Improving the performance of air conditioning system experimentally by a new type of heat pipe heat exchanger

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\textbf{ABSTRACT}

The air conditioning system efficiency is measured by it is coefficient of performance (COP). Higher COP means better system. However, the improving of COP is not an easy work since it linked the heat rejected by the system to power consumed by mechanical part in system, especially the compressor. In this study, a smart employing of heat pipe heat exchanger (HPHE) is used to reduce the power consumed by compressor through super heating the refrigerant vapor pre-enter the compressor and improve the cooling capacity. The results show that using (HPHE) improves the COP of the system by 10\% compared to other conventional system.

\textbf{Key words:} HPHE, COP, Air conditioning, Two phase heat exchanger, Gravity assist heat pipe heat exchanger.

1. Introduction

The vast growing in modern technology and employing such technology in industry lead to reduce product prices. Low prices mean more availability and wide use of differential devices to bring luxury to human everyday life. Most of these devices are run by electricity directly or need to be charged in advance to use them. In both cases, the result is one, expand in power demand and the power plants have to stand for cover this
The growing need. In dry regions or in extreme hot weather area, the using of air conditioning devices turn from being luxury to be essential for most people, especially in residential building, in middle east the air conditioning consumes more than 60% of the total generated power during the summer session. The line of consumed energy still moving up and at the same time the amount of the emission and green gases from burning fossil fuel to generate electricity are piling every day. Therefore, finding smart engineering solution to reduce the energy needed to run the air conditioning devices will reflect on the power demand. In air conditioning devices, compressor consumes most of the electrical power because it is used to compress the refrigerant from evaporator low pressure to high pressure at condenser, higher difference in pressure lead to high energy consumes, but at the same time higher difference means good range of work. So, in this study, the heat pipe technology is used smartly to raise up the pressure of the refrigerant before enters the compressor and reduce the pressure before enters the condenser. The heat pipe works as a closed heat exchanger which employs the physical properties of the working fluid to remove or transfer heat energy between the heat pipe terminals. In refrigeration cycles, heat pipe is used for dehumidification or heat recovery. Using heat pipe in dehumidification can reduce the energy consumption of air handling unit with air return between 23-27% as reported by (1-8). A recommendation of using heat pipe exchanger to control the dehumidification enhancement in tropical HVAC was introduced by (9) based on a study conducted using 8-row thermosyphon-based heat pipe heat exchanger (HPHX) for tropical building HVAC systems. The effect of the heat pipe location in air conditioning system on system COP was studied by (10) his finding was that the best location of the heat pipe a cross the cooling coil. Increasing of dehumidification capacity and cooling capacity by using of pump-assisted separate heat pipe (PASHP) was reported by (11), he used four sets of PASHP filled into R134a as the working fluid and his conclusion was that using PASHP has a significant enhancement on dehumidification and cooling capacity. The effect of using oscillating heat pipe heat exchanger with methanol, mix of water and methanol and water as working fluid on dehumidification was conducted by (12) and they reported an enhancement between 17-25%. Also using heat pipe exchanger to enhance the condensing unit performance is reported by (13), the study shows an increase by 3.11% in energy efficient ratio (EER) of the system. On the other hand, using heat pipe as heat recovery tool are common in many applications (14-21).

To the best of author’ knowledge, there are many paper presented on the thermal performance improvement of the air conditioning system with various techniques to reduce energy consumption. However, a smart employing of heat pipe heat exchanger (HPHE) in the air conditioning system has not mentioned. Therefore, there are not the previous papers for validated the present study. The objective of this paper is to study the improvement performance of air conditioning system with HPHE for subcooling the refrigerant in capillary tube and superheated it before interring the compressor. The
results show that using (HPHE) improves the COP of the system by 10% compared to other conventional system.

2. Experimental test apparatus

The main objective of experiment is to study the thermal performance of direct expansion air conditioning system the influence after install heat pipe heat exchanger. The studied parameters are AC system with/without HPHE and sub-tropical weather conditions (Iraq regain). A special gravity assist heat pipe heat exchanger was designed, manufactured and installed as shown in Fig. 1. A Copper shell has two cylindrical ends the bottom represents the evaporator HPHE section and collects the liquid phase of the working fluid. The capillary tube which carries a hot liquid R22 returns from condenser penetrates and submerges in a liquid working fluid. The upper section represents the condenser HPHE section, where the section pipe back from evaporator and carries cold R22 vapor comes through the upper section before inter the compressor.

Fig. 2 shows the comparison between the conventional HPHE and the type used in the present work. Where the vapor is generated by contacting the working fluid with the outer surface of the capillary tube and the bubbles separate to leave the liquid after completion of growth and by the buoyancy force to rise to the condensation area. Then dew contacting of the vapor with the outer surface of the cold tube condenses in a layer and then returns to the bottom by gravity.

The applicable parameters for the as-designed experimental HPHE and AC system are shown in Table 2.

