Research Article
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Experimental evaluation of water source heat pump by Taguchi method

Mansur MUSTAFAOĞLU [1]
[1] Department of Mechanical Engineering, Engineering Faculty, Atatürk University, Türkiye

Reza MATIN [2]
[2] Researchers and Elite Club, Tabriz Branch, Islamic Azad University, Tabriz, Iran

İsak KOTCİOĞLU [3]
[3] Department of Mechanical Engineering, Engineering Faculty, Atatürk University, Türkiye

Muhammet Kaan YEŞİLYURT [4]
[4] Department of Mechanical Engineering, Engineering Faculty, Atatürk University, Türkiye

ABSTRACT

Water source heat pumps are devices that can produce heating or cooling in the place using the energy in the ambient water which serves as the easiest source of heat. The heat pumps, which utilize the ambient water on the boiling side, are able to transfer the energy they have obtained to the water or air on the load side. The renewable geothermal energy, which is produced by the alternative energy sources, is also an important potential in Turkey as a sustainable and environmental- friendly source. The subject of utilizing geothermal energy has been among the most balanced and high efficiency, low maintenance comfortable energy sources in pace with the technological developments of the heat pumps. The widespread and daily use of the ground source heat pumps and the examination of the situation in Turkey lead us to the determination of the potential applicability which is one of the important issues. In this study, the COP of various parameters and different levels of the water source heat pumps were calculated according to the Taguchi experiment design.

Keywords: Heat Pumps, COP, Taguchi experiment design, energy

INTRODUCTION

The commonly used air source heat pumps are air-to-air heat pumps which are often referred as "air conditioners". Air-to-water heat ramps provide the possibility of more comfortable heating by the floor heating or radiators (static heating) since they can transfer their energy to the load side. In general, cooling by fan coils can be done in the areas where the relative humidity is suitable by using the underfloor heating pipes. The heat pump is a system that simply transfers heat energy from one medium to another while it is powered by the electricity. The heat pump takes its name from its ability to "pump" or "transport" heat energy from one medium to another. So, when the necessary conditions are met, high amounts of energy are offered at low costs.[1]

In general, the heating pumps aim to transport heat than producing it, and they need a heat pit to remove heat. Almost all of the heat pumps used in our country use air as a heat sink. Today, heat pumps using air as a heat sink are called as Split air conditioners. Efficiencies of air-borne devices take different values with changing of outside temperature. The unexpected increases in operating costs occur because the yield values do not remain constant even during the day.[1] There are also heat pits that can accept the temperature as constant while preventing these changes in efficiency. The heat pits which can accept the temperature used for this purpose are soil and water.

Water source heat pump technology at a certain depth of the earth is based on the fact that the temperature remains relatively constant throughout the year. The soil layer in the mentioned depth takes this advantage provided by nature by carrying the heat which is stored under the ground or underground water in the winter to the building, and the heat inside the building underground in the summer. Briefly, underground serves as a heat source in winter and a heat sink in summer.

We can simply consider the heat pump as a reverse cycle of the heat machine. The heat machine is the machine which draws heat from the high temperature environment while transfers it to the low temperature environment and employs the outside by doing this operation. The heat pump, on the other hand, is the machine that supplies the heat taken from the low temperature heat source to the high temperature environment by providing energy from the outside.[1] The main elements of a simple heat pump are two compressors, expansion valves, evaporators, and two heat exchangers called condensers.[1]

Groundwater is a suitable medium for storing solar heat. It gives the advantage of providing a constant temperature between +7 and +12°C even in cold winter days. Since the temperature level of the heat source remains constant, the heat pump's performance coefficient would be high all year round.[2] When surface waters such as lakes and rivers are used as the water source, the temperature varies more than well water, but not as much as the air. It is also an advantage that surface waters do not fall below (0°C) in our country.

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Corresponding author:
Muhammet Kaan YEŞİLYURT
E-mail:
Kaan.yesilyurt@atauni.edu.tr

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The first principle of the heat pump, which operates according to the same thermodynamic cycle as the cooling machine, was introduced by Carnot in 1824. Its implementation was carried out in 1850, when Lord Kelvin proposed the use of cooling devices for heating.[3] In this system, where Lord Kelvin uses air as a working fluid, outdoor air is drawn into a cylinder where it is expanded to reduce both temperature and pressure. The air is then expanded by sending it to a heat exchanger which is placed outside in order to allow the cooled air to draw heat from the outside. The heated air is again compressed to normal atmospheric air pressure and is delivered to the room. However, since it is compressed, its temperature is higher than normal atmospheric temperature. Lord Kelvin stated that the device, which he called "heat booster", produces heat with 3% of the energy which is given directly to combustion. Later, as a result of the researches done by many scientists and engineers in a period of about 80 years, the heat pump became applicable in comfort heating.[3]

In the USA, the interest in Ground Source Heat Pumps technology surfaced between 1940 and 1950. At the time, research could be done in a limited way with inappropriate pipe materials. In addition, the need for the development of the heat pump was not much due to the relatively inexpensive natural gas. Due to research, technology accelerated again in Europe during the 1973 oil embargo which, in turn, led to the launch of a research program at Oklahoma State University a few years later.[3]

Further, some of the US power companies, with an aim to increase residents, use Ground Source Heat Pumps for the space heating / cooling purposes and reduce peak loads in the electrical systems which, in turn, helps conduct monetary incentive programs. The "Geothermal Heat Pump Consortium" created six-year programs of $ 100 million in order to increase Ground Source Heat Pumps sales from 40,000 to 400,000 annually which led to reducing greenhouse gas emissions by 1.5 million tons of carbon equivalent annually.[3]

There have been many studies and researches over the subject.[1-27] Water source heat pumps can be a potential technology in both residential and commercial applications, as they have outstanding heating performance. In this study, a small experimental prototype water source heat pump was tested using the Taguchi method to improve the heating performance of the water source heat pump system. In addition, R830 was used as the refrigerant in this system. The coefficient of performance (COP) was done based on Taguchi method and the best parameters were determined.

METHOD

Working principle of the heat pumps

The heat and work concepts and the forms of the energy are measured in the same units, although they are very different in nature.

