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Effect of Aluminum Fin on the performance of Stratified Chambers Gas to Gas Heat Exchanger with Porous Medium

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Abstract: An experimental study is carried out to investigate the effect of fin material on the performance of stratified chambers gas to gas heat exchanger with and without porous media. The target of these experiments is to study the change of the rate of heat transfer under different hot and cold air stream rates, different porous material thicknesses and different hot air inlet temperatures. Using two different fin materials enables us to investigate the difference in the heat exchanger performance when using steel and aluminum fins. Also, the difference in the heat exchanger performance in the absence of porous material and its presence is obtained. The determination of the optimum operating parameters to achieve maximum total heat recovery ratio is also investigated. The test rig used in these experiments consists of the air supply system, flow and temperature measurement instruments, heating system with its control system and five heat exchanger chambers, each chamber provided with corrugated fins. The experimental study showed that using aluminum fins instead of steel fins had much improvement on the performance of the heat transfer rate also Adding the porous material to the heat exchanger chambers leads to improvement of the heat transfer rate on the expense of an increase in pressure drop.

Keywords: heat exchanger, aluminum fins, steel fins, porous material, heat transfer.

I. INTRODUCTION

For many years, studying the enhancement of heat transfer rates by using porous media has received more attention due to its wide applications such as collectors of solar energy, cooling of nuclear reactors, geothermal energy systems, cooling of electronic devices, catalytic chemical reactors, extraction of crude oil and many others. Porous media improves the heat transfer rate and increases it because the porous media reduce the thickness of the boundary layer, improves the convection heat transfer and increases the surface area in contact with the fluid. As the concept of enhancement of the rate of heat transfer, the porous media is considered as a perfect way in enhancement of the heat transfer rate, because of its great performance in temperature uniformity. Many experimental and theoretical researches have been done on using porous media with different material, construction, porosity, and applications, which proved that the porous media enhancement the rate of heat transfer. Dadkhodazadeh [1] have studied numerically the parameters that affect improving convection heat transfer in a 2-D porous gas heat exchanger for symmetric barriers and asymmetric barriers. The results showed improvement in the rate of heat transfer within porous gas heat exchanger due to barriers and porous medium were obtained. Darcy number effect on the rate of the heat transfer in the chamber as the Darcy number increase the heat transfer increases and Asymmetrical arrangement better than symmetric arrangement in improving the rate of heat transfer. Surtaev, Kuznetsov, Serdyukov, Pavlenko, Kalita, and Komlev, [2] investigated at atmospheric pressure the pool boiling heat transfer in capillary porous coatings by using two different coolants (liquid nitrogen and water). The results showed that using capillary-porous coatings improves the rate of heat transfer up to 3.5 times in case of boiling the water and up to 4 times in case of boiling of liquid nitrogen and the properties of the liquid used and the morphology of coatings affect the rate of heat transfer. Lochan and Sharma [3] examined experimentally and computational fluid dynamics (CFD) to find out calculations employed the enhancement of the rate of heat transfers in a cylindrical heat exchanger (shell and tube) by using porous media. The experiments showed that by using the porous medium, the heat transfer rate increases as compared with simple heat exchanger and the design 1 (spherical metal balls) gives better heat transfer rate than design 2 (cylindrical metal chips). Anis [4] investigated experimentally the effect of using a five-chamber gas-to-gas heat exchanger with and without a porous material on the rate of heat transfer. The experiments showed improving the rate of heat transfer by using porous material. An optimum thickness of porous material was found to be 50 mm as a result of asymptotic value for more than 50 mm thickness porous material and the pressure the drop increases as porous material thickness increases. Mansoori, Tiari, Saffar-Avval, and Mahdavi [5] studied numerically the heat transfer by convection and the generation of entropy through a partially filled pipe with porous material. The results showed that the location of the porous medium affects the performance of the composite pipe, the thermal conductivity ratio has a considerable effect on the heat transfer enhancement in case 1 for all porous thicknesses. While, in case 2, its effect on the enhanced heat transfer is more obvious at higher porous thicknesses. Guo, Shi Zhang, and Rong [6] investigated numerically the enhancement of the heat transfer for fluid flow in pipe partially filled with porous medium. The results show that changing the thickness of porous medium affect the rate of heat transfer and flow resistance, small effect of porosity on temperature and flow field (other parameters were fixed) and at the same parameter values, pipe partially filled with porous media enchanted the rate of heat transfer effect comparing with blank pipe. Aziz, Kundu, and Bhanja [7] investigated numerically the rate of heat transfer on fixed and moving porous fin material by studying the temperature distribution, optimum design parameters and efficiency of the moving porous fin. The investigation shows that the results of both decomposition method and finite difference method approach with each other and the moving porous fin better than fixed ones in the rate of heat transfer. Mehrizi, Farhadi, Sedighi, and Delavar [8] studied the extent of enhancement of the heat transfer at a ventilated porous media plate heat exchanger by using method of Boltzmann which was designed by square cavity with thermal insulated inlet and outlet and three fins with constant hot temperature. The study shows that the rate of heat transfer enhanced due to adding porous medium to the heat exchanger, at high Reynolds number, the porous medium has high effect in Nusselt number, the position of the fin affects sensibly on Nusselt number and as porosity decreases, the rate of heat transfer increases. Elhosseiny [9] investigated the effect of using three-layer gas-to-gas heat exchanger with and without a porous material on the rate of heat transfer. The experiments show that the optimum thickness of porous material was 50 mm as a result of asymptotic value for more than 50 mm thickness porous material found to be improving rate of heat transfer by using fin walls & porous material and Pressure drop increases as porous material thickness increases. Huang, Nakayama, Yang, Yang, and Liu [10] investigates the enhancement of the rate of heat transfer & studied the flow resistance and characteristic of heat transfer numerically and experimentally of a tube filled with slightly smaller diameter porous media inserted in the tube's core for turbulent and laminar flow. The results show that using porous media results on an increase of the heat transfer rate with acceptable resistance flow, a Porous radius ratio affects the heat transfer rate and using the porous media in the core of the tube results in more uniform temperature profile. Wu and Wang [11] investigated numerically convective heat transfer over a heated square porous cylinder in a channel by studies the following parameters porosity, Darcy number and Reynolds number on the performance of the heat transfer the investigation show that as the fluid flows faster through the gap of the internal square porous cylinder, the Darcy number and the thermal transfer effect increases, the local Nusselt number influenced by the porosity slightly along the bottom side of the square porous cylinder in the middle of the channel and the porous enhance the heat transfer rate better than fluid at 10-2 Darcy number, the average time mean temperature and Nusselt number is greater for the internal part than the external part. Hetsroniet, Gurevich, and Rozenblit [12] experimentally investigated pressure drop and the rate of heat transfer in rectangular channels with different porosity of stainless steel sintered porous inserts. The experiments show that the heat transfer rate of the heat sink gets high value and the pumping power increase in stainless steel sintered porous heat sink. Mahmoudi and Karimi [13] numerically determined the enhancement of the rate of heat transfer in a partially filled pipe with a porous medium. It was found that at high Darcy the influence of F noticeable and as F increases the temperature difference between two phases decreases, while at low Darcy numbers there is no influence on the temperature difference between two phases. Rashidi, Shokri, Tamayol, and Valipour [14] determined numerically the flow field and heat transfer around a cylinder embedded in a layer of homogenous porous media. The study shows that the wake length increases due to the presence of porous layer around the cylinder which lead to decreases in Darcy number, the Darcy number increases as the drag coefficient decreases, the Darcy number decreases as the magnitude of velocity components decreases and the High permeability porous medium increases the rate of heat transfer and improves the thermal performance. Kiwan, Oztop, and Al-Salem[15] examined experimentally the effects of porosity and thickness of porous sheets on heat transfer enhancement across flow overheated cylinder by investigating the thermal impact of wrapping aluminum porous a circular tube. The results show that as the porosity of the porous layer increases the Nusselt number increases and the thickness of the porous layer is inversely proportional to the Nusselt number

II. THE SCOPE OF WORK

The experiments carried during this work were undertaken to find out the effect of the fin material on the performance of the five-chamber heat exchangers. This was achieved as described above by using four aluminum fins penetrating from both sides of the 4 mm steel plates separating adjacent chamber, while the two 4 mm steel plates covering the top of the upper chambers and the bottom of the lowest chamber were provided with aluminum fins protruding inside the two chambers. The experiments were conducted in two phases. In the first phase, the tests were carried out without the use of the porous material, which correspond to the zero thickness porous material while in the second phase the heat exchanger chambers were fitted with the porous material. The tests in the two cases were run at similar thermal and dynamic conditions in which the inlet temperatures and the volume flow rates into each of the cold and the hot chambers were the same. The obtained results of the two phases are then compared with available published results using steel fins carried out at the same thermal and dynamic conditions without and with the same porous material.

