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Studying The Characteristics Of The Heat Pipe Heat Exchangers In Air Conditioning

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Abstract:- An experimental study has been carried out on a heat pipe heat exchanger used for heat recovery, the test rig has been built to simulate the same conditions of the heat recovery systems in air conditioning applications, in which the heat pipe heat exchanger is considered from the best solution specially in hospitals & laboratories in which zero cross contamination is required, the measured data acquired from the test rig were analyzed to investigate the thermal performance and effectiveness of the heat recovery system. Cold and hot streams have been connected with heat pipe heat exchanger, the first two experiments have been carried out by changing the hot air inlet temperature from 32 ~ 55 °C, while the inlet cold air temperatures has maintained constant at 26 °C in one experiment and 28 °C in the other one.Another three experiments have been carried out, through changing ratios of mass flow rate between return and fresh air from 1 to almost 2, while the cold air inlet temperature is kept constant at 26 °C and the inlet hot air temperature is maintained constant at 35 °C in one experiment, 40 °C & 45 °C in the other two experiments, hence for each experiment the thermal performance and effectiveness of the heat recovery system were investigated.The results showed that the temperature changes of hot and cold air are increased with increasing the inlet temperature of fresh air. The effectiveness and heat transfer for the evaporator section are also increased to about 39 % with increasing the inlet fresh air temperature to 55 °C. The effect of mass flow rate ratio on effectiveness is positive for evaporator side, The inlet hot air temperature is the most dominant parameter to enhance the heat transfer rate in the evaporator side of the heat pipes heat exchanger.

Nomenclature
$m°_C$: Air mass flow rate of the cold air, ($kg\ hr^{-1}$)
$m°_H$: Air mass flow rate of the hot air, ($kg\ hr^{-1}$)
T: Temperature, (°C)
T_{Ci} : Temperature of inlet cold air, (°C)
T_{Co} : Temperature of outlet cold air, (°C)
T_{Hi} : Temperature of inlet hot air, (°C)
T_{Ho} : Temperature of outlet hot air, (°C)
ΔT: Temperature change of air stream, (°C)
ϵ: Effectiveness
ϵ_C: Effectiveness of the condenser section
ϵ_E: Effectiveness of the evaporator section

Subscript
C : Cold air
$C.i$: Cold air inlet
$C.o$: Cold air outlet
Cn : Condenser
H : Hot air
$H.i$: Hot air inlet
$H.o$: Hot air outlet
E : Evaporator

I. INTRODUCTION

The environmental aspect now is one of the most important aspects that humanity shall give a special priority in its way to progress and prosperity. Waste energy recovering techniques are considered one of the major tools that engineers use to reduce the harsh impact of the civilization on the environment.Since it was initially introduced to the world by R.S. Gaugler in a patent application dated 1942, heat pipes have been utilized in many application like energy storage systems, chemical reactors, space craft, energy conservation & renewable energy & as heat exchangers in heat recovery [1,2].

Waste heat recovery system utilizes the heat pipe in the form of heat pipe heat exchangers, these heat exchangers are used to extract energy from the waste medium and return it back to the process again, by focusing on the medium temperature heat recovery system, many investigations has been introduced to study the thermal performance and reach optimum design of the heat pipe heat exchanger, an example of this application is to use the exhaust flue gases resulting from hot furnace combustion process to heat the air used to warm up another furnace [3], the study aim was to reach the optimum design of different finned heat pipe materials against different air velocities and temperature differences, a feasibility study for using the exhaust gases resulting from internal combustion engines to heat automobiles passenger enclosure has been carried out numerically and experimentally in which the results from both were in good agreement and it was obvious that the heat transferred by the heat pipe heat exchanger is increased by increasing exhaust gas temperature [4]. For waste heat recovery in air conditioning application, fixed plate heat exchangers, rotary air to air energy exchanger, coil energy recovery (run around loops), heat pipe heat exchanger & twin tower enthalpy recovery loop are common methods used [5], is that large quantities of heat can be conveyed within a relatively small sectional area over a considerable distance with no additional power input to the system[6], the advantage that the heat pipe heat exchanger has over the others heat recovery techniques is that no contamination between the two exchanging streams will occur, in which make it the appropriate choice in air-conditioning application for hospital and laboratories. For the same application a computer simulation has been made for a three single heat pipes with different wick structure and working fluids to study the characteristic design and heat transfer limitations, the most appropriate working fluid and pipe construction was selected and used to build the experimental setup, the result showed that to increase the effectiveness, the number of rows shall be increased and the pipes shall be finned [6]. Also an experimental and numerical study have been made to investigate the effectiveness of the heat exchanger against increasing inlet hot air temperature and mass flow ratios between the two exchanging streams [7], the results showed that increasing inlet hot air temperature from 32-40 °C leads to increasing the effectiveness to about 48%, the effect of mass flow ratio is positive to the evaporator side and negative to the condenser side, and enthalpy is increased to about 85% with increasing hot air inlet temperature to 40 °C. Finally a literature review of the application of heat pipes heat exchangers for the heat recovery, where carried out for different heat pipe types [8], the study summarized and analyzed the previous works to pave the way and facilitate relevant future work.