Heat is the transfer of energy between the system and the environment due to the difference in temperature and Work is not simply an influence of force. It is the transfer of energy to a system that results in a displacement against a resisting force.

Thermal energy typically flows in the direction of decreasing temperature, as per our experience. In simpler terms, we are aware that heat naturally moves from a high-temperature environment to a low-temperature one. This phenomenon occurs spontaneously without the need for any machinery. On the contrary, there is a reverse scenario where heat transfer from a low-temperature environment to a high-temperature environment does not occur spontaneously.

When thermal energy is transferred from a low-temperature environment to a high-temperature environment, then the thermal machine is referred to as a heat pump, particularly when the intended purpose is heating. To visualize functioning of a heat pump, the operation of a common refrigerator that is placed at a window of a house facing outside as its door open to the external environment, can be considered. In this case, the refrigerator would absorb heat from the outside air, which is colder than the inside of the house, convey it into the house. The operational principle of heat pumps is illustrated in Figure 1. The objective is to increase the temperature of the warm environment, by drawing the Q_l heat from colder environment and imparting the Q_h heat into the warm environment, consuming the work W.

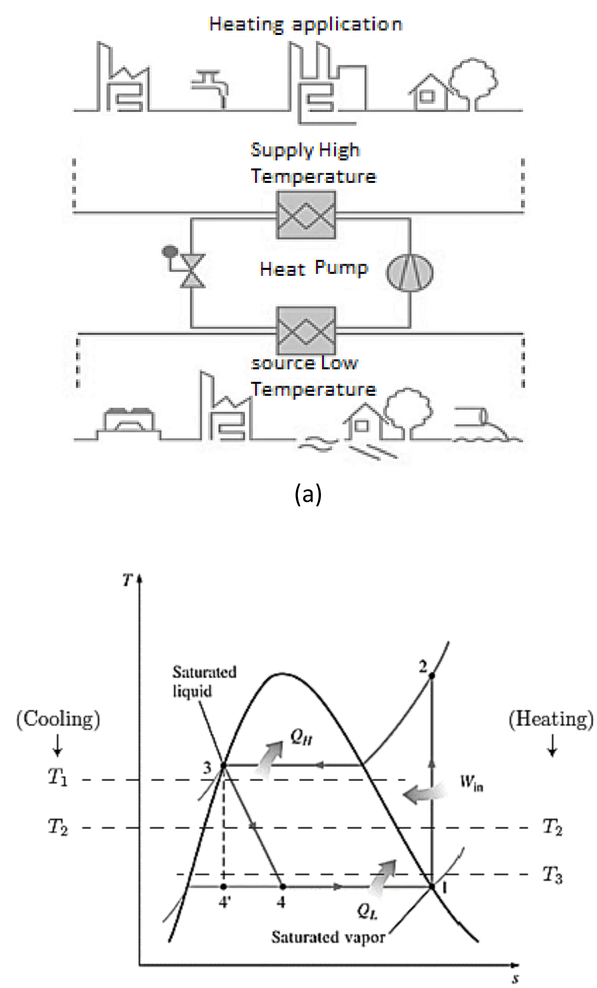

Fig. 1. Schematic view **(a)** and T-S diagram **(b)** of vapor-driven heat pump cycle.

The most important characteristic of a heat pump is the coefficient of performance (COP), which is defined as follows:

$$\text{COP} = \frac{\text{(set point is to be obtained)}}{\text{(value required to be spent)}} = \frac{\text{(cooling effect)}}{\text{(work input)}}$$

There are many theoretical cycles, but reverse Carnot cycle is the most ideal heat pump cycle (Figure 2).

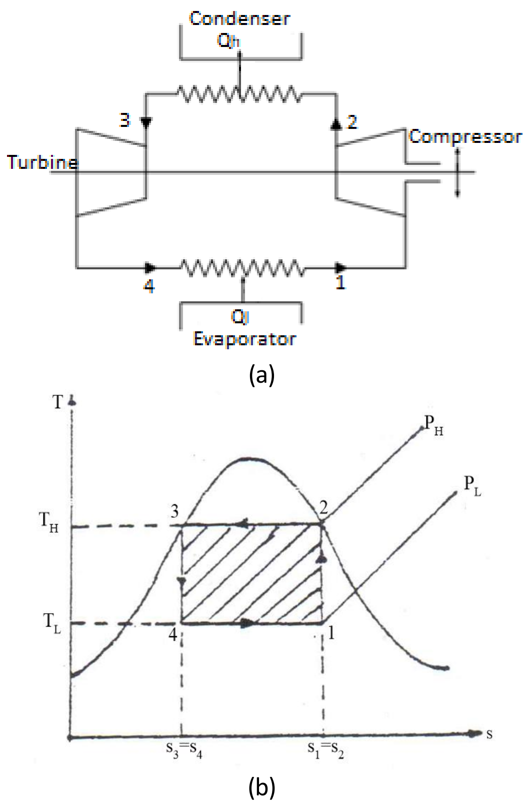

Fig. 2. Schematic view **(a)** and T-S diagram **(b)** of vapor-driven reversed Carnot Cycle

The ideal vapor compression cycle is used in refrigeration and air conditioning systems. It consists of four main processes: compression, condensation, expansion, and evaporation (Figure 3). In the compression stage, between 1 – 2, the refrigerant vapor is compressed adiabatically and isentropically to a high pressure and temperature and gains enthalpy. In condensation stage, between 2- 3, the high-pressure, high-temperature refrigerant vapor is condensed into a liquid by rejecting heat to the surroundings at constant pressure and loses enthalpy and temperature. In the third stage between 3 – 4, expansion occurs and the high-pressure liquid refrigerant is throttled through an expansion valve to reduce its pressure and temperature. This process causes a decrease in enthalpy and pressure. In the evaporation stage, which is the last stage of the cycle between 4 – 1, the low-pressure, low-temperature liquid refrigerant evaporates into a vapor by absorbing heat from the surroundings at constant pressure, resulting in an increase in its enthalpy and temperature.

The cycle is visualized through P-h or T-S diagrams shown in Figure 3. The P-h diagram is a plot of pressure against enthalpy whereas a T-S diagram is a plot of temperature against entropy. In these diagrams, the compression and condensation processes are represented by vertical lines and the expansion and evaporation processes are represented by horizontal lines.