III. THE EXPERIMENTAL APPARATUS

3.1. The Test Section

The heat exchanger consists of five chambers. Each of these chambers is provided with a steel plate on which aluminum fins are fixed. In each chamber, the porous material was installed. The cold gas stream passes through three chambers and the hot air passes through two chambers. The airstream passes from the centrifugal blower as shown in figures 1 and 2, through an electric heater which raises the temperature of the air stream which will pass through the first high-temperature chamber (T hot 1). On the other hand, the cold air stream at atmospheric temperature enters the first cold air chamber with almost the same ambient temperature of the air (T cold 1). During these experiments, both air streams (hot & cold) velocities are adjusted to be the same. The hot air stream enters the first hot air chamber at a temperature (T hot 1), leaves it at a temperature (T hot 2), then it will continue flowing to enter the second hot air chamber at a temperature (T hot 3). Finally will continue flowing to the exhaust chimney at a temperature (T hot 4) as shown in figures 1 and 2. On the other hand, the cold air stream enters the first cold air chamber at a temperature

(T cold 1), leaves it at a temperature (T cold 2) then continued to enter the second cold air chamber at a temperature (T cold 3) and leaves it at a temperature (T cold 4). Finally, it enters the third cold air chamber at a temperature (T cold 5) and leaves it at a temperature (T cold 6), The cold air stream is exhausted at its outlet temperature at a temperature (T cold 6) as shown in figures 1 and 2.

The design of each of the chambers of the tested five chambers of the heat exchanger has theses specifications:

- Material: steel sheets
- Cross-section area= 200 mm x 200 mm
- Different thicknesses of porous media were placed each separately in the middle of the height of the chamber leaving 50 mm space between the top and the bottom of the chamber which serve as inlet and outlet passages of the gas stream into and out of the chambers.
- The porous medium placed in each chamber is made of alumina foamed alloy 200 mm in length, 200 mm in width and thickness varied from 30 mm to 70 mm
- The porosity of the porous medium is 88% and the surface area equal to 1700 m2/m3
- Cross-section area of the inlet and outlet ducts of each of the chambers were =50 mm x 200 mm
- The internal surfaces are painted by heat- resisting black paint to improve heat transfer by radiation.
- Calibrated thermocouples type K set in each inlet and outlet of each chamber

The five chambers are assembled such that each chamber is separated from the lower and the upper chamber by a steel plate.

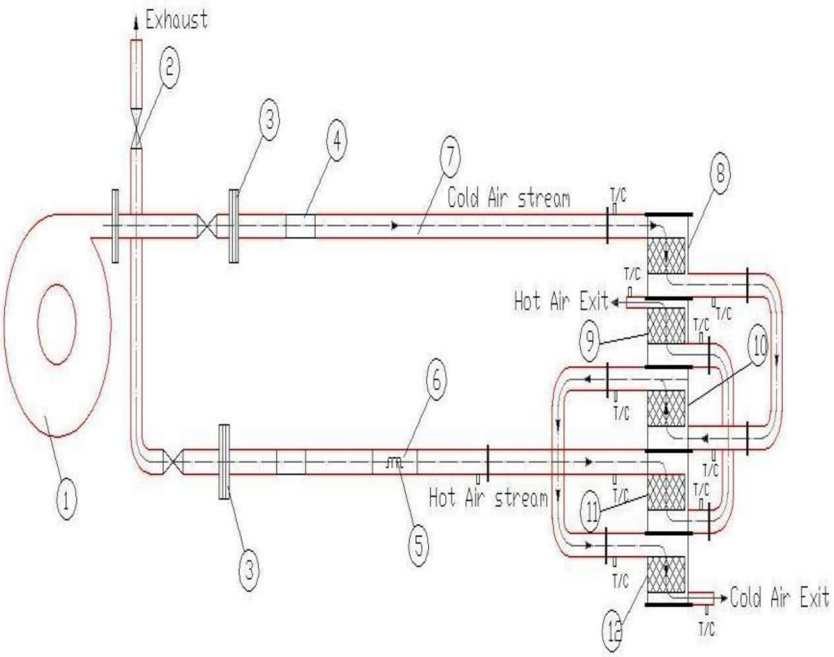

Figure 1 Schematic Layout of The Test Rig.

NO.	Description
1	Centrifugal blower
2	Control valve
3	Orifices
4	Reducer rectangular duct 12 cm x 5 cm / pipe of 2 inch diameter
5	Electric heater section
6	Hot air rectangular duct 12 cm x 5 cm
7	Cold air rectangular duct 12 cm x 5 cm
8	First cold air stream chamber
9	Second hot air stream chamber
10	Second cold air stream chamber
11	First hot air stream chamber
12	Third cold air stream chamber.

3.2. Essential Equipment
3.2.1. Air Supply Systems

An air supply system is provided by using a centrifugal air blower driven by a single-phase motor (220v,1.12 kW, 2900 rpm). Rotating at 2900 rpm to achieve maximum 128 m3/h volume flow at 0.07 bar air maintained pressure, it has a circular cross-section exit of 0.05 m diameter which the air charged through it. An expansion joint was installed after the centrifugal air blower to damp the centrifugal air blower vibration.

3.2.2. Electric Heater

The hot air stream enters a rectangular steel channel of 4 mm thickness, 600 mm length, 250 mm width and 160 mm height, In which the air heaters are placed. The metallic rectangular channel contains four electric heaters with a total power of 7.2 KW at 220 V, each one with 8 mm diameter, 9 turns, 450 mm length, 200 mm width and of 1.8 KW rated power, 220 V. Two variacs with 8 KW each heating capacity has been used in order to control the hot air stream temperature over the range of 100 °C to 400 °C by changing the rate of electric heating.

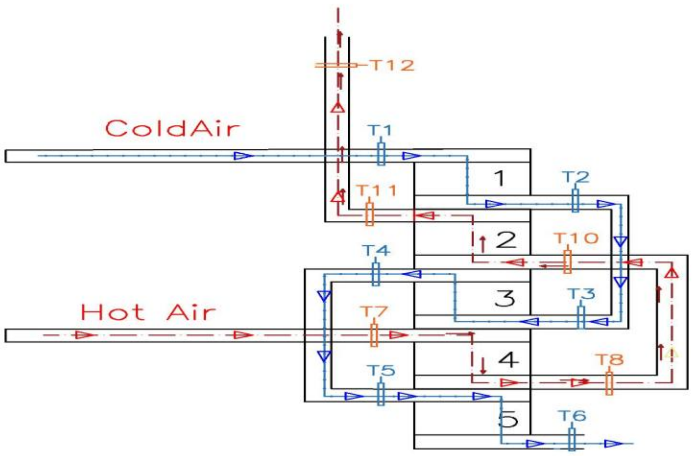

Figure 2 Diagrammatic of The Inlet and Outlet of The Cold and Hot Air Streams into and out The Cold and Hot Air Chambers.

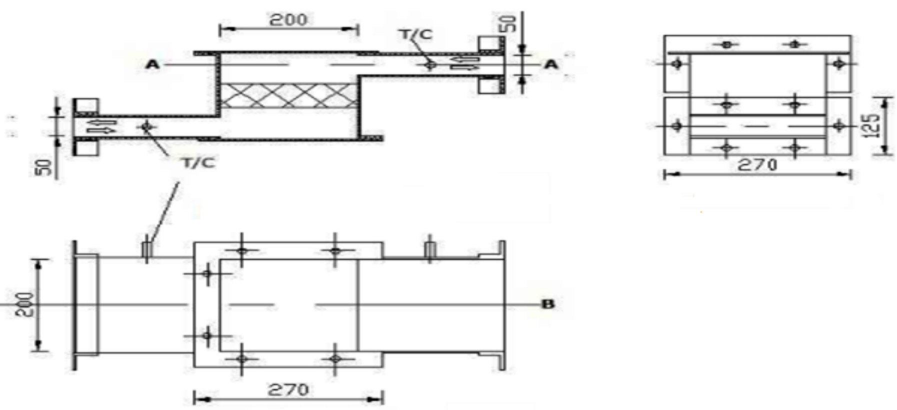

Figure 3 Dimensions of the Intermediate Chamber (all dimensions in mm).

