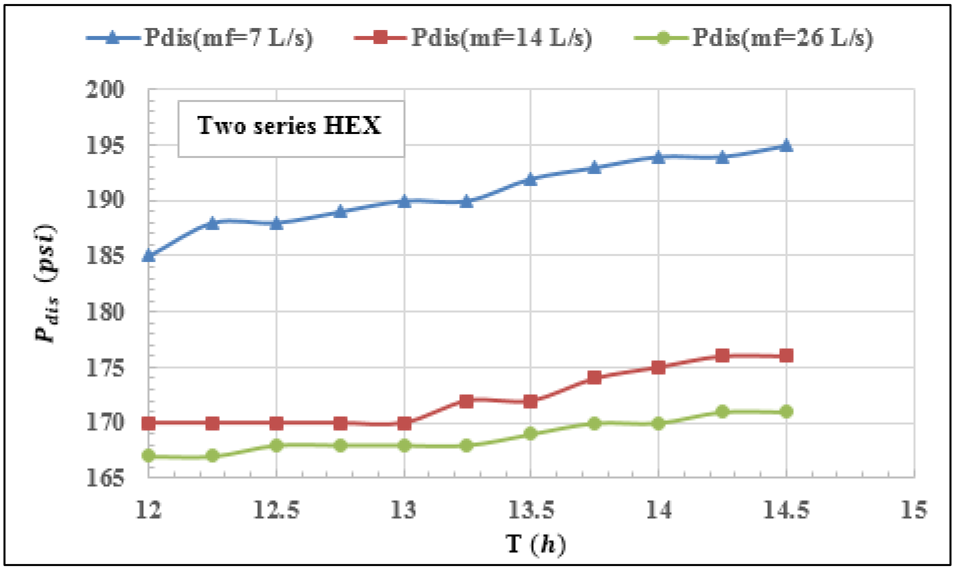

Figure (17): The discharge pressure of GSHP with two series condenser HEX for input fluid temperature=25 ^{o}C

5. Conclusions

1. GSHP with series HEXs reduced the current consumption and improve the coefficient of performance (COP) when compared with the conventional heat pump system, GSHP with one and two parallel HEXs, respectively.
2. The series connection is better than other two cases because it is simple and need to one circulation pump in comparison with parallel case which need to two circulation pump.

References

1- Subramani N., Aswin M. and Jose P. M., **"Performance Studies On A Vapour Compression Refrigeration System Using Nano-Lubricant"**, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Special Issue 1, 2013.

2- Rahul W.,Taliv H., Gourav R. and Rahul Th., **"Experimental Study of Improving the COP of VCRS system by using Single and Double Cellulose pad in Cooling Tower"**, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), National Conference on Advances in Engineering, Technology & Management, pp.64-68, 2015.

3- Manoj P., Alok Ch., **"Enhancement the Performance of Condenser of Split type Air Conditioning System by using Evaporative Cooling: A Review"**, International Journal Of Engineering Sciences & Research Technology (IJESRT), Vol.3, No.7, pp.398-403.

4- Sarbu, I. and Sebarchievici, C., **"General review of ground-source heat pump systems for heating and cooling of buildings"**, Energy Build., Vol.70, PP.441-454, 2014.

5- Soni, S.K., Pandey M. and Bartaria, V.N., **"Ground coupled heat exchangers: A review and applications"**, Renew. Sustain. Energy Rev., Vol.47, PP.83–92, 2015.

6- Lund J.W., Boyd T.L., **“Direct utilization of geothermal energy 2015 worldwide review”**, Geothermics, Vol.60, PP.66–93, 2016.

7- Mohammed Sajid N. K., Sankar Ram K., Shafi K. A., **“Performance Improvement of an Air Conditioning System Using Matrix Heat Exchanger”**, International Journal of Engineering Research and Development, Vol.2, Issue 11, PP. 66-70, 2012.

8- Ibrahim M. I., **"Theoretical and Experimental Analysis of Combined Thermal Solar Collector and Horizontal loop Ground Source Heat Pump"**, M.Sc. Thesis, An-Najah National University, Nablus, Palestine, 2012.

9- Abeer S. A. and Ahmad H. S., **"Energy Saving by the Means of Geothermal Energy"**, Journal of Clean Energy Technologies, Vol. 1, No. 3,PP.243-245, 2013**.**

10- Alaa H. Shneishil, “**Design of Hybrid Solar-Geothermal Heat Pump”**, Ph.D thesis, Physics department, college of education, the university of Mustansiriyah, 2014.

11- Apostolos M., Aikaterini T., Vasiliki V. and Theodoros Z., **“Analysis of Ground Source Heat Pump Systems in Residential Buildings”**, Proceedings World Geothermal Congress, Melbourne, Australia, 19-25 April 2015.

12- Young-Ju J., Hyo-Jun K., Bo-Eun Ch., Jae-Hun J. and Young-Hum Ch., **“A Study on the Efficiency Improvement of Multi-Geothermal Heat Pump Systems in Korea Using Coefficient of Performance”**, Energies, Vol.9, 356, PP.1-19, 2016.

13- Maha Ch., Mikael Ph., and Yves C., “**A Field Experiment to Assess the Influence of Heat and Mass Transfer at the Soil Surface on Shallow Ground Heat Exchanger Performances”**, Proceedings World Geothermal Congress, Melbourne, Australia, 19-25 April 2015

14- Yu J. N., Xin Y. G., Sung H. Y. and Kwang H. L., **“Study on the Performance of a Ground Source Heat Pump System Assisted by Solar Thermal Storage”**, Energies, Vol.8, PP.13378–13394, 2015.

15- ASHRAE, 2009, ASHRAE Handbook-Fundamentals, **American Society of Heating, Refrigerating and Air-conditioning Engineers**, Inc., Atlanta, GA.

16- BiranganeV.V., Patil A.M., 2014,**"Comparison of air cooled and evaporatively cooled refrigerartion systems**", Int. Journal of Engineering Research and Applications , Vol.4(6), 208-211.

17- Manish B. and Bartaria V. N., "**A Review on Performance Analysis of Air-Cooled Condenser under Various Atmospheric Conditions"**, International Journal of Modern Engineering Research (IJMER), Vol.3, Issue.1, pp-411-414, 2013.

18- Najim A. J., **"Thermal Performance Evaluation of Water Mist Assisted Air Conditioner"**, International Journal of Computer Applications, Vol. 105, No. 16, PP.5-10, 2014.

19- Daniel E. F. and Simon J. R., **"Modeling Ground Source Heat Pump Systems in a Building Energy Simulation Program (Energyplus)"**, Ninth International IBPSA Conference, **Montréal, Canada, August 15-18, 2005**

20- Jay J. B., Matawala V. K. and Dixit S., "**Design and Experimental Analysis of Spiral Tube Heat Exchanger"**, International Journal of Mechanical and Production Engineering, Vol.1, Issue-1, 2013.