Real vapor compression cycles fall short of the ideal cycle in that real cycles experience friction, pressure drops, and non-isothermal processes (Figure 4). These factors reduce efficiency compared to the ideal cycle's perfect operation. Incomplete evaporation in real systems can lead to wet compression, which further reduces efficiency and can damage the compressor. Real-world factors like ambient temperature and component wear can affect performance more significantly than in the ideal, controlled environment.

There are many problems in the process of the wet compression. The high-pressure fluid in the expansion of low-pressure wet steam with many problems in practice. At the same time, due to the enlargement of a small net loss of work entering the system, an insignificant reduction is made.

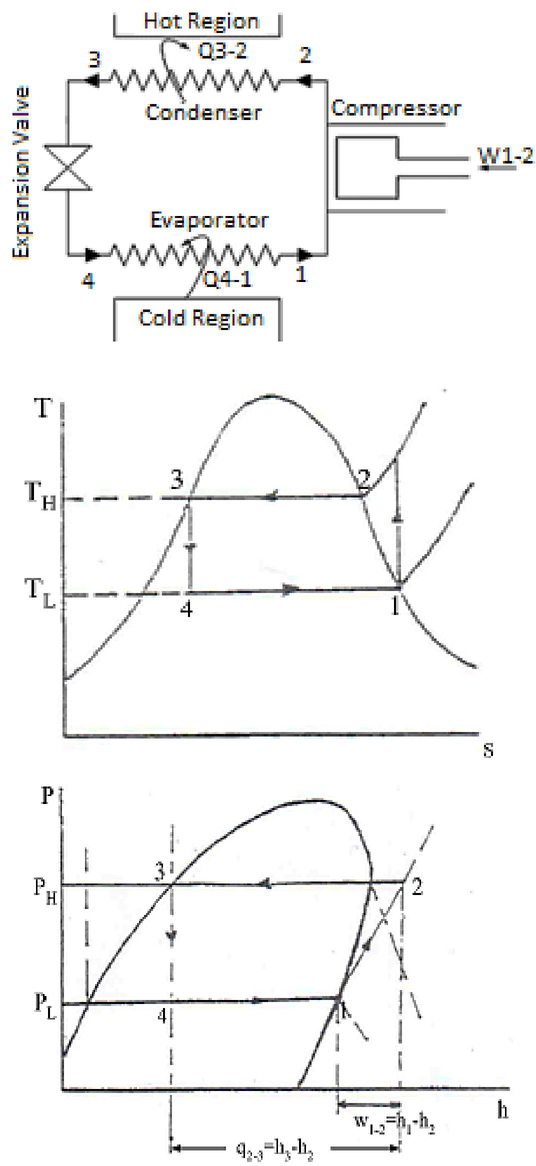

Fig. 3. The ideal vapor compression cycle diagram, and P-h and T-S diagrams.

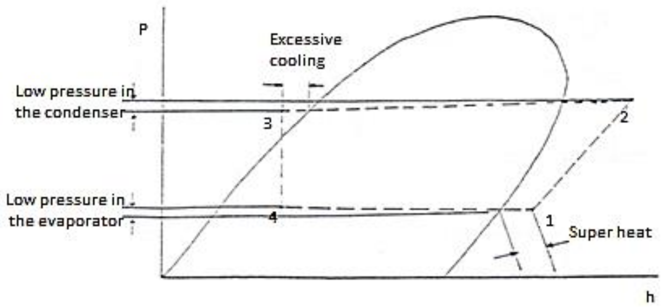

Fig. 4. State Change in a real cycle

Heat pumps are versatile systems that can extract heat from various sources to provide heating or cooling. Therefore, heat pumps can be used when low-temperature common heat sources are available. So, different types of heat pump applications are available based on the heat source they run on. Each type of heat pump system has its advantages and is suitable for different applications and environmental conditions. The choice of a heat source depends on factors such as climate, available space, and the specific requirements of the heating or cooling system. Some typical heat sources for heat pump cycles are as follows:

Air Source Heat Pumps (ASHP) extract heat from the ambient air, even in cold conditions. ASHPs are common in residential and commercial settings. Ground Source Heat Pumps (GSHP or Geothermal Heat Pumps) utilize the relatively constant temperature of the ground to extract or reject heat. GSHPs are highly efficient but may require more complex installation. Water Source Heat Pumps extract or reject heat using a water source, such as a river, lake, or well. Water source heat pumps are efficient but may be limited by the availability of suitable water sources. Hybrid Heat Pumps combine multiple heat sources, such as air and ground, to optimize efficiency and performance in different conditions. Absorption Heat Pumps use a heat source to drive an absorption process, typically involving a refrigerant and an absorbent. Common heat sources include natural gas, solar energy, or waste heat. Gas-fired Heat Pumps combine conventional vapor compression technology with a gas burner, often using natural gas or propane as a supplementary heat source. Solar Thermal Heat Pumps integrate solar collectors to absorb sunlight and generate thermal energy, which is then used as a heat source for the heat pump cycle. Waste Heat Recovery Heat Pumps extract heat from industrial processes, machinery, or other sources of waste heat to improve overall energy efficiency. Air-Conditioning Waste Heat Pumps capture and utilize waste heat generated during the air-conditioning process to provide additional heating.

The schematic view and photographic image of the heat pump system used in the experiments is given in Figure 5. The components and instrumentation of the system is as described below:

Compressor: A hermetically sealed compressor with oil bath cooling. The design ensures appropriate cooling, and installations are protected against excessive heat.

Condenser: Consisting of concentric tube bundles where water flow occurs in a ring.

Expansion Valve: Thermostatically controlled and balanced. R830 controls the amount of gas flow evaporator.

Deflect Valve: R830 keeps the gas separated from air or water.

Evaporator: (I) Used in the air as a Source of Heat Evaporators: Continuous tube and the outer wings. Copper / aluminum galvanized steel construction. For the drops of condensation, the air fan is provided with a cap. (II) Evaporators Heat as a Source of Water Used in: surrounded by the concentric tubes. Water flow is in the ring.