3.2.3. Measuring Instruments

The air temperatures are measured by means of type K thermocouples with a wire diameter of 0.1 mm, a shield tube diameter of 3 mm and 12 cm Length. The thermocouples' ends are connected by copper wire leads to a voltmeter that is used to measure the E.M.F in milli-volt, which indicates the temperature difference between each of the cold and hot air streams and the ambient temperature. A calibration experiment was carried out in which the milli-voltmeter measured e.m.f was calibrated against the temperature of the hot junction inserted in an electric air heater as indicated by the furnace temperature indicator

Each of the cold and the hot air stream pass is equipped with an orifice meter to measure the mass flow rate. The orifices are the same of identical geometrical specifications, it is designed and constructed according to British standard code B.S 1042; 1943 [16] , the orifice diameter is 18 mm. The orifice to duct diameter ratio (ß) is selected to be 0.33. Location of upstream and downstream pressure is set at respectively tapping (d and d/2) according to the orifice meter standard specification, [16], Every upstream and downstream tapping of each orifice is connected to a U- tube manometer that measures the differential pressure across the orifice plate, and the discharge coefficient of the orifice Cd = 0.613

IV. OPERATING CONDITIONS

The following operating conditions and experimental procedures are used for testing experimentally the capability of the use of the five-chamber gas to gas heat exchanger for the recovery of heat from the hot to the cold air streams. Through determining the rate of heat transfer from the hot to the cold streams, the heat recovery ratio, the rate of heat losses, their percentage ratios and the Pressure drop resulting from using different porous material thicknesses at different air volume flow rates using aluminum fins.

Tests were conducted at seven different hot and cold air volume flow rates (0.2 m3/min which is equal to 0.083 m/s, 0.25 m3/min which is equal to 0.104 m/s, 0.3 m3/min which is equal to 0.125 m/s, 0.35 m3/min which is equal to 0.146 m/s, 0.4 m3/min which is equal to 0.167 m/s, 0.45 m3/min which equals to 0.1875 m/s and 0.5 m3/min which equals to 0.208 m/s).In all of these experimental conditions, each of the hot and cold airflow rate was the same.

The above given hot and cold airflow rates were applied to the 4 different hot air inlet temperatures which flows in the heat exchanger (100 ˚, 200 ˚, 300 ˚, and 400 ˚C). During all of these experiments, the cold air temperature was kept at 37 ˚C, although its variation insignificantly affects the heat exchanger performance. Experiments were carried out using variable porous material thicknesses of 0, 30, 50 and 70 mm. The zero mm thickness of the porous material is used to determine the effect of the absence of porous material on the heat exchanger performance.

V. THE METHOD OF THERMO-HYDRAULIC PERFORMANCE ANALYSIS

The thermal performance of the heat exchanger is evaluated by measuring the inlet and outlet temperatures of each chamber of the hot and cold airstreams under different operating conditions

The equation to calculate the heat recovery rate $\dot{Q}_c$ which is the net rate of the heat gained by the cold air as it flows through the heat exchanger is given by the following equation,

$$\dot{Q}_c = \dot{m}_c . C_{p,c} . (T_{c,o} - T_{c,i}) \quad (1)$$

The equation to obtain the rate of the enthalpy drop from the hot air stream which is the heat transferred from it as it flows through the heat exchanger:

$$\dot{Q}_h = \dot{m}_h . C_{p,h} . (T_{h,i} - T_{h,o}) \quad (2)$$

The equation used to determine the heat recovery ratio HR which is an important performance parameter of the heat exchanger is given by the ratio of the rate of the recovered heat by the cold air stream $\dot{Q}_c$ to the maximum possible rate of heat that can be transferred from the hot air stream to the cold air stream $\dot{Q}_{max}$ is given by.

$$\dot{Q}_{max} = \dot{m}_h . C_{p,h} . (T_{h,i} - T_{c,i}) \quad (3)$$

$$HR = \frac{\dot{m}_c \times c_{p,c} \times (T_{c,o} - T_{c,i})}{\dot{m}_h \times c_{p,h} \times (T_{h,i} - T_{c,i})} \quad (4)$$

The above equation is also equal to the heat exchanger effectiveness because the cold and hot streams mass flow rates are the same and the variation of the air specific heat with temperature is quite low. This means that ($\dot{m}_c . C_{p,c}$) almost equal to ($\dot{m}_h . C_{p,h}$) if considering the C_p to be the same for the hot and cold airstreams.

The rate of the heat loss from the hot air stream to the ambient through the insulation of the heat exchanger chambers and the connecting channels is the difference between the rate of the enthalpy drop of the hot air stream $\dot{Q}_h$ and the enthalpy rise of the cold air stream $\dot{Q}_c$ is given by:

$$\dot{Q}_{loss} = \dot{Q}_{hc} - \dot{Q}_c \quad (5)$$

The percentage heat loss is given by:

$$\%\dot{Q}_{loss} = \frac{Q_h - Q_c}{Q_h} \times 100 \qquad (6)$$

The pressure drop of the longest path which is that of the cold air flow stream from the entry to the exit of the cold air chambers is a measure of the aerodynamic performance of the heat exchanger.

VI. RESULTS AND DISCUSSIONS

In these experiments, the increase in the rate of heat transfer in the five-chamber heat exchanger was examined. Each of these chambers is provided with a steel plate in which aluminum fins are fixed on it. Four different thicknesses of the same porous material were inserted, by calculating the heat recovery ratio and the pressure drop across the heat exchanger. Also, the results obtained from the aluminum fins were compared with the corresponding results obtained previously using steel fins [4].

6.1. Cold Air Outlet Temperature

The cold air outlet temperatures of the heat exchanger represent the performance characteristics of it. Figures 4, 5 and 6 show the effect of the inlet hot air temperature, volume flow rates of the cold and hot air streams and the porous medium thickness on the cold air outlet temperature when using aluminum fins. It also shows the results obtained previously when using steel fins under the same operating conditions abstracted from reference [4].

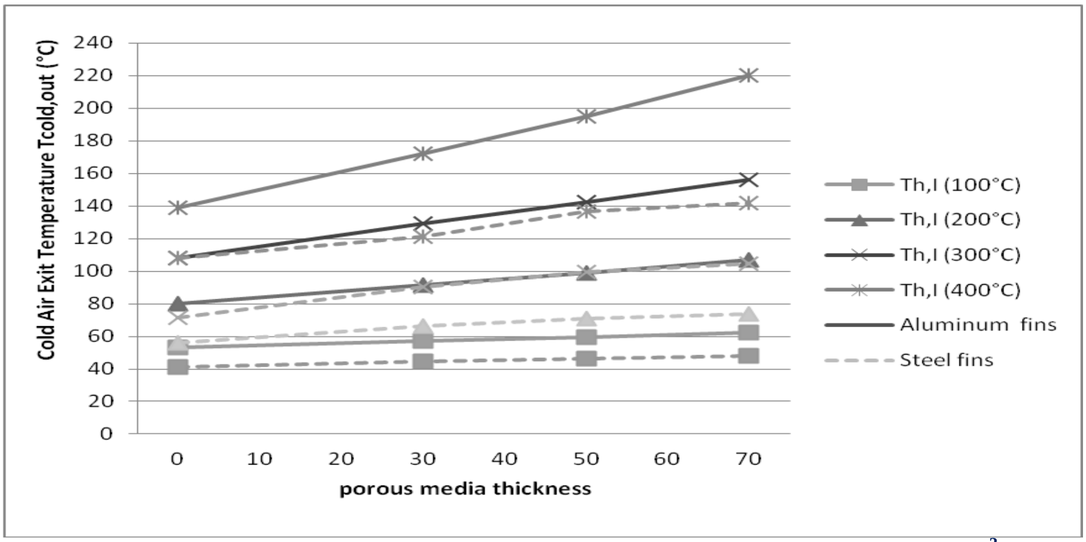

Figure 4 Effects of $T_{h,i}$ and Porous Media Thickness on $T_{c,o}$ at a Volume Flow Rate of 0.2 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