The HPHE is covered with 5cm glass wool as insulation to minimize heat loss. Eight K-type thermocouples are used to measure the temperatures of refrigerant before and after each vapor compression cycle as well as the HPHE inlet/outlet temperatures. An acquisition system (T7 Series Lab-Jack type, USA) was used to record the Measured temperatures every five seconds.

2.2 Data reduction and Error analysis

HPHE effectiveness is a significant parameter that expresses the overall thermal performance of HPHE, which is represented by the ratio of heat rejected in condenser section to the heat add in evaporator section or in this application could be represented as:

$$\eta = \frac{Q_{\text{cond,HPHE}}}{Q_{\text{Evap,HPHE}}} = \frac{Q_{\text{superheat}}}{Q_{\text{subcool}}} = \frac{(h_4-h'_4)}{(h'_1-h_1)} \equiv \frac{\Delta T_{\text{superheat}}}{\Delta T_{\text{subcool}}}$$ (1)

Where $Q_{\text{superheat}}$ is the heat add to the vapour of refrigerant in the suction pipe process (1-2) as shown in Fig. (3) (where the subscripts, 1 to 4 indicate the thermodynamic states. States 1-2 refer to the isentropic compression suction and discharge, states 2-3 represent the superheated vapor inlet and saturated or sub cooled liquid exit conditions of the condenser, states 3-4 refers to the throttling process condition across the capillary tube, and states 4-1 refers to the inlet and saturated or superheated vapor at exit conditions.
across the evaporator). And $Q_{\text{subcool}}$ is the heat rejected from liquid refrigerant during capillary tube as process (2-3).

The refrigerant mass flow rate ($m_r$) with and without HPHE according the variation of different parameters can be calculated from:

$$
m_{r \text{ without HPHE}} = \frac{IV\cos\phi}{(h_2-h_1)} \tag{2}$$

$$
m_{r \text{ with HPHE}} = \frac{IV\cos\phi}{(h'_2-h'_1)} \tag{3}$$

Where $h_1$ and $h_2$ are the specific enthalpy of refrigerant during the isentropic compression process (without HPHE) as shown in Fig. : $h'_1$ and $h'_2$ are the specific enthalpy of refrigerant during the isentropic compression process (with HPHE). $I$, $V$ and $\cos\phi$ are the current, voltage and power factor respectively.

The condenser capacity can be expressed as:

$$Q_{C \text{ without HPHE}} = m_r(h_2 - h_3) \tag{4}$$

$$Q_{C \text{ with HPHE}} = m_r(h'_2 - h_3) \tag{5}$$

The coefficient of performance COP for the two AC systems can be determined from:

$$COP_{\text{without HPHE}} = \frac{(h_1-h_4)}{(h_2-h_1)} \tag{6}$$

$$COP_{\text{without HPHE}} = \frac{(h'_1-h'_4)}{(h'_2-h'_1)} \tag{7}$$

In any system with measurement the results have a margin of uncertainty usually comes from errors of the instrument, human professionalism and calibration errors. Table1 shows the uncertainty and error analysis of the measurement. Based on these uncertainties, the uncertainty of the total COP is indicated to be± 5% which is the error can be obtained by using the Root-Sum-Squares (RSS) uncertainty method [15] as follows:

$$U_{COP} = \sqrt{\sum_{i=1}^{n}(\frac{\partial COP}{\partial X_i} \Delta X_i)^2} \tag{8}$$

3. Results and discussion

There are many factors and parameters that play crucial rules in the study of the thermal performance of a vapor compression cycle with heat pipe heat exchanger. One can notice the number of the wide range of steady-state DBT and mostly dry air at 10% RH are used to represent the climate outside air conditions since these values are represented the typical summer hot weather in Iraq [21].

Table (4) shows the maximum expected effect of add HPHE on the A/C system (power consumption, refrigerant effect, cooling capacity and COP), these quantities are shown in Fig. (4)
on the P-h chart. Fig. (4) shows the effect of add HPHE and without HPHE on the P-h chart at three BDTs 45, 50 and 55ºC. It is obvious from these figures that the system with HPHE in all cases has an increasing in refrigeration effect (cooling capacity) due to the sub cooling the liquid refrigerant in HPHE before entrance the evaporator (process (3-3')) and the increasing the refrigerant mass flow rate within the range (6-10) %, whereas the reductions in energy used in compressor are (2-5) %. It implies that the AC unit worked at design value cooling capacity or larger than it and reduced the fluctuation voltage effect on the compressor at the peak hot weather conditions (The voltage drop during severe hot weather is one of the most challenging obstacles that still unsolvable in Middle East region and especially in Iraq, where the National Power Network is old and the voltage drops from 220 to about 190 V during the peak time in summer. The power that is consumed in A/C systems is related to the applied voltage and input current, for instant, an A/C system takes 5-6 A when the voltage is 220 V. Also, Fig. (4) show that a sub cool phenomenon occurs in the capillary tube (supported by HPHE) and this insure that the refrigeration capacity will be increased and it is recorded within the range of (5-7.5) % for each ton of refrigeration.