Non-return valves: Prevents the rotation of the evaporator flow which is ideal.

Consolidated Electric Power Measurement Device: A device for measuring the power which is drawn by the compressor.

Water Flow Measurement System: Respectively measure the water flow rate through the evaporator and condenser.

Flowmeter R830 Gas Flow meter: R830 measures the amount of gas mass flow.

Thermometers: Glass temperature measurement points in the regional instruments do this.

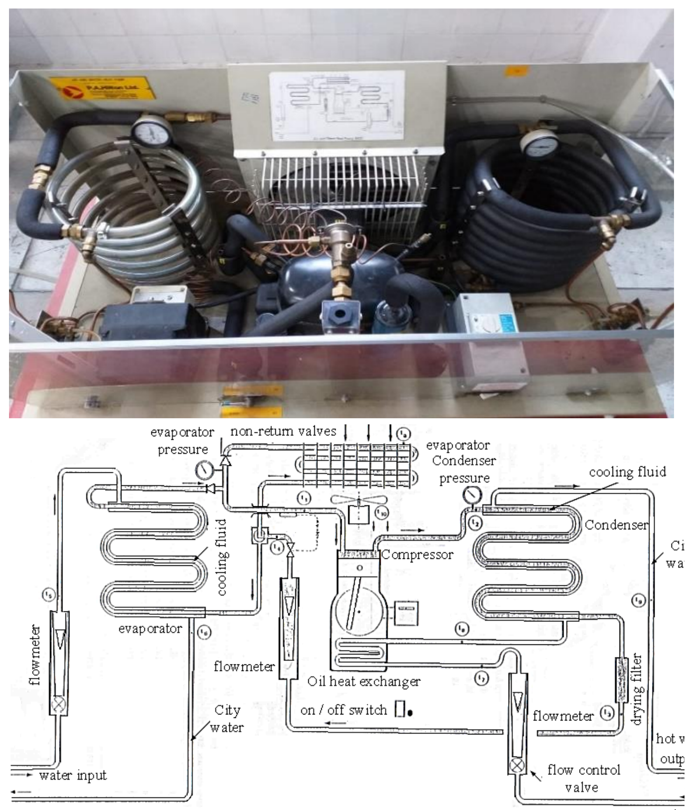

Fig. 5. Air and Water Source Heat Pump (photo and schematic)

Taguchi Method

Dr. Taguchi defined quality as the amount of damage inflicted on society by the production of defective products, and based on this, introduced the method of quality improvement called "Taguchi method". The Taguchi method is completely different from the conventional quality engineering methods. Taguchi methodology emphasizes quality design when designing products and processes. While conventional methods emphasize on inspection and quality control during the production process or after production. In fact, Taguchi believed that the best way to improve quality was to design and create it in the product itself. The Taguchi method greatly reduces the number of experiments using orthogonal arrays (OAs), which are selected with special features from the total number of experiments in the complete factorial method.[29,30] Although the number of parameters of a Process increases, a large number of tests will be required. In the Taguchi method, it is necessary to create a special design set of factors and levels that can cover all experiments. In this study, special design sets consist of orthogonal arrays and it is necessary to use these arrays, to determine the minimum number of experiments required for the four factors at three levels shown in Table 1, and therefore to be carried out with this logic in the experiments.

To achieve the desired quality using the design, the Taguchi method simplified the following three-step process:

Systems Design: The focus of the system design phase is on determining the appropriate working levels of design factors, which includes designing and testing a system based on the engineer's diagnosis of the nominal process parameters based on the desired technology. System design helps determine the working levels of design factors.

Parameter design: Parameter design is concerned with determining the levels of factors that create the best performance of the process under consideration.

Tolerance design: A step used to fine-tune parameter design results. At this stage, the output quality will increase due to limiting the tolerance of factors that have a major impact on process quality.

In other words, The Taguchi method is designed to improve the quality of products and processes in which system performance depends more on factors. In planning experiments and development strategies, simple logic is usually used to create all possible combinations of factors with acceptable ranges in each of the relevant factors.

In engineering projects that have a large number of effective factors, the number of possible combinations is very high. In addition, in certain projects we may need to examine the interactions between the influencing factors. The conventional method of reducing the number of test compounds is to use partial factorial experiments. Taguchi has developed a special set of general designs for factorial experiments that cover most applications. Orthogonal arrays are part of this set of designs. Using these arrays helps us determine the minimum number of tests required for a set of factors.

Orthogonal arrays provide instructions for partial factorial experiments that include a number of test combinations. When all factors are a mixture of the surfaces in question and the interference of the factors is insignificant, standard orthogonal arrays will meet most of the test design needs. Modification of orthogonal arrays is inevitable if there is a mixture of surfaces and interactions.

Using an orthogonal array to design the experiment and the effect of multiple controllable factors on average quality characteristics and variations, while using a signal-noise (S / N) ratio to analyze experimental data, helped designers come to conclusions economically and quickly.[30]

Table 1. Control parameters and levels

	Parameters	**Levels**		
		1	**2**	**3**
A	Evaporator water mass flow rate (g/s)	50	35	20
B	Condenser water mass flow rate (g/s)	18	12	6
C	Evaporator water inlet temperature (C)	15	16	17
D	Condenser water inlet temperature (C)	15	16	17

The degree of freedom (DOF) that is defined separately for each of the input parameters and is equal to the number of levels minus one. Also, the degree of total freedom is equal to the number of trials minus one, and the degree of error freedom is equal to the difference between the total degree of freedom and the sum of the degrees of freedom of the inputs. DOF while related to a process can be calculated for each factor and each interaction as follows:

DoF=(number of levels-1) for each factor + (number of levels-1)(number of levels-1) for each interaction +1*

Heat transfer occurs from high-temperature regions to low-temperature regions. The first law of thermodynamics states that the total energy in a closed system remains constant. In this case, the heat transferred from the high-temperature region can be used for work or be disposed of as waste heat. The Reverse Carnot Cycle offers a theoretical ideal for refrigeration. By analyzing this cycle, we can derive a formula for COP that represents the maximum achievable efficiency for a refrigerator or heat pump operating between specific temperature reservoirs.