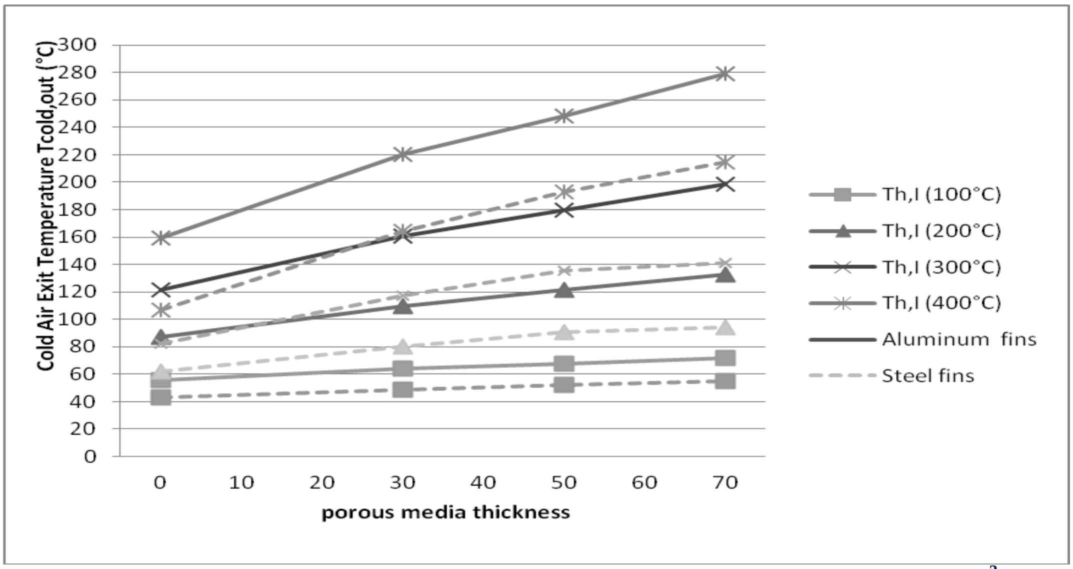

Figure 5 Effects of $T_{h,i}$ and Porous Media Thickness on $T_{c,o}$ at a Volume Flow Rate of 0.35 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

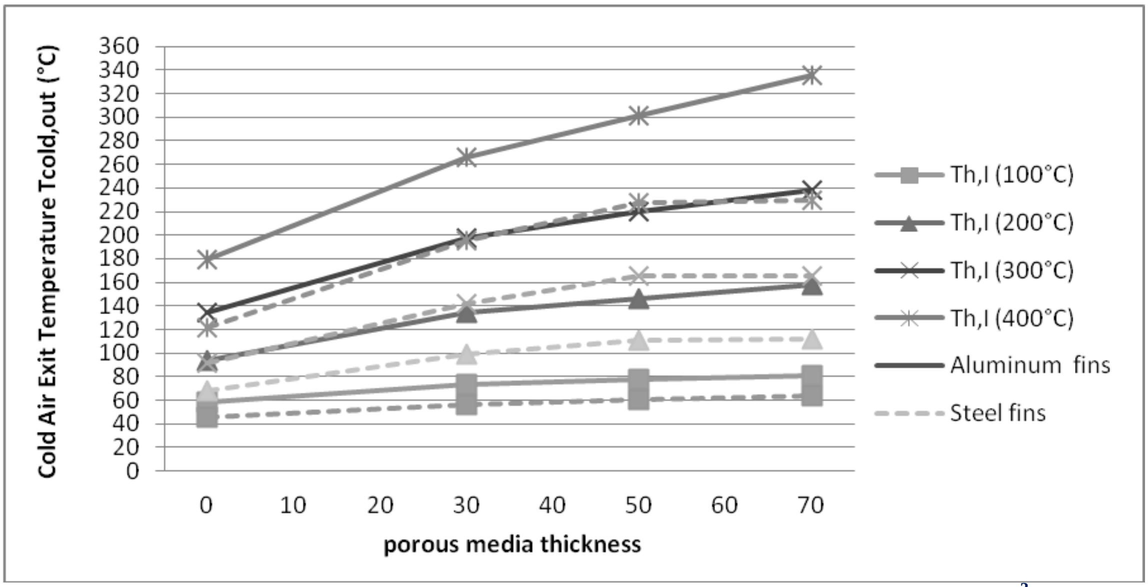

Figure 6 Effects of $T_{h,i}$ and Porous Media Thickness on $T_{c,o}$ at a Volume Flow Rate of 0.5 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

The study shows that the increase in both of the porous material thickness and the inlet temperature of the hot air stream increases the out temperature of the cold air stream considerably in both cases (aluminum fins and steel fins) while keeping the hot and cold airstreams constant. Also, the fins material has a big effect on the cold air stream output temperatures.

In case of aluminum fins, as the porous material thickness was increased and the hot air stream inlet temperature was increased to 400°C, the out temperature of the cold air stream increased to 335.3°C, at 0.5 m3/min volume flow rate of the cold and hot air streams. While in the case of steel fins with the same conditions of the hot air inlet temperature, porous material thicknesses and the volume flow rates of the cold and hot air streams, the out temperature of the cold air stream increased to 229.72°C.

It is observed that in aluminum fins case the cold air outlet temperature increases by approximately 45% of the case of the steel fins. Also figures 4, 5 and 6 show that in all measurements conditions cases of the porous material thicknesses and the volume flow rates of the cold and hot air streams while keeping the hot air inlet temperature at 400°C. The cold air temperatures outlet of the steel fins case is nearly closed equal to the cold air temperatures outlet of the aluminum fins case at 300°C hot air inlet temperature.

6.2. Hot Air Outlet Temperature

The determination of the optimum conditions of the operation of the heat exchanger behavior is important. Therefore measuring the hot air outlet temperature (Th,o) as shown in Figs. 7,8 and 9, as the cold and hot air streams flow through the heat exchanger resulting in heat exchange between the cold and hot air streams. Also measuring the volume flow rate of the cold and hot air has the same as measuring the hot air stream outlet temperature Th,o. The hot air outlet temperatures decrease varies with the porous medium thickness, the hot and cold airstreams volume flow rates, and the hot air inlet temperatures, also the material of the fins affect the hot air outlet temperatures.