In all air conditioning systems that work with the principle of the vapor compression cycle without HPHE, the saturated vapor refrigerant (1) was compressed isentropically by compressor unit and inter the condenser unit as a superheated state (2). After that the refrigerant at saturated liquid state (3) flows out the condenser. However, because of the global warming problem and the harsh subtropical summer climate for four months in the Middle East region, the outside air temperature usually increases which results in decrease cooling capacity as well as the COP for the AC systems. Therefore, increase subcooled level of refrigerant liquid before entering the expansion devise has been introduced as one of techniques for increase refrigeration effect and refrigerant mass flow rate indeed it improved the COP.

Average enhancements in COP due to using HPHE instead of conventional AC system (without HPHE) are shown in Fig. 5, where the percentage enhancement (Φ) is defined as,

\[
\phi = \frac{\text{COP}_{\text{wit:out HPHE}} - \text{COP}_{\text{wit:out HPHE}}}{\text{COP}_{\text{wit:out HPHE}}}
\]

(9)

Fig. 5 shows the percentage of COP enhancement related to the case of original AC system ((without HPHE)), It is clear that add HPHE to the AC system has a more remarkable influence on COP than without it. The COP enhancement percentage of vapor compression cycle using the HPHE can reach a maximum of approximately 10%.

4. Conclusions
The change in climate and continuous raise in temperature especially in dry region combined with increase in urban cities and modern living standard shows the significant need to energy. The air conditioning systems consume most of the power of domestic energy bill. The results of current work show that a significant improve in COP of domestic type air conditioning system (window type) when add HPHE. The HPHE works on increasing the thermal performance of the system which significantly improve the COP. The highest value of COP is around 10% compared to reference system.

5. References

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Table 1: Design specifications of the experimental rig components.

| Specifications                                      | Value                                                                 |
|-----------------------------------------------------|----------------------------------------------------------------------|
| A/C system window type                              |                                                                      |
| Cooling capacity at indoor design condition DBT 25 °C and RH 50%, outdoor design condition DBT 40 °C and RH 50% | 7 Kw                                                                |
| Refrigerant charge                                   | (R22) 1.8 Kg                                                          |
| Expansion device,                                    | capillary tube with diameter 2mm                                     |
| HPHE                                                |                                                                      |
| Working fluid container                             | Copper thickness 2mm                                                  |
| Evaporator section                                  | Copper tube thickness 1mm with inner diameter 2mm and 2m length      |
| Adiabatic section                                   | 3 cm                                                                 |
| Condenser section                                   | Copper tube thickness 1mm with inner diameter 12mm and 50cm length   |

Table 2: Uncertainty of measurement systems.

| Parameter   | Instrument                     | Accuracy (%) | Total uncertainty (%) |
|-------------|--------------------------------|--------------|-----------------------|
| Temperature | K-type thermocouple, ºC        | 0.1          | ±0.3                  |
|             | Data logger, ºC                | 0.1          | ±0.19                 |
| Pressure    | Gage pressure, bar             | 0.01         | ±0.232                |
| Electric power | Multi power meter          | 0.05         | ±0.18                 |
Table 3. The experimental results for three working fluids with and without HPHE

| Parameters                                 | Unit | Working fluid water at FR=100% |
|--------------------------------------------|------|-------------------------------|
|                                            |      | A/C without HPHE A/C with HPHE A/C without HPHE A/C with HPHE A/C without HPHE A/C with HPHE |
| Dray bulb temperature for atmospheric air  | ºC   | 45 50 55                        |
| Inlet Condenser temperature ($T_2$)        | ºC   | 87.3 90.2 89.4 91.5 93.5 99.1   |
| Outlet Condenser temperature ($T_3$)       | ºC   | 59.5 56.8 62.2 58.5 65.5 61     |
| Degree of sub cool ($T_{subcool}$)         | ºC   | 0 2.7 0 3.3 0 4.5               |
| Outlet Evaporator temperature ($T_1$)      | ºC   | -1 1.1 4.14 6.7 4.2 7.8        |
| Degree of super heat ($T_{superheat}$)     | ºC   | 0 2.1 0 2.58 0 3.5             |
| Refrigeration effect                       | kJ/kg| 125.76 130.16 125.9 130.9 125.56 133.13 |
| Compressor work                            | kJ/kg| 39.74 39.21 39.81 39.01 39.63 38.76 |
| Percentage in power saving                 | %    | - 1.33 - 2.01 - 2.195          |
| Coefficient of Performance, COP            | -    | 3.164 3.32 3.1625 3.356 3.168 3.435 |
| Percentage improvement of COP              | %    | - 4.93 - 6.1 - - 8.42          |

Fig.1. Schematic diagram for the experimental.

Conventional HPHE used in HVAC systems

HPHE used in this work

Fig.2. Comparison between the conventional HPHE and the type used in the present work
**Fig. 3.** The P-h diagram for vapor compression cycle with and without HPHE.
Fig. 4. The experimental results for vapor compression cycle with and without HPHE on P-h diagram at 55°C DBT.
Fig. 5. Percentage of COP enhancement for the AC system with HPHE