Accordingly, for the Reverse Carnot Cycle, COP_h is:

$$COP_H = \frac{T_H(s_2 - s_3)}{(T_H - T_L)(s_2 - s_3)} = \frac{T_H}{T_H - T_L} \quad (1)$$

Vapor Compression Cycle is achieved while the reversible operations in the reverse Carnot cycle cannot be performed.

Through P-h diagram,

$$W_{1-2} = h_2 - h_1 \quad \& \quad Q_{2-3} = h_2 - h_3 \quad (2)$$

$$q_{4-1} = h_1 - h_4 \quad (3)$$

$$COP_H = \frac{h_2 - h_3}{h_2 - h_1} \quad (4)$$

Real vapor compression cycle is the reverse of the adiabatic compression. The reason for that is the effect of the compressor in addition to the heat transfer and friction.

Table 2 shows an L27 orthogonal array with 27 rows which is related to the number of parameter combination. After we analyze the experimental results, we see that the variability in the performance of the product goes through a reduction by using control parameters to the target value by using the adjustment parameter(s). It can be said that if all factor interactions in experiment systems, which include three factors at three levels, are considered, L27 orthogonal array would be the most appropriate experiment plan. Further, it is possible for us to use it effectively to regression and correlation analysis as it includes all combinations of factors and levels. We see a new experimental design method, such as orthogonal array (OA), performance statistics (signal-to-noise ratio) in Taguchi method which is different from traditional methods. In this study, we have 27 experiments (each row in the L27 orthogonal array) and assigned the columns of OA to factors and their interactions. We should determine optimum working using experimental data and provide the same or very close performance values (COP and energy efficiency) in similar or different working environments.

Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal to noise ratio (SNR). Taguchi recommends the use of the SNR to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the SNR, i.e. the-lower-the-better, the-higher-the-better, and the nominal-the-better. The SNR for each level of process parameters is computed based on the SNR analysis. Regardless of the category of the quality characteristic, a greater SNR corresponds to superior quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest SNR. All experiments are conducted as shown in experimental plan in Tables 2&3. Contribution ratios of all factors on the performance criteria are defined depending on the SNR as given in Tables 2&3. The optimal combination of the process parameters can be predicted. Finally, an experiment of confirmation is conducted to verify the optimal process parameters which are obtained from the parameter design.

Table 2. Orthogonal array for L27 design

Experimental NO	**Parameters and their levels**						**COP**		**SNR**
	A	**B**	**C**	**D**	**E (empty)**	**F (empty)**	**Repetition 1**	**Repetition 2**	
1	1	1	1	1	1	1	1.945447	1.64440	4.98920
2	1	1	1	1	2	2	2.115925	2.27076	6.80589
3	1	1	1	1	3	3	2.682511	3.38989	9.46940
4	1	2	2	2	1	1	2.948255	1.00241	2.55609
5	1	2	2	2	2	2	3.118732	1.41998	5.23776
6	1	2	2	2	3	3	3.685319	2.16606	8.43503
7	1	3	3	3	1	1	3.354392	0.45909	3.83242
8	1	3	3	3	2	2	3.920979	0.66787	0.62007
9	1	3	3	3	3	3	3.920979	1.04091	3.06283
10	2	1	2	3	1	2	2.348075	1.64440	5.59730
11	2	1	2	3	2	3	2.744685	2.27076	7.86908
12	2	1	2	3	3	1	2.22874	3.38989	8.41126
13	2	2	3	1	1	2	1.481147	0.91817	0.85652
14	2	2	3	1	2	3	1.877758	1.33574	3.74644
15	2	2	3	1	3	1	1.361813	2.08183	4.14566
16	2	3	1	2	1	2	2.183113	0.54813	2.47745
17	2	3	1	2	2	3	2.579723	0.75692	0.23263
18	2	3	1	2	3	1	2.063779	1.12996	2.93289
19	3	1	3	2	1	3	1.474128	1.50361	3.45585
20	3	1	3	2	2	1	1.179302	2.12996	3.28153
21	3	1	3	2	3	2	1.247493	3.24910	4.33385
22	3	2	1	3	1	3	1.56438	1.09627	2.07364
23	3	2	1	3	2	1	1.273566	1.51384	2.78647
24	3	2	1	3	3	2	1.341757	2.25993	4.25241
25	3	3	2	1	1	3	1.073004	0.54813	3.21896
26	3	3	2	1	2	1	0.778179	0.75692	2.30038
27	3	3	2	1	3	2	0.84637	1.12996	0.37263

Statistical analysis

In statistical analysis, the ANOVA (Analysis of Variance) and regression are commonly used techniques to assess the relationship between variables and to determine the significance of these relationships. These methods are essential for understanding the impact of different factors on a response variable and for making informed decisions based on the data. ANOVA is used to compare the means of three or more groups to determine if there is a statistically significant difference between them. It provides insights into the variation within and between groups, allowing us to assess the impact of different factors on the response variable.

Regression analysis, on the other hand, is used to model the relationship between a dependent variable and one or more independent variables. It helps us understand how the independent variables affect the dependent variable and allows us to make predictions based on the model. Both ANOVA and regression analysis are conducted at a specific confidence level, such as 95%, to ensure that the results are statistically significant and reliable. In this study, Statistical analyses (ANOVA, regression) were performed for a 95% confidence level.

(S/N) analysis

Taguchi method employs a signal-to-noise ratio (S/N) to measure the present variation. The definition of (S/N) ratio differs according to an objective function, i.e., a characteristic value. There are three kinds of characteristic value: Nominal is Best (NB), Smaller is Better (SB) and Larger is Better (LB).

(S/N) ratio of LB is formulated as follows:

$$\frac{S}{N} = -10 * \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{\,2}}\right) \tag{5}$$

In equation 5, n is the number of measurements, the measured characteristic value, and the unit of the (S / N) ratio is decibels.

Analysis of variance

In the experiments of this study, the Taguchi method minimizes the variability around the target while bringing the performance value to the target value and another advantage is that the working conditions can be reproduced in the optimum real applications determined by the laboratory study. Since the partial experiment is only an example of the complete experiment, the analysis of the partial experiment includes a confidence analysis that can be placed in the results. however, a standard statistical technique called ANOVA was used.