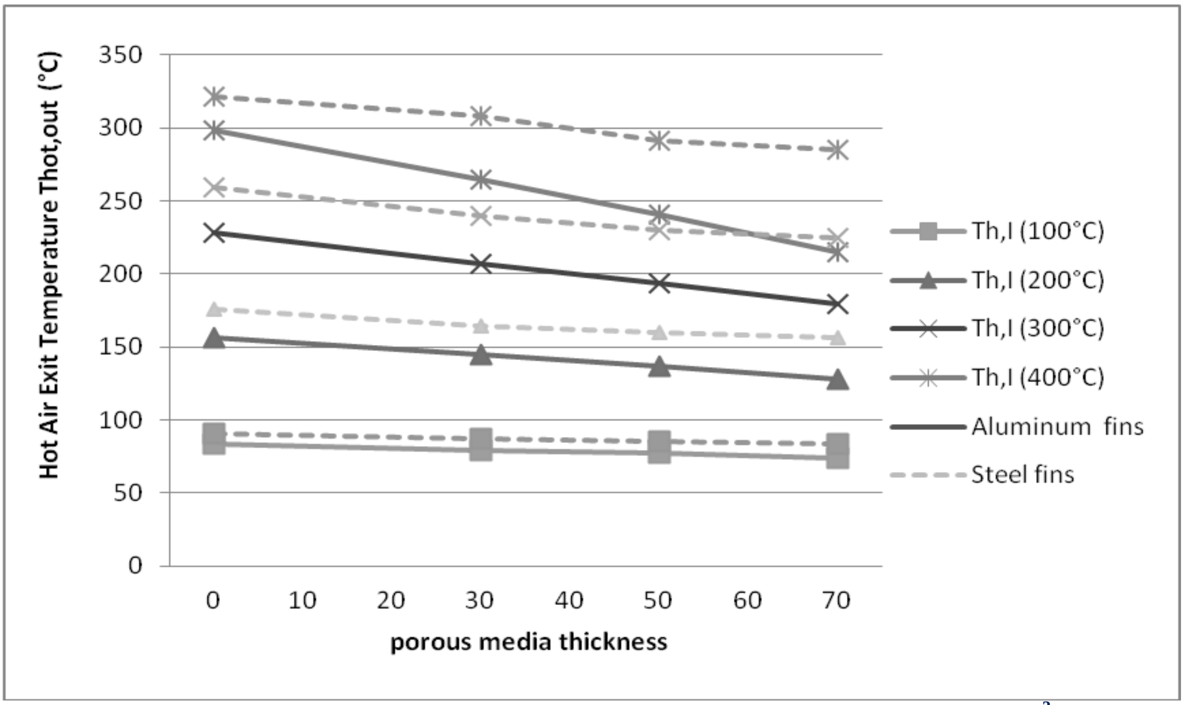

Figure 7 Effects of $T_{h,i}$ and Porous Media Thickness on T_{h},o at a Volume Flow Rate of 0.2 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

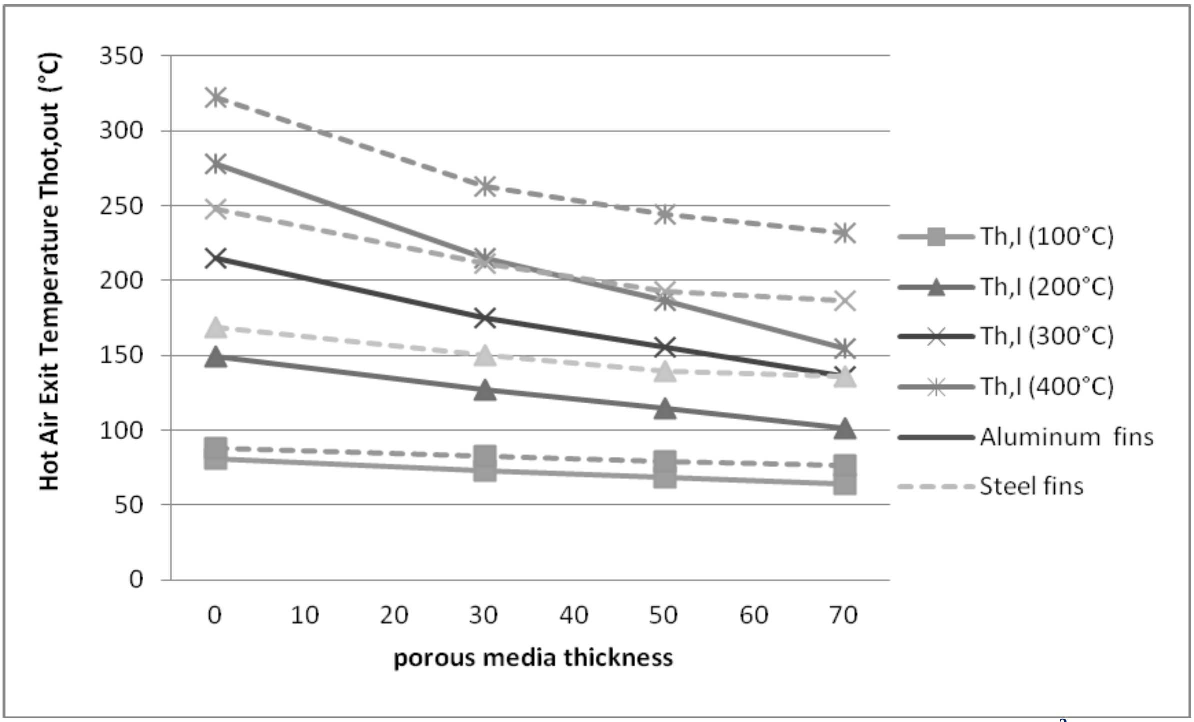

Figure 8 Effects of $T_{h,i}$ and Porous Media Thickness on T_{h},o at a Volume Flow Rate of 0.35 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger..

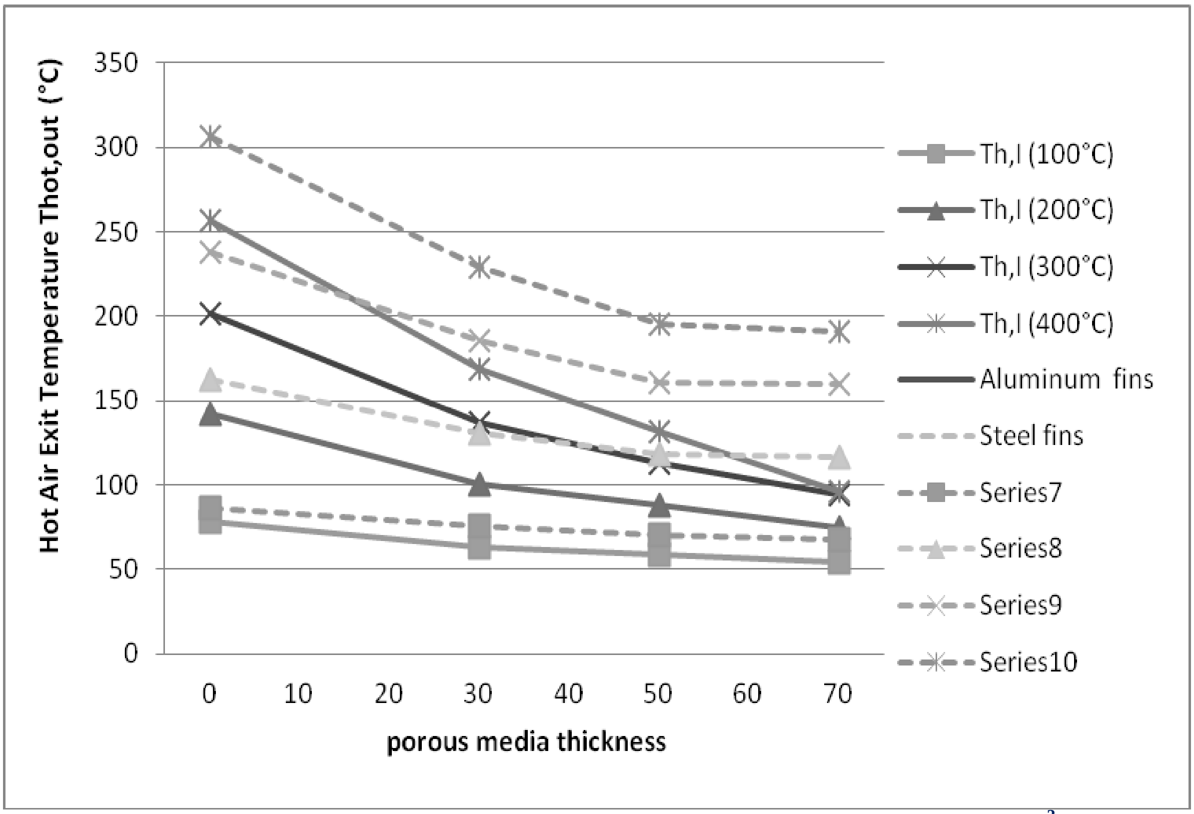

Figure 9 Effects of $T_{h,i}$ and Porous Media Thickness on $T_{h,o}$ at a Volume Flow Rate of 0.5 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

The hot air stream enters the fourth chamber (T hot 1) then continues flowing to enter the second chamber (T hot 2) and leaves it at (T hot 3) then finally will go to the exhaust chimney (Th,o) as shown in figure 2. The cold air stream gaining heat from the hot air stream as the cold air stream flows in the heat exchanger starting from the first cold chamber at

(TC1) till it leaves the heat exchanger at (Tc,o), while the hot air stream flows in a heat exchanger at the same time starting from fourth chamber at (Th1) till it reaches the exhaust chimney (Th,o) as shown in figure 3

In case of aluminum fins, as the porous material thickness was increased to 70 mm and the hot air stream inlet temperature was increased to 400°C, the out temperature of the hot air stream decreased to 95.5°C, at 0.5 m3/min volume flow rate of the cold and hot air streams. While in case of steel fins with the same conditions of the hot air inlet temperature, porous material thicknesses and the volume flow rates of the cold and hot air streams, the out temperature of the cold hot stream decreased to 191.31°C.