II. TEST RIG CONSTRUCTION & COMPONENTS.

The test rig consists of the following components ***(Fig. 1)***:Air ducts, air fans, refrigeration unit, heaters, temperature measuring device & heat pipe heat exchanger.Air ducts: eight air ducts have been used, four for the cold (extracted / return) air side and the other four ducts are for the hot (fresh) air side, all are made from galvanized steel sheet of 0.5mm thickness and the four ducts directly connected to the heat exchanger are insulated with glass wool of 15 *mm* thickness to minimize the heat transfer to surrounding air. For the cold air side the first air duct is reducer with inlet section of 0.10 × 0.10 m^2 and outlet section 0.30 × 0.30 m^2 & length of 0.30 *m*, second air duct with a cross section 0.30 × 0.30 m^2 & length of 0.30 *m* in which used to install the evaporator part of the refrigeration unit inside it, Third air duct with a cross section 0.30 × 0.30 m^2 & length of 0.46 *m* and connected directly to the condenser side of the heat pipe heat exchanger & fourth air duct with a cross section 0.30 × 0.30 m^2 & length of 0.46 *m* connected directly to the exit side of the heat exchanger condenser side. For the hot air side the first air duct is reducer with inlet section of 0.10 × 0.10 m^2 and outlet section 0.30 × 0.30 m^2 with length of 0.24 *m*, second air duct with a cross section 0.30 × 0.30 m^2 & length of 0.27 *m* in which used to install the three heaters inside it. Third air duct with a cross section 0.30 × 0.30 m^2 & length of 0.46 *m* and connected directly to the evaporator side of the heat pipe heat exchanger & fourth air duct with a cross section 0.30 × 0.30 m^2 & length of 0.46 *m* connected directly to the exit side of the heat exchanger evaporator side.

Air fans: two identical air fans were used, the suction part of the two fans were marked up and scaled, and by controlling the cross section area of the fan suction, different air flow can be obtained.Refrigeration unit: a direct expansion unit consisting of evaporator; compressor, condenser, and expansion device were used to supply the return cold air to the condenser side of the heat pipes heat exchanger. The refrigeration unit was charged with R-134a and the evaporator was made from copper-finned tubes cooling coil, installed in the duct of 0.30×0.30 m^2.Heaters: Three (1 kW) heaters have been used to supply the hot fresh air to the evaporator side of the heat pipes heat exchanger, the three heater were connected to the AC power supply source through variable auto transformer to have a wide range of hot air temperature form 32 °C to 55 °C.

Temperature measuring device: Four J-type thermo couples were used to measure the cold air in/out & hot air in/out, the thermo couples were connected to a digital reader to obtain the temperature value in centigrade.

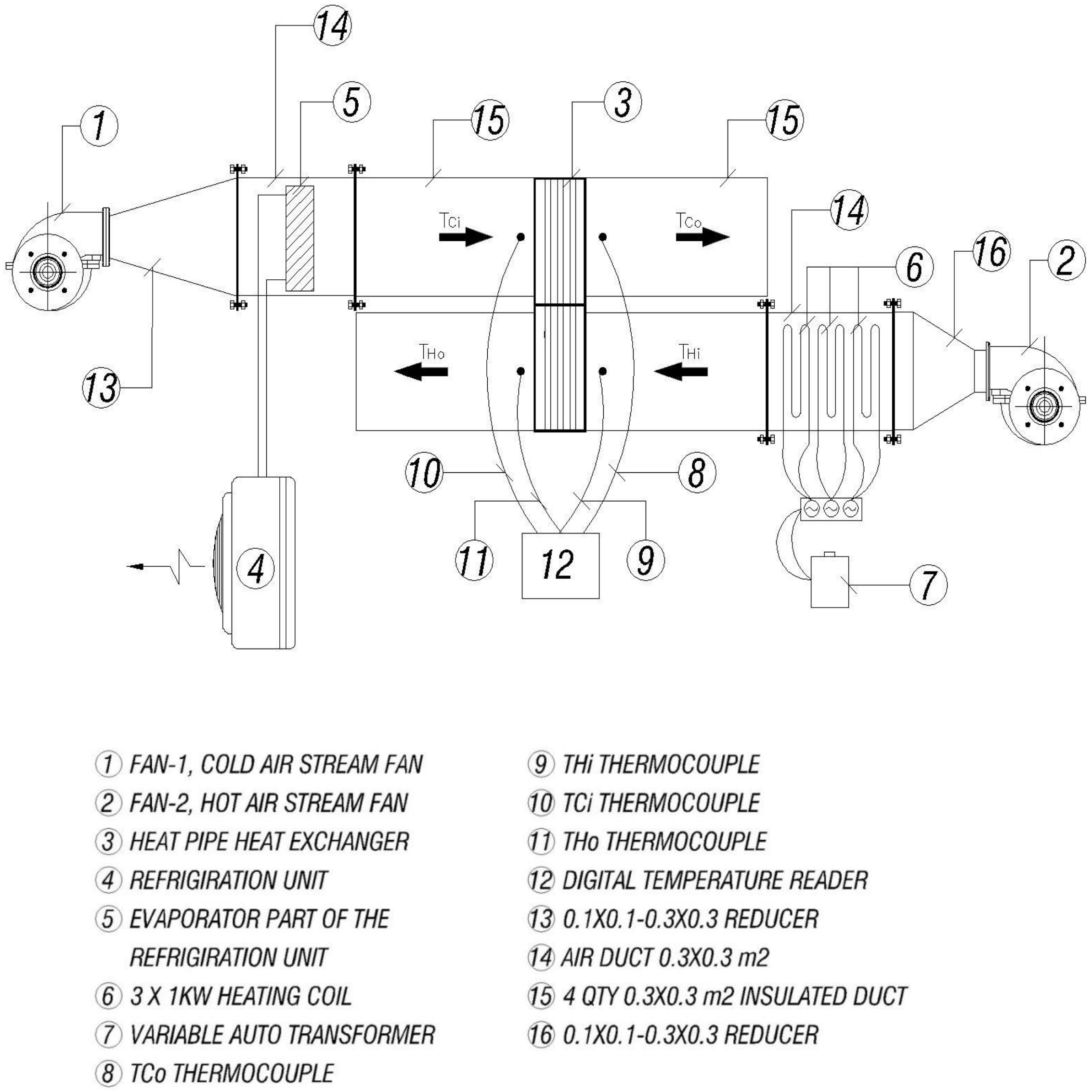

Fig. (1). Laboratory test rig used for studying thermal performance of heat pipe heat exchanger used for heat recovery in air conditioning applications