ANOVA determines the significance of individual factors and interaction effects, so (S / N) performance statistics, (n), number of repetitions for an experimental combination, and (Y_i) are performance values of the experiment. The variance ratio, commonly referred to as the F statistic, is the variance ratio caused by the variance and error term caused by the effect of a factor, and this ratio was used to measure the importance of the investigated factor according to the variance of all the factors included in the error term.

To create an ANOVA table, following steps were followed:

- the total mean of the observations was calculated
- the sum of squares between (SSB), which is the variance due to the interaction between the different levels, was calculated
- the sum of squares within (SSW), which is the variance within each level, were calculated
- the sum of squares total (SST), which is the total variance in the data, was calculated
- the degrees of freedom between (DFB) and within (DFW were calculated.
- the mean square between (MSB) and mean square within (MSW) were calculated by dividing the sum of squares by the respective degrees of freedom.
- the F-statistic was calculated by dividing MSB by MSW.
- finally, the p-value was determined using the F-statistic.

As seen in Table 3, the sum of squares between groups (SSB) is very small, indicating that the variance between the different factors is minimal. The sum of squares within groups (SSW) is much larger, suggesting that there is more variance within the levels of each factor. The F-value is extremely small, and the P-value is effectively 1.0, which suggests that there is no statistically significant difference between the means of the different factors at the conventional significance levels. This implies that, based on the ANOVA, the factors do not have a statistically significant effect on the response variable. However, the practical significance should also be considered in the context of the specific domain or application.

In the Taguchi method, the experiment corresponding to the optimum working conditions might not have been undertaken during the whole period of the experimentation. In such cases, the performance value corresponding to optimum working conditions can be predicted by utilizing the balanced characteristic of the OA.

Table 3. ANOVA Table

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value	P-Value
Between Groups	1.0944444e-07	5	2.188889e-08	7.0704573e-09	0.999999
Within Groups	37.14988317	12	3.095823597		
Total	37.14988328	17			

Analysis of variance (ANOVA) was used to examine the importance of trust and effect of adjustable and independent parameters on performance, and in Taguchi method, additive model was created and used to estimate the effect of control factors on response.

In Figure 7, each factor's distribution is visualized as overlaid with varying colors. The histogram provides a visual comparison of the frequency and spread of the response variable across different factors.

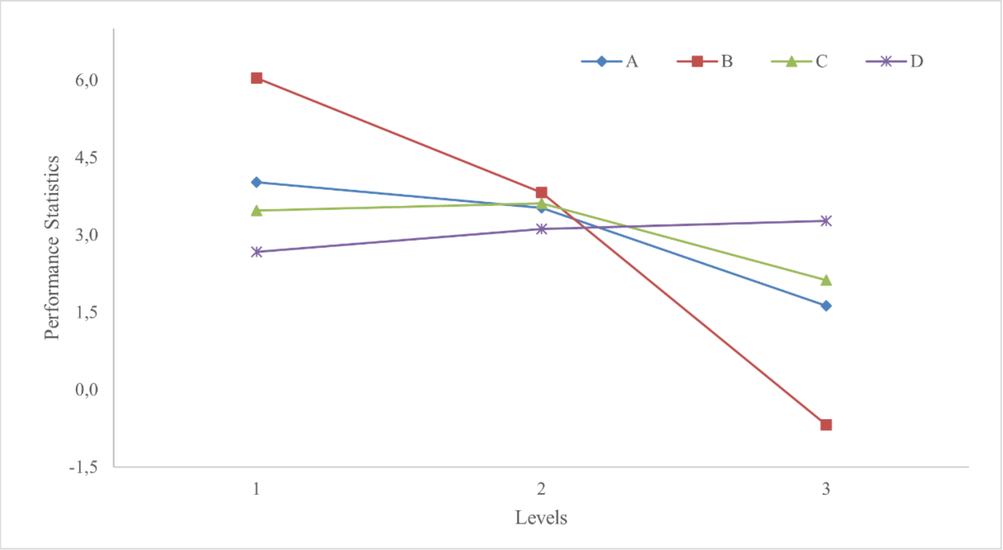

Fig. 6. The effect of the parameters used on the coefficient of performance (COP).

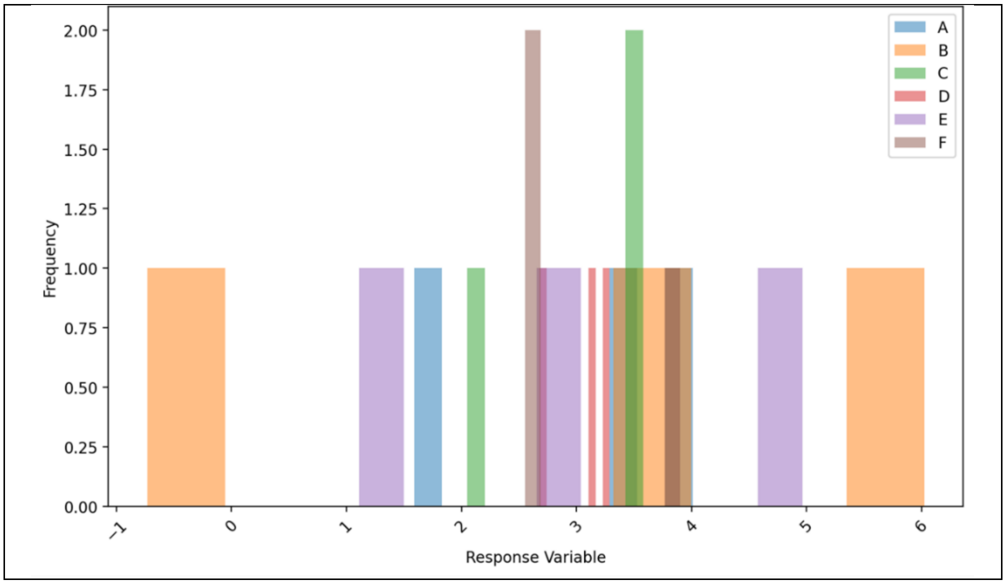

Fig. 7. A histogram of distribution of Response Variables by Factor

Table 4. Variance analysis for efficiency

Level	A	B	C	D	E	F
1	4.0115	6.0237	3.4517	2.6801	1.1111	2.5523
2	3.4794	3.7878	3.5794	3.1098	3.0044	2.6237
3	1.588	-0.732	2.0478	3.2889	4.9634	3.9029
Delta	2.4235	6.7563	1.5316	0.6088	3.8523	1.3506
Rank	3	1	4	6	2	5