It is observed that in aluminum fins case the hot air outlet temperature decreases by approximately 50% of the case of the steel fins as shown in figures 7,8 and 9.

6.3. Heat Recovery Ratio

The heat recovery ratio HR which is a performance parameter of the heat exchanger is the ratio of the rate transferred heat to the cold air stream to the maximum possible rate of heat transfer that can be transferred from the hot stream to the cold one. As the flow rates of the cold and hot air stream are equal and the specific heats are almost the same. The heat recovery ratio is the measure of the heat exchanger effectiveness

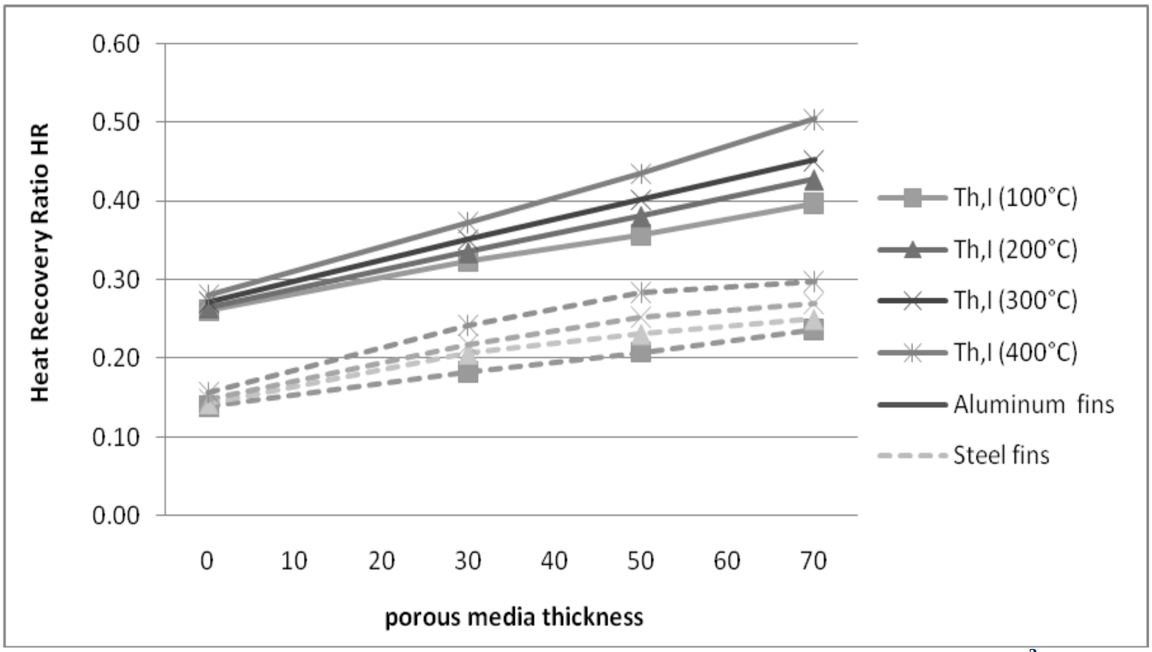

Figure 10 Effects of $T_{h,i}$ and Porous Media Thickness on HR at a Volume Flow Rate of 0.2 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

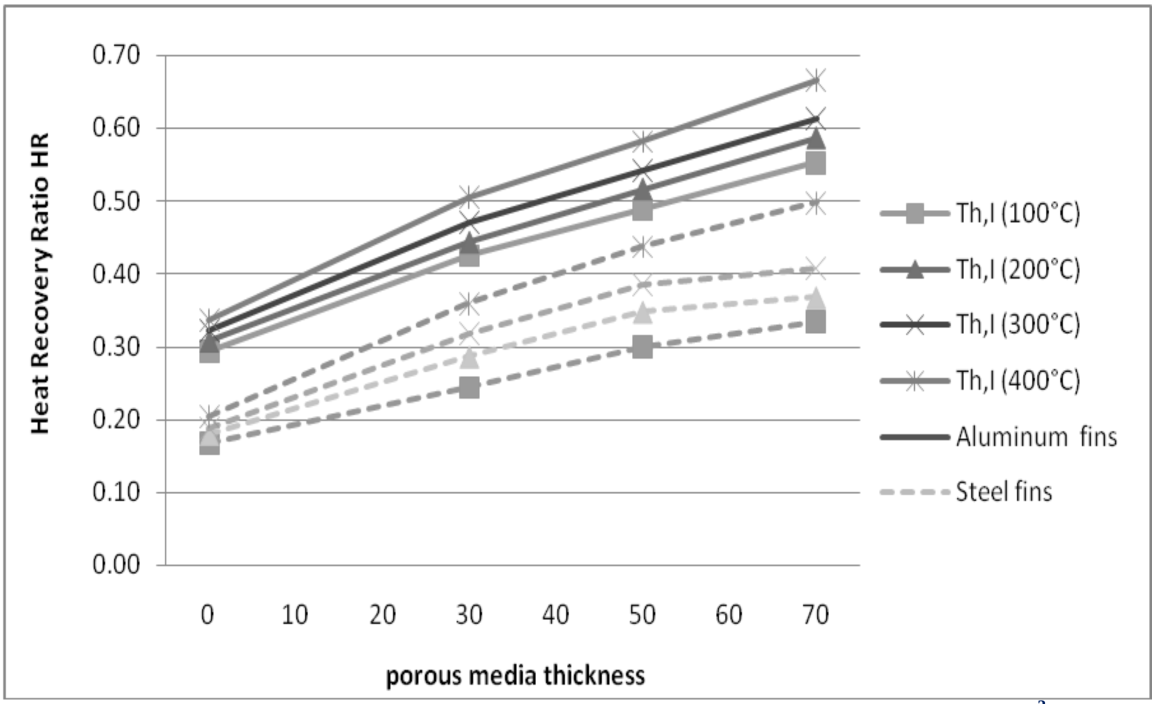

Figure 11 Effects of $T_{h,i}$ and Porous Media Thickness on HR at a Volume Flow Rate of 0.35 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger..

