Experimental Investigation Effect of Capillary Tube Number on Window Type Air Conditioning Unit Performance

دراسة عملية لتأثير عدد الأنابيب الشعرية على أداء مكييف هواء جداري

Ali Khalid Shaker Al-Sayyab
Thermal Mechanical Engineering Department
College of Technical Engineering-Basra
Southern Technical University
ali.alsayyab@stu.edu.iq

Abstract:
Capillary tubes are widely used in refrigerating and air conditioning units. It has no moving part however, a capillary tube is less expensive and generally performs nearly as well. In this work, the effect of capillary tube numbers on air conditioning system performance is studied for refrigerant R22. The study was adopted with the five capillary tubes at same diameter of 2.2 mm and length of 0.6 m. The experimental work shows that, the air conditioning operates with three capillary tubes gives highest COP from other of the same diameter with 14% increasing from base case of two capillary tubes, where the performance of the air conditioning that operates with one capillary tube gives the lowest COP from other.
key words :- Air conditioning, capillary tube , R22.

الخلاصة:
تستخدم ألأنابيب الشعرية على نطاق واسع في وحدات التبريد وتكييف الهواء. تمتاز بعدم وجود اي جزء متحرك ويعتبر ألأنبوب الشعري أقل تكلفة .في هذا العمل، تم دراسة تأثير عدد ألأنابيب الشعرية على أداء منظومة تكييف هواء جدارية تعمل بالمائع R22. واعتمدت في هذه الدراسة خمسة أنابيب شعرية ذات قطر 2.2 ملم وطول 0.6 متر. اظهر الجانب العملي أن مكييف الهواء الذي يعمل مع ثلاثة أنابيب شعرية يعطي أعلى معامل اداء من غيرها لنفس القطر مع زيادة 14٪ عن حالة الاساسية (انبوبين شعريين)، كذلك مكييف الهواء الذي يعمل مع أنبوب شعري واحد يعطي أدنى معامل اداء.
كلمات دلالية: مكييف هواء; انبوب شعري;مائع تبريد R22

1. Introduction:
Each air conditioning unit requires an expansion device to regulate the refrigerant flow from the condenser high-pressure side to the evaporator low-pressure side of the refrigerating system according to load required. The capillary tube is especially popular for smaller unitary hermetic equipment such as room air conditioners. The principle of the capillary tube is that liquid passes through it much more readily than vapor. It connects the condenser outlet to the evaporator inlet. A capillary tube should be probably designed to compatible with other system parts. In general, the design of capillary tube depends on system capacity, compressor type, application and type of refrigerants. A capillary tube pushs through liquid much more easily than vapor due to the increased friction with the vapor; as a result, it is a practical metering device. If capillary tube properly sized for the application, it compensates automatically for load and system variations and gives acceptable performance over a wide range of operating conditions [1].There are many studies performed on capillary tube size and configurations. Issam M. et al. [2] did an experimental study to perform the effect of capillary tube geometry on system performance work with R134a and R12. They used three capillary tubes with different size 0.81mm, 1.4 mm and 1.5 mm. They found that the temperature gradient for the two refrigerants is the same, but after approximately one meter, the temperature gradient of R134a is faster than R12. Decreasing the discharge causes faster temperature gradient leads to faster vaporization. The effect of changing the discharge becomes insensible for small diameters. Akkarat Poolkrajang et al. [3] steadied the effect of capillary tube on