The deltas and ranks help in prioritizing which factors to focus on for further analysis or optimization. Factors with higher ranks (lower delta values) might be considered less critical to the outcome of the process or system being studied. As seen in Table 4, Factor B has the highest delta (6.7563), indicating that it has the most significant effect on the response variable. It is ranked 1, confirming its strong influence. Factor A and Factor E are the next most significant factors, with deltas of 2.4235 and 3.8523, respectively, and ranks of 3 and 2. These factors also have a considerable impact on the response variable. Factor C and Factor F have moderate deltas (1.5316 and 1.3506) and are ranked 4 and 5, indicating a lesser but still notable effect on the response variable. Factor D has the smallest delta (0.6088) and is ranked 6, suggesting it has the least impact on the response variable among the factors tested.
After the (S / N) analyzes were calculated, the (ANOVA) analysis verification tests were carried out using the experimental results, so that first the optimum parameters were selected and then, using these parameters, to predict and verify the improvements in performance characteristics. The results of validation experiments using optimum design parameters are presented in Table 5 and comparisons between estimated and actual (COP) are shown. As can be seen in Table 5, it is seen that there is a good agreement between the estimated and actual (COP) values. By comparison of the initial parameters and the optimum parameters which are obtained by the Taguchi approach, it is observed that the improvement of (S/N) ratio for (COP) value is 3.375. Using the results from validation experiments, the Taguchi approach validated in optimization of design parameters.
The boxplots illustrate the distribution of COP values obtained in repetitions across different levels of parameter B. The variation within each level of B and the median values can indicate how parameter B might influence the COP values. It provides a clear visualization of how the COP values vary across different levels of parameter B. For the COP in the first repetition, the boxplots show the median, interquartile range, and outliers for COP1 at each level of parameter B. It can be observed how the median COP value in repetition 1 changed with different levels of B, and whether there were any significant differences in the distribution across these levels. For COP in the first repetition, similarly, we can identify differences in the distribution of these two COP values with respect to parameter B by comparing the boxplots.

Regression Analysis

The regression analysis done has revealed that the model has a high R-squared value of 0.975, indicating that the independent variables explain a large portion of the variance in the dependent variable, COP. The F-statistic is significant with a probability of 3.47e-08, suggesting that the model is a good fit for the data. The coefficients for the independent variables A, B, C, D, E, and F have been estimated along with their standard errors, t-values, and p-values.

Table 5. Optimum working parameters

Optimums		Parameters				COP		
		A	B	C	D	Prediction	Confidence interval	Real
COP	Level	1c	1b	2d	3a	2.7	1.48 - 3.92	3.375
	Value	50	18	16	18			
General	Level	1	1	2	3	2.7	1.48 – 3.92	3.375
	Value	50	18	16	18			

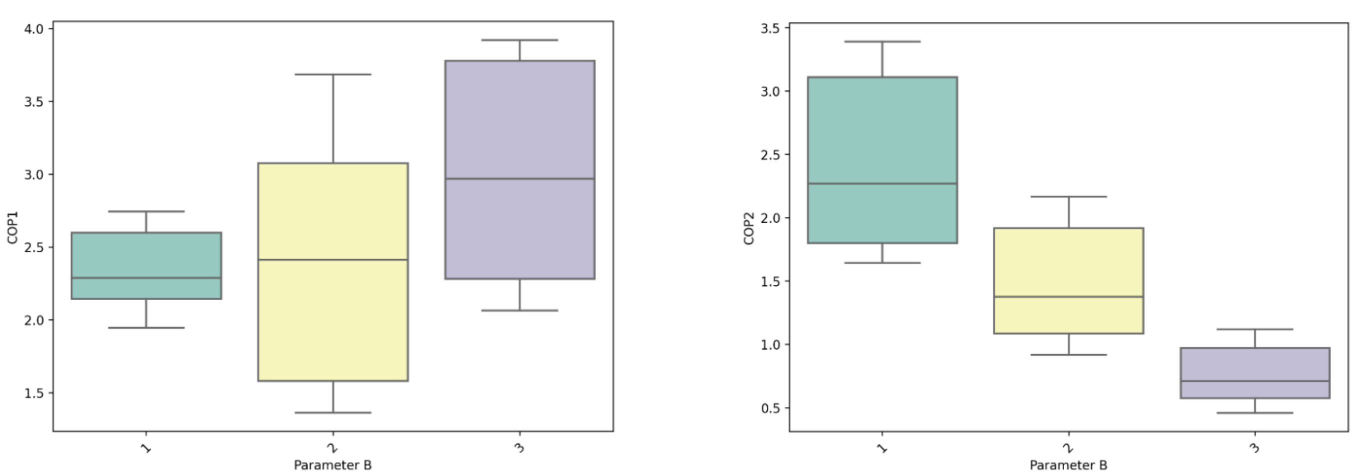

Fig 8. Correlation between the levels of factor B and COP values obtained in repetitions of experiments

The output of the regression analysis is presented in three tables, Table 6, Table 7 and Table 8. Table 6 provides an overview of the regression results, including the R-squared value, the F-statistic, and other statistical measures. The second table displays the coefficients, standard errors, t-values, and p-values for each independent variable, along with their 95% confidence intervals.

The R-squared value of 0.975 indicates that the model explains 97.5% of the variance in the dependent variable, COP. This suggests that the independent variables A, B, C, D, E, and F collectively have a strong explanatory power for COP.

Looking at the coefficients presented in Table 7, it can be seen that the constant term has a value of 1.8704, and the coefficients for A, B, C, and D are -0.9804, 0.1924, 0.0134, and 0.5363, respectively. The t-values and p-values provide information about the statistical significance of each coefficient. In this case, A, B, and D are statistically significant, while C is not.