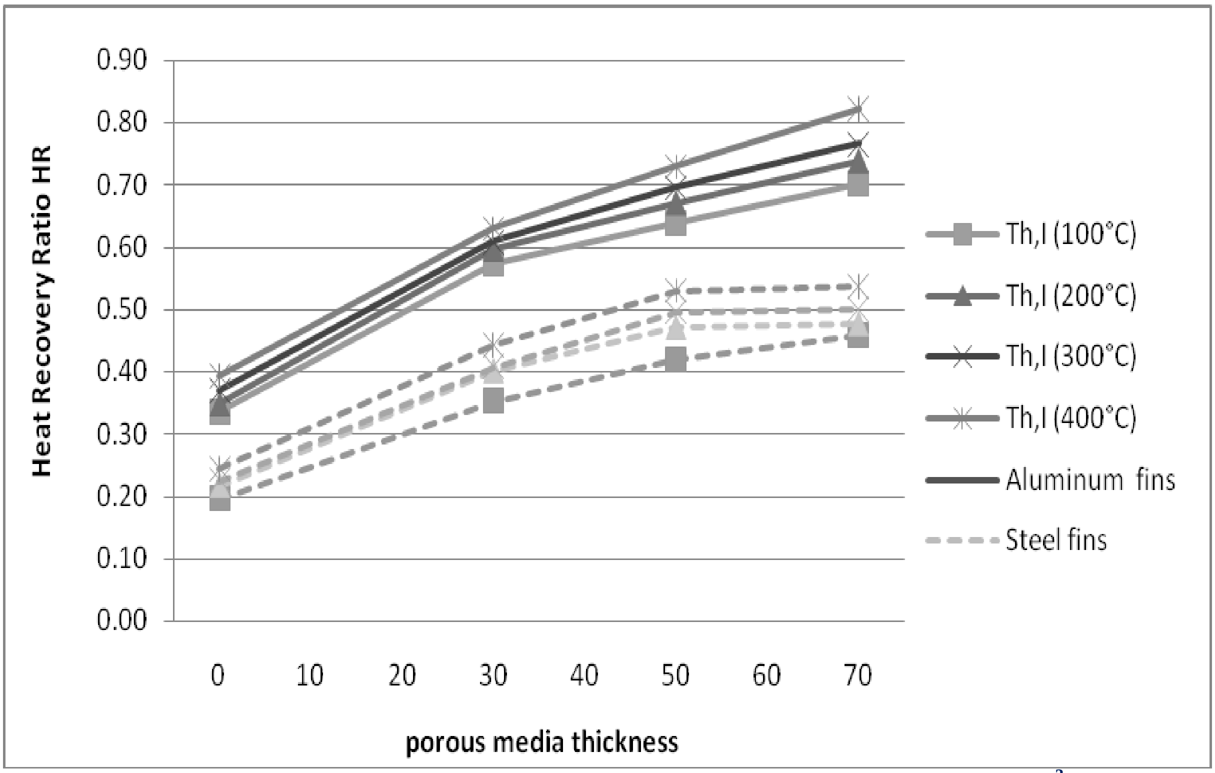

Figure 12 Effects of $T_{h,i}$ and Porous Media Thickness on HR at a Volume Flow Rate of 0.5 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

The heat recovery ratio HR depends on the rate of volume flow rates of the cold and hot air streams , the heat recovery rate $\dot{Q}c$ to the cold air stream , the inlet air stream temperature, the outlet cold air stream temperature, the porous medium thickness and the material of the fins.

It is observed that In the case of aluminum fins, the porous material thickness is 70 mm and the hot air stream inlet temperature is 400°C, the heat recovery ratio increased to 0.822, at 0.5 m3/min volume flow rate of the cold and hot air streams. While in the case of steel fins with the same conditions of the hot air inlet temperature, porous material thicknesses, and the volume flow rates of the cold and hot air streams, the heat recovery ratio was 0.459 as shown in Figs. 10, 11 and 12. It is observed that in aluminum fins case the heat recovery ratio increases by approximately 44% of the case of the steel fins.

6.4. The Heat Recovery Rate

The heat recovery rate (QC) defined as the rate of increase of the cold air stream enthalpy due to the net heat gained by the cold air stream as it flows through the heat exchanger.

In the case of the aluminum fins, it was observed that the hot air stream inlet temperature is much more effective on this heat exchanger performance than the volume flow rate of the cold and hot air streams as shown in Figs. 13,14 and 15 that at porous material thickness 70 mm, 0.5 m3/min volume flow rate and 100°C inlet hot air stream temperature, the rate of the heat gain by the cold air stream is 425 Watt. While at the same porous material thickness, same volume flow rate of the cold and hot air streams and raising the hot air inlet temperature t0 400°C, the rate of the heat gain by the cold air stream increased to 2869 Watt, which is approximately increased by 86% due to the increases in the hot air stream inlet temperature from 100°C to 400°C. In the other hand at 70 mm porous material thickness and

100°C inlet hot air stream temperature, the rate of the heat gain by the cold air stream is 234.3 Watt at 0.35 m3/min and increased to 425 Watt at 0.5 m3/min, which is approximately increased by 44% due to the increases in the cold and hot volume flow rate streams from 0.35 m3/min to 0.5 m3/min .aluminum fins case the heat recovery ratio increases by approximately 44% of the case of the steel fins.

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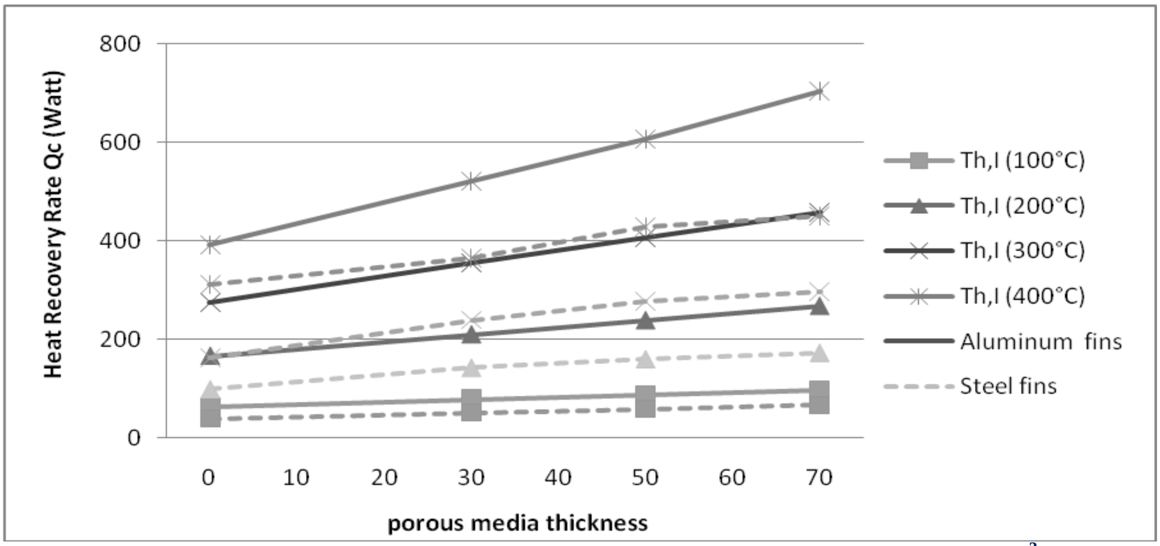

Figure 13 Effects of $T_{h,i}$ and Porous Media Thickness on Q_c at a Volume Flow Rate of 0.2 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

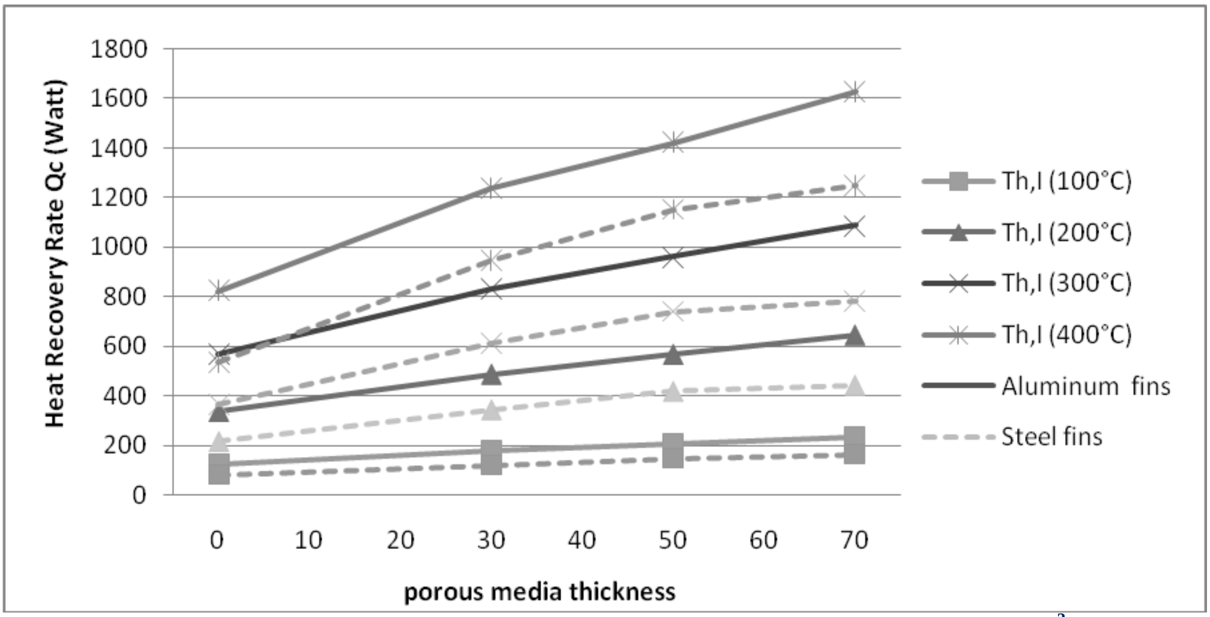

Figure 14 Effects of $T_{h,i}$ and Porous Media Thickness on Q_c at a Volume Flow Rate of 0.35 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