Heat pipe heat exchanger ***(Fig. 2)***: The heat pipes heat exchanger consists of 30 copper tubes arranged in three rows with length of 0.6 m, and outer/inner diameters of 15.6/14.8. The heat pipe consists of three parts with straight length, evaporator section of 0.28 m, adiabatic section of 0.04 m and condenser section of 0.28 m. the tubes are wickless. The heat pipes are closed at both ends and evacuated from air and charged with R-22 as a working medium at pressure of 3.1 bars, the weight of refrigerant for each copper tube is 37 Grams. The evaporator and condenser sections are finned, fin material is aluminum (Louvered type), fin spacing is 12 fins/inch and fin thickness is (0.12 mm).

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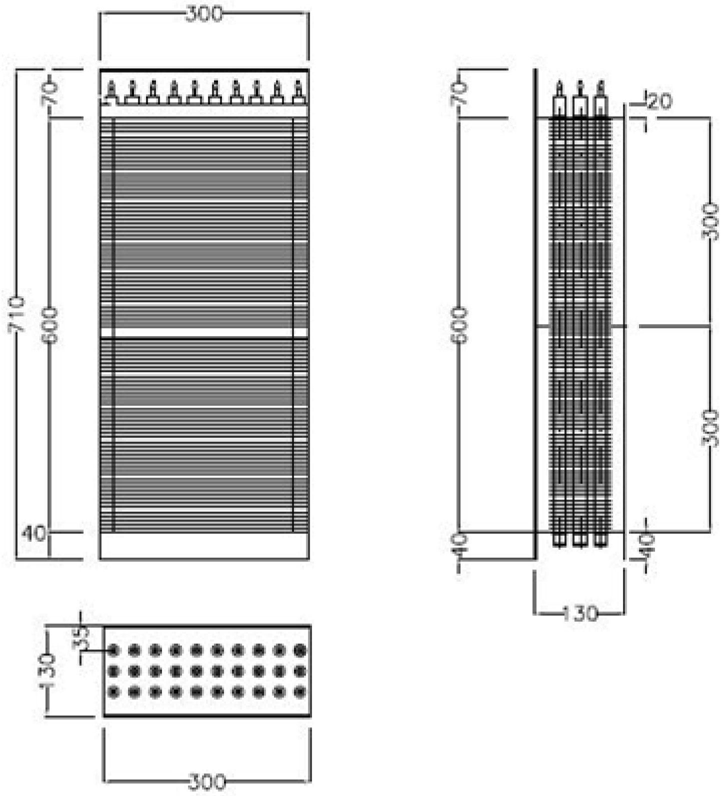

Fig. (2). Heat pipe heat exchanger construction details

III. EXPERIMENTAL METHOD

Five experiments have been carried out, two of them were about changing the fresh hot air temperature from 32 °C up to 55 °C, while the cold return air is kept constant at 26 °C in the first experiment & at 28 °C in the second experiment & also the mass flow ratio between the hot & cold air side was kept constant at 1, the other three experiment where about changing mass flow rate ratios between cold & hot air streams to alternate between 1 up to 1.87 ratio, while cold return air inlet temperature was kept constant at 26 °C and also the hot fresh air inlet temperature was kept constant at 35 °C in one experiment, 40 °C & 45 °C in the other two experiments.In each experiment the two fans run, the heaters & refrigeration unit operate & the inlet cold air temperature (T_{Ci}), outlet cold air temperature (T_{Co}), inlet hot air temperature (T_{Hi}) & outlet hot air temperature (T_{Ho}) were measured & recorded using J-type thermo couples connected to a digital temperature reading device and the measured data were conducted in steady state. In the two experiments in which the mass flow rate ratio is constant at 1, the fresh hot air temperature was controlled to range from 32 °C up to 55 °C using the three 1kW heaters installed in the fresh air duct and connected to the AC supply through variable autotransformer in which it helps in getting the 1 centigrade step, and for the cold air the temperature was kept constant at 26 °C using the laboratory refrigeration machine and by fixing the flow rate of the two fans at 615 kg/hr.

The flow rates of the two fans were controlled through changing the cross section area of the fan suction, the flow rates of air in the fan corresponding to each suction cross section area were measured & recorded using anemometer. In the other three experiments in which the return air was kept constant at 615 kg/hr, while the fresh air was changed to these values 327, 373, 393, 425, 451, 474, 520, 533, 576, 589, 615 kg/hr. The ratios between return air and fresh are 1.87, 1.64, 1.56, 1.44, 1.36, 1.29, 1.18, 1.15, 1.06, 1.04, and 1.0 respectively. The refrigeration unit also used to keep the cold air temperature at 26 °C while the heaters were operated to maintain a constant hot water temperature for each flow rate at 35 °C in one experiment, 40 °C & 45 °C in the other two experiments. After enough time, the temperatures of fresh and return cold air before and after heat pipes heat exchanger were recorded when they became nearly constant.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Five tests were performed to investigate the characteristic of the heat pipe heat exchanger, particularly the temperature change of the hot & cold streams & the effectiveness of both evaporator & condenser sides.
These characteristics have been investigates against changing fresh air temperature from 32 ~ 55 °C & changing mass flow rate ratios between cold & hot air streams to alternate between 1 up to 1.87 .