Several diagnostic tests were conducted to assess the validity of the regression model and results are presented in Table 8. Omnibus/Prob(Omnibus) tests the hypothesis that the residuals are normally distributed. A lower value indicates a closer approximation to the normal distribution. In this case, the Omnibus value is 1.689 and the Prob(Omnibus) is 0.43, suggesting that the residuals could be normally distributed since the p-value is not low enough to reject the normality assumption.

Durbin-Watson diagnostics tests for the presence of autocorrelation in the residuals from a regression analysis. The value ranges from 0 to 4, with values around 2 suggesting no autocorrelation. The Durbin-Watson statistic here is 2.258, which is close to 2, indicating a low likelihood of autocorrelation. Jarque-Bera (JB)/Prob(JB) is another test of the normality of the residuals. A large JB value indicates that the residuals are not normally distributed. Here, the JB value is 0.34 and the Prob(JB) is 0.843, which again suggests that the residuals are normally distributed.

Skewness statistic measures the asymmetry of the probability distribution of the residuals. A skewness value of 0 indicates that the residuals are perfectly symmetrical. Here, the skewness is 0.053, which is very close to 0, suggesting the residuals are fairly symmetrical. Kurtosis, on the other hand, measures the 'tailedness' of the distribution of the residuals. A kurtosis value of 3 indicates a normal distribution. The kurtosis value here is 3.665, which is slightly higher than 3, suggesting a leptokurtic distribution (with slightly heavier tails than a normal distribution).

Condition number measures the sensitivity of the model's output to its input. A high condition number indicates potential multicollinearity or other numerical problems. The condition number here is 28.4, which does not indicate a severe multicollinearity problem.

Table 6. Ordinary Least Squares (OLS) Regression Results

Dep. Variable:	COP	***R-squared:***	0.975
Model:	OLS	***Adj. R-squared:***	0.962
Method:	Least Squares	***F-statistic:***	72.02
No. Observations:	18	***Prob (F-statistic):***	3.47e-08
Df Residuals:	11	***Log-Likelihood:***	12.761
Df Model:	6	***AIC:***	-11.52
Covariance Type:	nonrobust	***BIC:***	-5.289

Table 7. Coefficients, standard errors, t-values, p-values, and 95% confidence intervals for each independent variable.

	Coefficients	**Std Err**	**t**	**P>|t|**	**[0.025**	**0.975]**
Const	18.704	0.202	9.266	0.000	1.426	2.315
A	-0.9804	0.072	-13.652	0.000	-1.138	-0.822
B	0.1924	0.046	4.150	0.002	0.090	0.294
C	0.0134	0.046	0.288	0.778	-0.089	0.115
D	0.5363	0.046	11.570	0.000	0.434	0.638
E	0.0698	0.045	1.537	0.152	-0.030	0.170
F	0.2816	0.045	6.200	0.000	0.182	0.382

Table 8. Values for several diagnostic tests

Omnibus:	1.689	**Durbin-Watson:**	2.258
Prob(Omnibus):	0.430	**Jarque-Bera (JB):**	0.340
Skew:	0.053	**Prob(JB):**	0.843
Kurtosis:	3.665	**Condition Number**	28.Nis

These diagnostics indicate that the model does not violate the assumptions of linear regression significantly. Overall, the regression analysis indicates that the model is a good fit for the data, and the coefficients for A, B, and D have a statistically significant association with the dependent variable COP.

CONCLUSION

In this experimental study, the effect of water on the inlet and outlet flow rate and temperature was optimized with the Taguchi experimental design method and then obtained according to the analysis of the optimum parameter combination (S / N) ratio for the minimum inlet and outlet water flow, temperature and maximum heat transfer. (ANOVA) analysis using the obtained ratios and the contributions of the parameters on the performance characteristics were determined. At the end of this study, the validity of the approach of the Taguchi test method was checked by using the data of the validation experiments. The results obtained are expressed below:

• In this study, if the Taguchi method is not used 148 routine experiments may be required. however, to provide a significant advantage in both time and cost, the number of experiments was reduced to 27 after Taguchi used an experimental design.

• Optimum parameter levels for maximum heat transfer are determined as A1, B1, C2 and D3, but changes may occur in heat transfer according to Reynolds number and pressure values.

• The results of the experiments performed at the predicted values and optimum parameter levels using the Taguchi approach were compared with the results of the validation experiments.

• Quite satisfactory and close agreements appear between the predicted and experimental values, and this demonstrated that the Taguchi approach has been successfully used to determine optimum design parameters for heat pumps.

• The Taguchi method is a strategy to improve the quality of the process and achieve a reinforced product using the experimental design method and can be used in most heat transfer tests.

The study successfully applied the Taguchi method to determine the optimal conditions for high yields of heat water while it was validated by running a four-factor, three-level experimental design. The collected data were analyzed by using ANOVA-TM computer software package for evaluation of the effect of each parameter on the optimization criteria. The results obtained for investigating the performance of the heat pump after conducting the experiments are summarized as follow:

•The contributions of all the working parameters (heat input, fluid mass and flow rate) in heat pump performance have equal importance.

•The overall heat transfer coefficient of heat pipe of pump is almost same for all levels.

•Taguchi optimal solutions give the better results for heat pump operations while it also reduces the number of experiments that are required for finding its performance metrics.

•The experimental results show that the heat of water input and flow rate plays an important role in the operations of heat pipe and these contributions are almost equal.

The numerical value of the maximum point in each graph shows the best value of that particular parameter which is given in Table 5 for each one. Further, they indicate the optimum condition in the range of the experimental conditions. It may be stated that as the optimum conditions determined by the Taguchi method in a laboratory environment are also reproducible in the real production environments, the findings of the present laboratory-scale study may be very useful for heat pump applications in the industrial scale. The raw water source provides a favorable heat source compared to an ambient air source except for the time of spring as the ambient air temperature is higher than the raw water temperature by 18 ◦C during this time. In spring and autumn, the heating and cooling loads are extremely low which is the main reason of the poorer performance of the raw-water heat pump system in these seasons. The average unit COP in the heating season is low while the average unit COP for the cooling season increases.

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