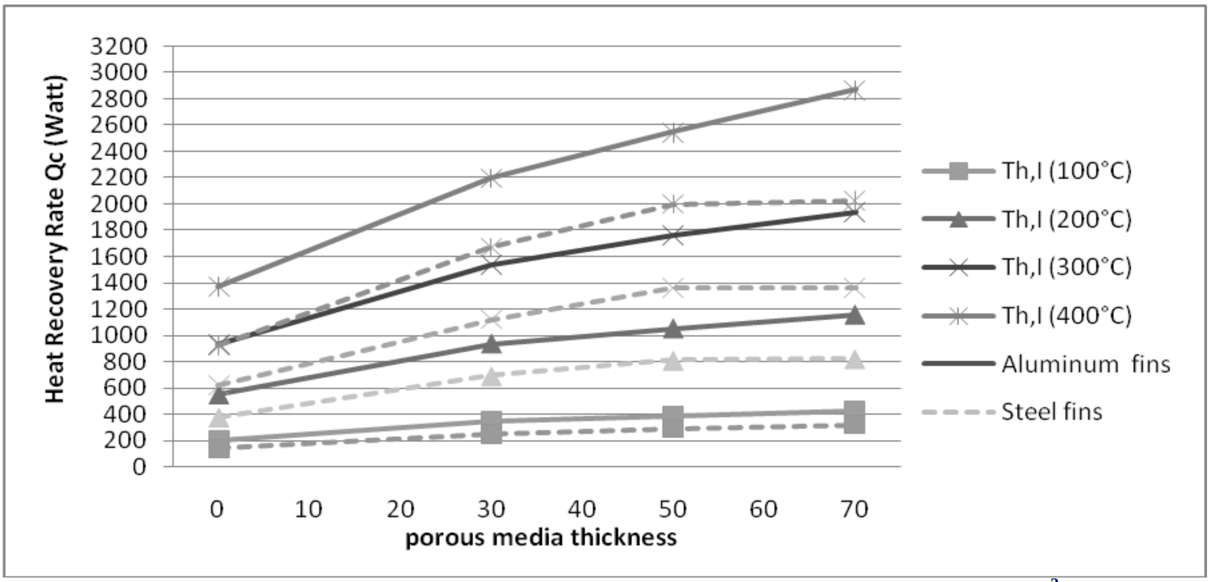

Figure 15 Effects of $T_{h,i}$ and Porous Media Thickness on Q_c at a Volume Flow Rate of 0.5 m^3/min. Using Aluminum and Steel Fins Walls Heat Exchanger.

Also the study shows that when keeping the operating conditions constant at porous material thickness 70 mm, 0.5 m3/min volume flow rate and 400°C inlet, while changing the material fins only, it was observe that the hot air stream temperature in aluminum fins case the heat recovery rate increases by approximately 29% of the case of the steel fins. Also figures 4, 5 and 6 show that in all measurements conditions cases of the porous material thicknesses and the volume flow rates of the cold and hot air streams while keeping the hot air inlet temperature at 400°C. The heat recovery rate of the steel fins case is nearly closed equal to the heat recovery rate of the aluminum fins case at 300°C hot air inlet temperature.

6.5. The Pressure Drop

The cold air stream pass is considered as the longest pass because it flows through three segments of porous material therefore it would face the highest pressure drop across the heat exchanger. The pressure drop is conducted by measuring the longest pass as shown in figure 16, which is the cold air stream pass. It was indicated that the pressure drop in both cases of the aluminum and steel fins is the same because the aluminum and steel fins have the same structural design and the material is the only difference between them.

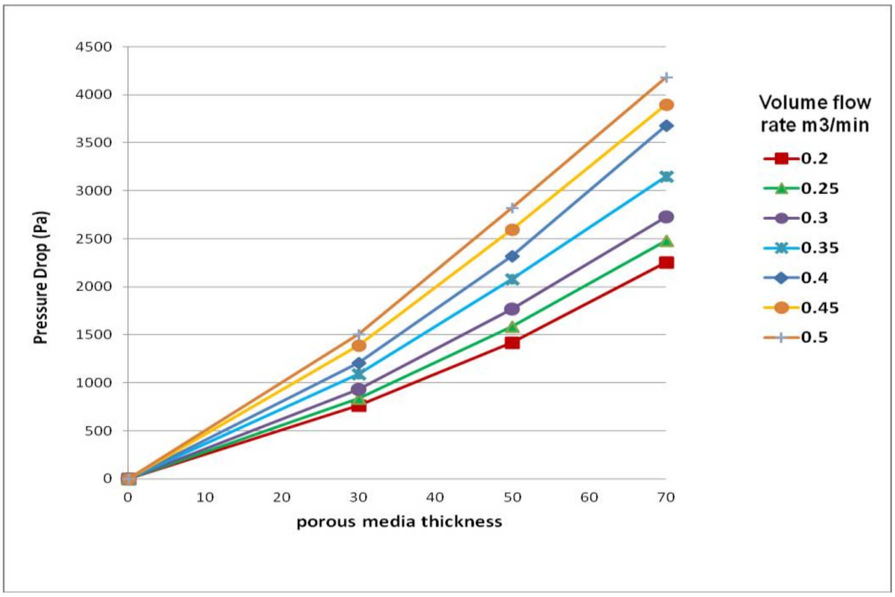

Figure 16 Effects of The Porous Media Thickness and The Material Fins on Pressure Drop Across The Cold Air Chambers at Different Air Volume Flow Rates Using Aluminum and Steel Fins Walls Heat Exchanger.

VII. CONCLUSIONS

A series of experiments have been performed to study the effect of fins material on the performance of stratified chambers gas to gas heat exchanger with and without porous medium. The major conclusions of this investigation are summarized as the following:

1. The hot air stream inlet temperature is much more effective on this heat exchanger performance than the volume flow rate of the cold and hot air streams.
2. The porous medium has a great effect on the enhancement of the heat transfer rate for the heat exchanger
3. As the porous medium thickness increases, the heat transfer rate increases and the pressure drop across the heat exchanger increases.
4. The material of the fins plays an important role in improving the heat transfer rate in the heat exchanger
5. The aluminum fins have effectively improved the heat transfer rate more than the steel fins
6. In the case of aluminum fins, the porous material thickness is 70 mm and the hot air stream inlet temperature is 400°C, the heat recovery ratio increased to 0.822, at 0.5 m3/min volume flow rate of the cold and hot air streams. While in the case of steel fins with the same conditions of the hot air inlet temperature, porous material thicknesses, and the volume flow rates of the cold and hot air streams, the heat recovery ratio was 0.459. It is concluded that in aluminum fins case the heat recovery ratio increases by approximately 44% of the case of the steel fins

7- The optimum thickness of the porous material is 50 mm which balance between the heat transfer and the pressure drop.

Nomenclature

$\dot{m}$	Air mass flow rate……………………………….….....	kg/sec.
$c_{p,c}$	Cold air specific heat capacity at constant pressure...	J/kg.K
$c_{p,h}$	Hot air specific heat capacity at constant pressure…	J/kg.K
$T_{c,i}$	Cold air inlet temperature…………………………..	℃
$T_{c,o}$	Cold air outlet temperature…………………………	℃
$\bar{T}_c$	Average cold air temperature………………………	℃
$T_{h,i}$	Hot air inlet temperature……………………………	℃
$T_{h,o}$	Hot air outlet temperature…………………………..	℃
$\bar{T}_h$	Average hot air temperature…..……………………	℃
$H_{R.}$	Heat recovery ratio…………………………………	--
Q_h	Rejected heat rate by the hot air…………………….	W
Q_c	Heat recovery rate. Heat gained by the cold air…….	W
Q_{hc}	Rate of heat transfer from the hot air to the cold air…….	W
$\%Q_{loss}$	Percentage of heat loss……………………………...	%

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