Temperature difference change study

In (***Fig.3&4***), the temperature change of the cold & hot air streams has been observed against changing hot, fresh air inlet temperature from 32 ~ 55 °C, while the temperature of the cold, return stream has been maintained at 26 °C in the first experiment & at 28 °C in the other one.

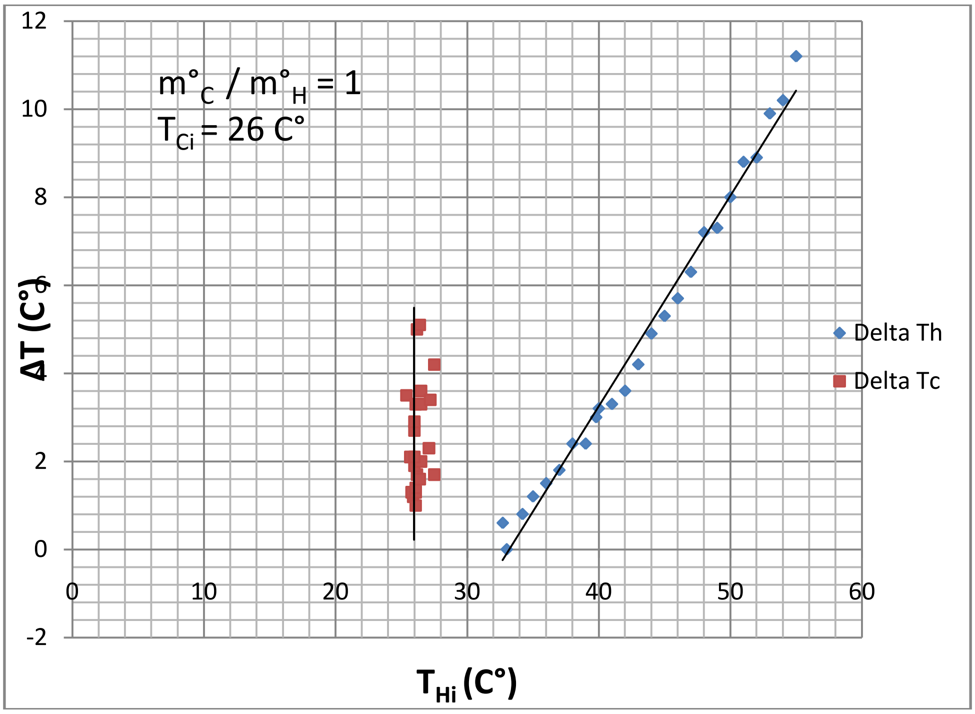

Fig. (3). Effect of fresh air temperature on ΔT_C & ΔT_H, and T_{Ci} = 26 °C

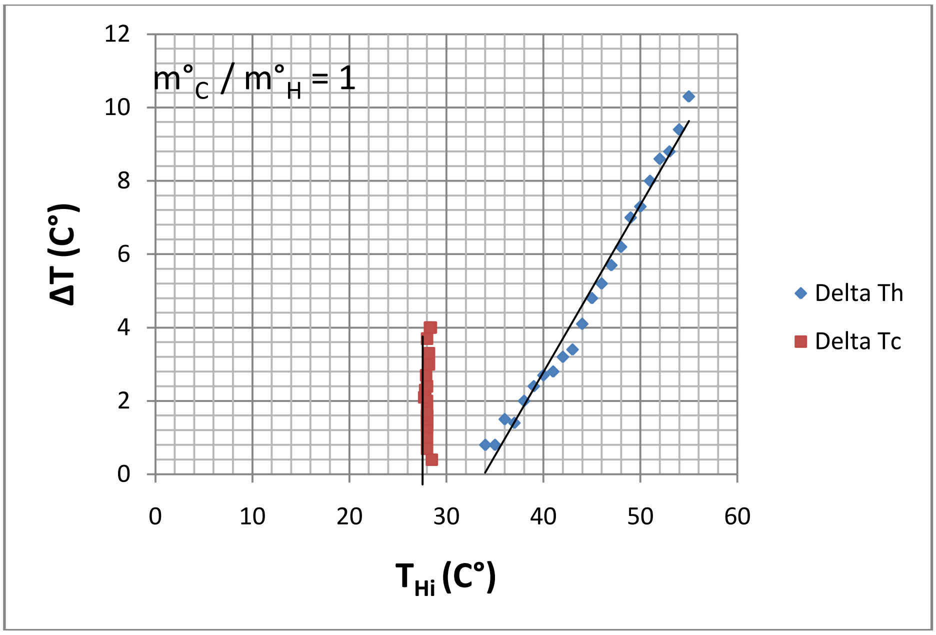

Fig. (4). Effect of fresh air temperature on ΔT_C & ΔT_H, and T_{Ci} = 28 °C

It is observed that for both hot and cold air streams, the temperature change increases with increasing the inlet hot air temperature in both experiments, and it is also observed that the temperature change for both streams increased, when the inlet cold temperature was at 26 °C compared to its corresponding values when the inlet cold temperature was at 28 °C.

In ***(Fig.5, 6&7)***, the temperature change of the cold & hot air streams has been observed against changing mass flow rate ratios between cold & hot air streams, while the temperature of the cold, return stream has been maintained at 26 °C, and also the hot, fresh air stream has been maintained constant for each flow rate at 35 °C in one experiment, 40 & 45 °C in the other two experiments.

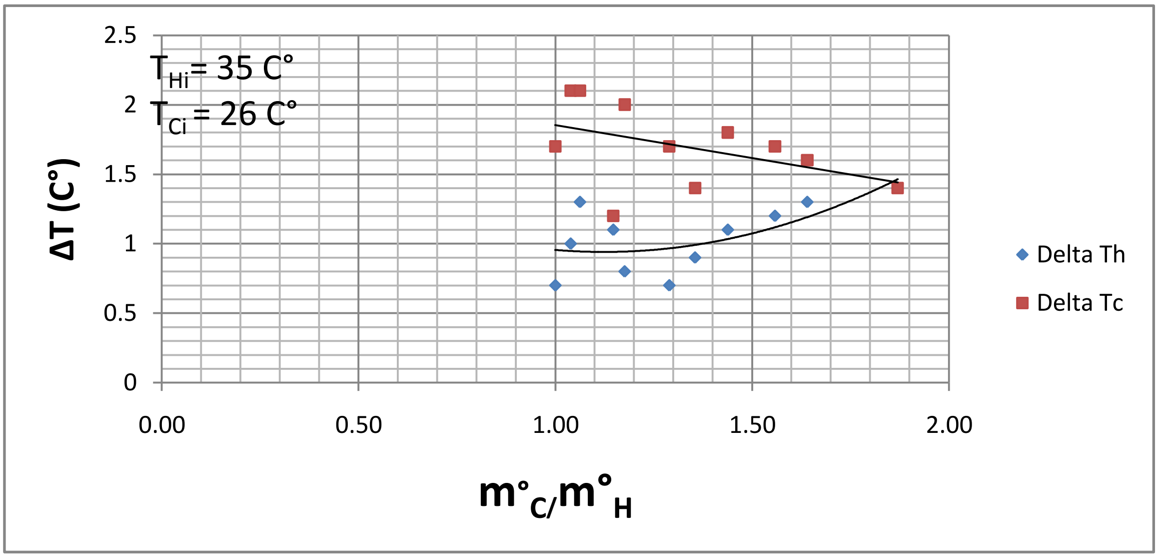

Fig. (5). Effect of mass flow rate ratios on ΔT_C & ΔT_H, T_{Hi} = 35 °C

From ***(Fig.5)***, it is obvious that increasing mass flow ratio between cold & hot stream leads to a slight negative effect on the temperature difference values of the cold air, while the hot air temperature difference is subjected to a slight positive change. With an additional observation that the temperature difference values of the cold stream are little bit higher than its corresponding values in the hot stream.

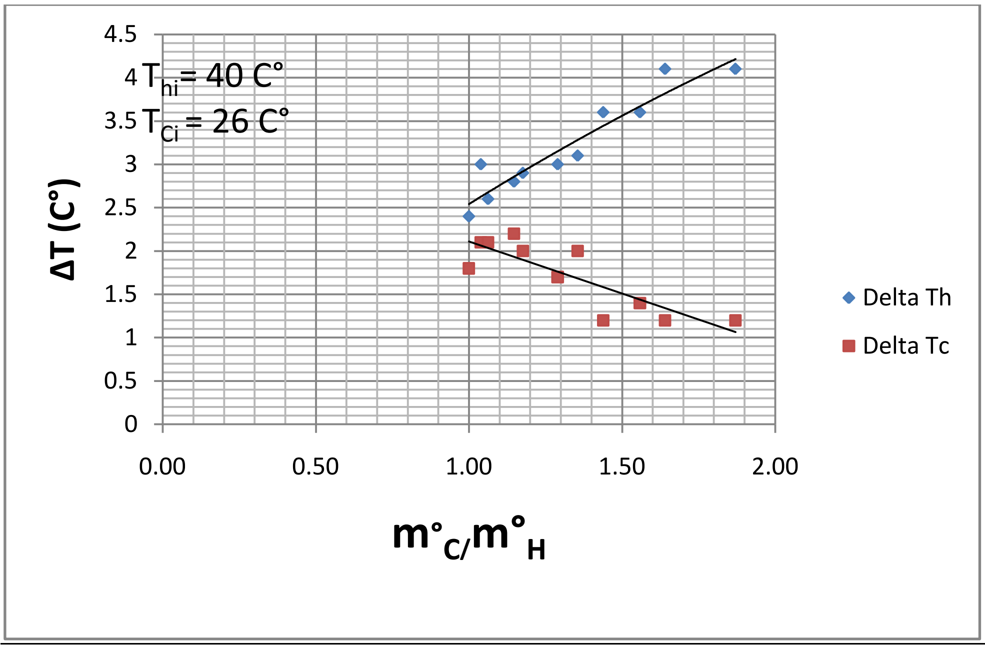

Fig. (6). Effect of mass flow rate ratios on ΔT_C & ΔT_H, T_{Hi} = 40 °C

From ***(Fig.6)***, it is obvious that increasing mass flow ratio between cold & hot stream leads to a slight positive effect on the temperature difference values of the hot air, while the cold air temperature difference is subjected to a slight negative change. With an additional observation that the temperature difference values of the hot stream are higher than its corresponding values in the cold stream, which is reversed than the situation in fig. (5)

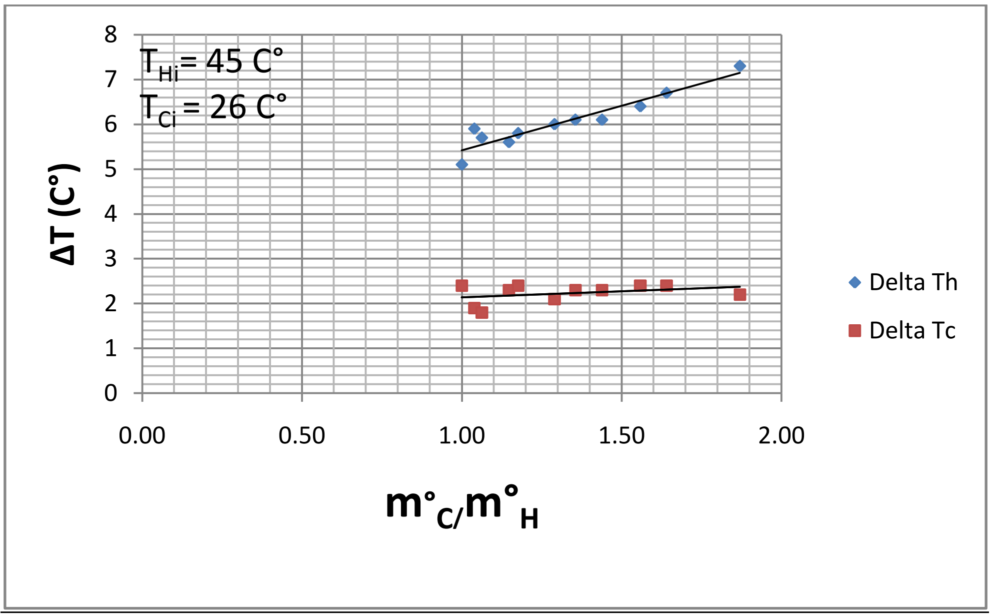

Fig. (7). Effect of mass flow rate ratios on ΔT_C ***&*** ΔT_H***,*** T_{Hi} ***= 45 °C***

From ***(Fig.7)***, it is obvious that increasing mass flow ratio between cold & hot stream leads to a positive effect on the temperature difference values of the hot air, and also a slight positive effect for the cold air temperature difference, in which was not the case in figures (5) & (6).

Effectiveness Change Study

The effectiveness of the heat exchanger is defined as the ratio of actual rate of heat transfer by the heat exchanger to the maximum possible heat transfer rate between the two air streams. Assuming, there is no water condensation in fresh air stream and also assuming the specific heat of air passing through the evaporator and condenser sections to be constant, then the effectiveness of heat pipes heat exchanger at evaporator side is represented as [9] ,

$$\varepsilon_E = \frac{T_{Hi} - T_{Ho}}{T_{Hi} - T_{Ci}} \qquad \varepsilon_{Cn} = \frac{T_{Co} - T_{Ci}}{T_{Hi} - T_{Ci}}$$

In ***(Fig.8&9)***, the effectiveness of both evaporator & condenser sides has been calculated against changing hot, fresh air inlet temperature from 32 ~ 55 °C, while the temperature of the cold, return stream has been maintained at 26 °C in the first experiment & at 28 °C in the other one.

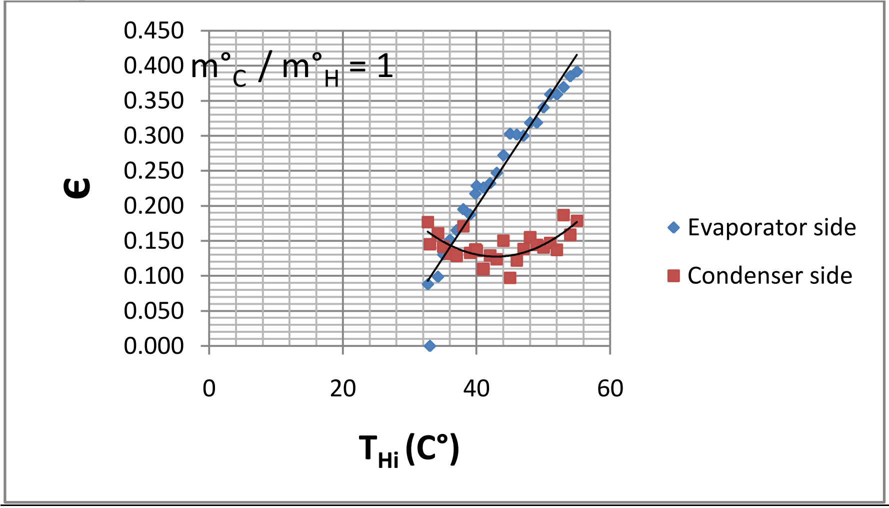

Fig. (8). Effect of fresh air temperature on effectiveness (ϵ), and T_{Ci} ***= 26 °C***

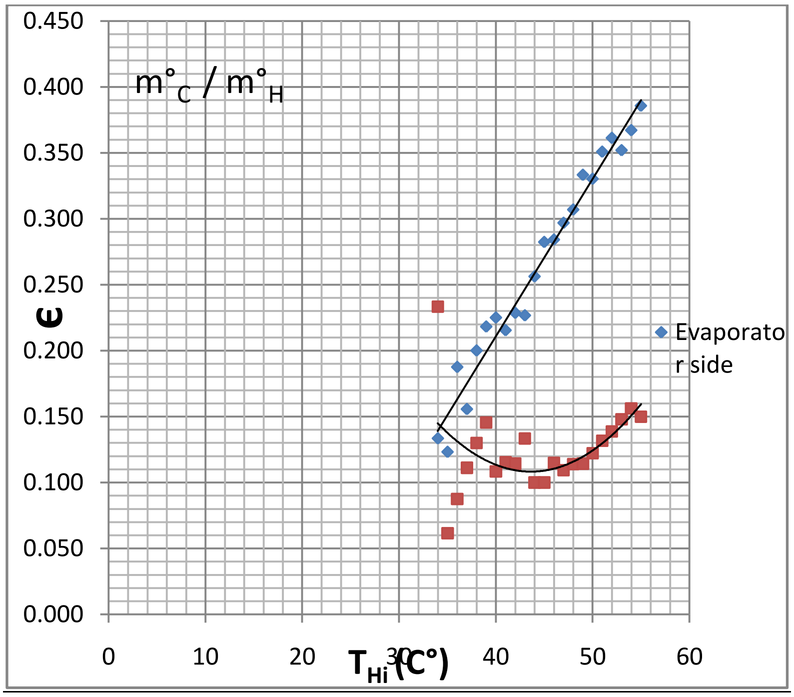

Fig. (9). Effect of fresh air temperature on effectiveness (ϵ), and T_{Ci} = 28 °C

It is observed that for both experiments the effectiveness of the evaporator side does largely increase with increasing the hot air temperature, while the effect of the hot air temperature increasing on the condenser side effectiveness is not considerable, starting with a slight negative effect then to a slight positive effect.

In **(Fig.10, 11&12)**, effectiveness of both evaporator & condenser sides has been calculated against changing mass flow rate ratios between cold & hot air streams, while the temperature of the cold, return stream has been maintained at 26 °C, and also the hot, fresh air stream has been maintained constant for each flow rate at 35 °C in one experiment, 40 & 45 °C in the other two experiments.

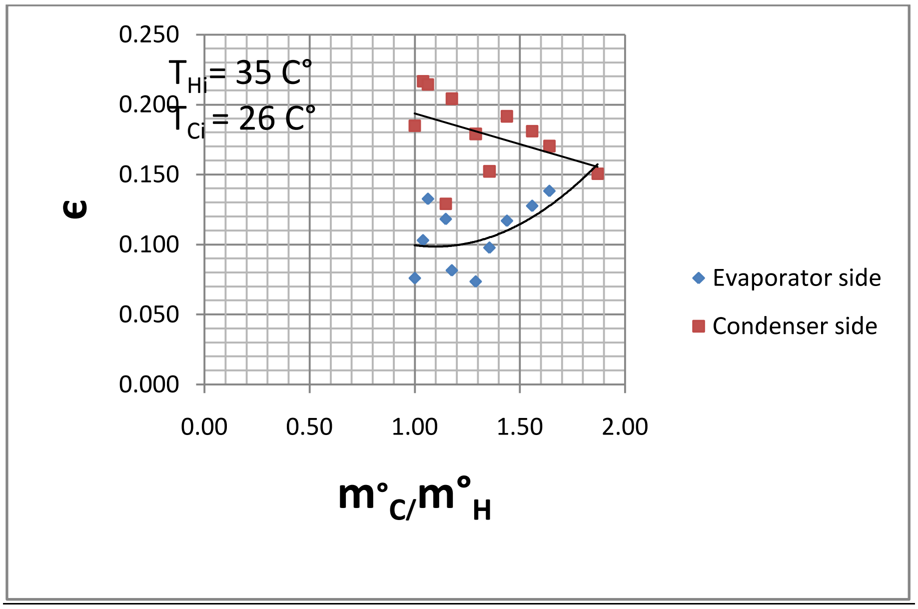

Fig. (10). Effect of mass flow rate ratios on effectiveness (ϵ), T_{Hi} = 35 °C

From *(Fig.10)*, it is obvious that increasing mass flow ratio between cold & hot air streams leads to a slight negative effect on the effectiveness of the condenser side, while the effectiveness of the evaporator side is subjected to a slight positive change. With an additional observation that the effectiveness values of the condenser side are little bit higher than its corresponding values of the evaporator side.

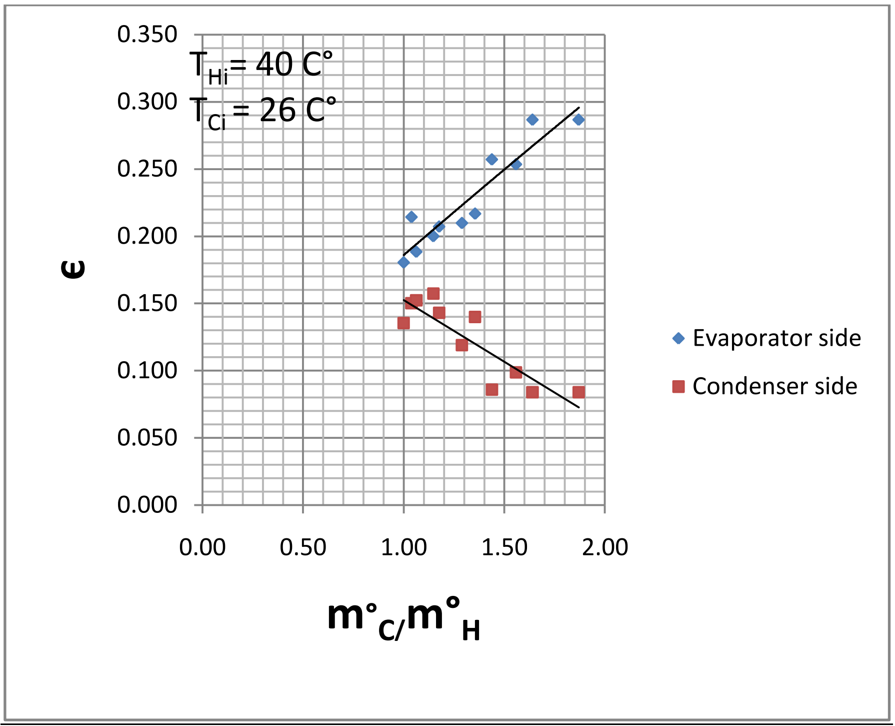

Fig. (11). Effect of mass flow rate ratios on effectiveness (ϵ), T_{Hi} = 40 °C

From (***Fig.11)***, it is obvious that increasing mass flow ratio between cold & hot air streams leads to a slight positive effect on the effectiveness of the evaporator side, while effectiveness of the condenser side is subjected to a slight negative change. With an additional observation that the effectiveness values of the evaporator side are higher than its corresponding values in the condenser side, which is reversed than the situation in fig. (10).

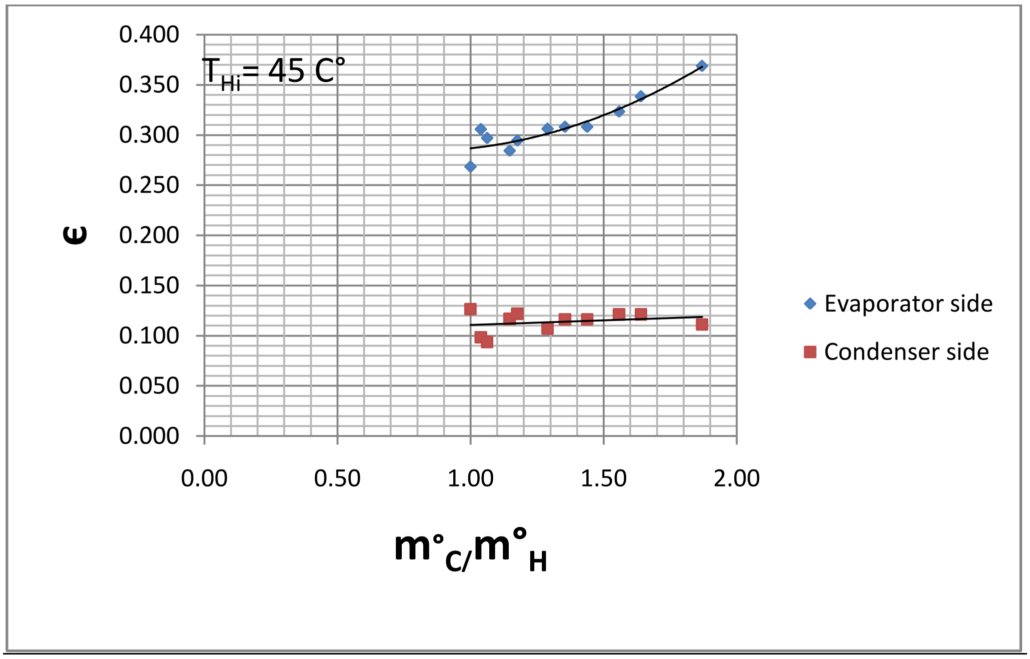

Fig. (12). Effect of mass flow rate ratios on effectiveness (ϵ), T_{Hi} = 45 °C

From ***(Fig.12)***, it is obvious that increasing mass flow ratio between cold & hot air streams leads to a slight positive effect on the effectiveness of the evaporator side, and also a slight positive effect for the effectiveness of the condenser side, in which was not the case in figures (10) & (11).

V. CONCLUSIONS

The experimental study of a heat pipe heat exchanger used as an air recovery system in air conditioning application leads to the following conclusions:

1. Increasing temperature of the T_{Hi} from 32 °C to 55 °C, leads to large increase in the ΔT_H, and slight increase of the ΔT_C.
2. Increasing mass flow ratio between cold and hot air from 1 to l.87, leads to a slight increase in the ΔT_H, and slight decrease of the ΔT_C, except when the T_{Hi} has been increased to 45 °C the ΔT_C started to positively change.
3. ΔT_H values are always larger than its corresponding ΔT_C values, except in the experiment in which T_{Hi} = 35 °C, hence ΔT_C values are larger than its corresponding ΔT_H values, which means that when T_{Hi} is close to the saturation temperature of the working fluid of the heat pipe, the ΔT_H will be in its lowest values.
4. Increasing temperature of the T_{Hi} from 32 °C to 55 °C, leads to large increase in the ϵ_E, while the effect on the ϵ_{Cn} is not considerable, starting with a slight negative effect then to a slight positive effect.
5. Increasing mass flow ratio between cold and hot air streams from 1 to l.87, leads to a slight increase in the ϵ_E, and slight decrease in the ϵ_{Cn}, except when the T_{Hi} has been increased to 45 °C the ϵ_{Cn} started to positively change.
6. ϵ_E values are always larger than its corresponding ϵ_{Cn} values, except in the experiment in which T_{Hi} = 35 °C, hence ϵ_{Cn} values are larger than its corresponding ϵ_E values, which means that when T_{Hi} is close to the saturation temperature of the working fluid of the heat pipe, the ϵ_E will be in its lowest values.
7. T_{Hi} is the most dominant parameter to enhance the heat transfer rate in the evaporator side of the heat pipes heat exchanger.

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