spilt unit performance working with R22. They use five capillary tubes with different size, the results show that the refrigerant effect increases as the capillary tube diameter decreases, while any change to the capillary tube diameter will give very little effect on compressor work (no changes) and, COP tends to be higher as the diameter of capillary tube decreases. Salim [4] used more than capillary tube. The study showed that when the capillary tube coil number increases, the compressor power decreases by 10.3% and refrigerant effect increases by 1.6%. So COP tends to be higher by 13.51%. And when the capillary coils number increasing from 0 to 4, the mass flow rate will increase by 4.3%. Researchers found the best coil number depending on the mass flow rate change is 4. Shashank et al. [5] studied the capillary tube diameter and coiled formation on system performance, the researchers used three capillary tube with different coiled shape helical, straight and serpentine. They revealed that the straight formation shows maximum mass flow rate and helical coiled give the lower. The maximum cooling effect is adopted by using the helical coiled where least by using straight coiled. The system mass flow rate is increased as the capillary tube diameter decreasing. Kareem et al. [6] did an experimental study to show the effect of the coiled diameter of capillary tube, also found that coiled diameter of capillary tube affects the cycle COP strongly, so as the capillary coiled diameter increases from 25 to 100 mm the cycle COP increases from 2.8 to 3.7. The increases in coiled diameter more than 100 mm shows insignificant effect on the cycle COP. Farayibi et al. [7] studied the effect of capillary tube line number on air conditioning system performance .The study found that as increasing the capillary tube number from one to three, the refrigerating effect was increases, while the compressor work decrease. So COP of the system was increases in the order of 5.69±0.04, 6.24±0.04 and 6.71±0.04 when one, two and three capillary lines were respectively used. In the current study, all tests are carried out for window type air conditioning unit working with refrigerant R22 , the capillary tubes numbers of same size (2 meter length and 2.2 mm inner tube diameter) are varying from one to five.

$$w_{scom} = h_2 - h_1 \qquad (1)$$

The specific heat rejected from condenser found by evaluating the refrigerant enthalpies at the inlet and outlet [8].

$$q_c = h_2 - h_3 \qquad (2)$$

The heat absorbed by evaporator is:

$$q_e = h_1 - h_4 \qquad (3)$$

To get an indicted about the vapour compression cycle performance the coefficient of performance should be adopted, which is the proportion of refrigerating effect to the compressor work, in this study the fan work was neglected because the capillary changes give no any effect on it [8].

$$\mathbf{COP} = \frac{\text{Refrigerating effect}}{\text{Compressor Work}}$$

$$\mathbf{COP} = \frac{h1 - h4}{h2 - h1} \qquad (4)$$

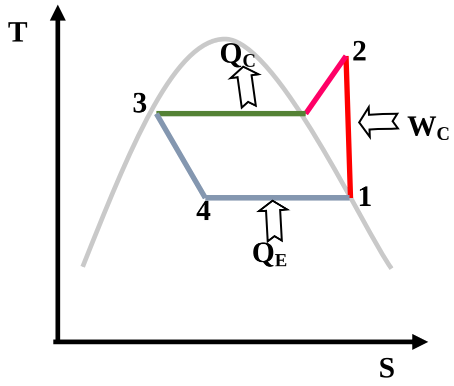

Figure (1) Vapor compression cycle on T-S diagram

3. Experimental test rig and measuring devices:

An environmental controlled test zone was adopted and designed to run all tests in which the temperature of supplied air was changed to follow the same seasonal air temperature gradient .A test zone consists of two galvanized short ducts with cross sectional area of (42cmX35cm) attached together on the air conditioning unit sides to produce the controlled zone duct. Six electrical heaters with (6*2000 Watt) heating capacity, were inserted inside the air duct. To achieve the required supply air temperature (as ambient air temperature for summer seasonal in Iraq), the voltage drop across heater was regulated by a solid state voltage regulator with heat snick .The solid state voltage regulator varied the voltage from 30 to 220 Volts with load capacity of 40 Amperes .A pressure gauge with a pressure range of (0 to 50 bar) is used to measure the pressure of the refrigerant. The gauge was connected to inlet and outlet of compressor by small capillary tube with connecting fitting.A digital thermometers with reading range of-200 to 190 ℃ of T-type thermocouples are used to measure the temperature .The thermocouples wire were attached to the inlet and outlet of the compressor,condenser and evaporator to measure the temperature.With five thermocouples wire attached inside the duct to measure the supply air temperature.The test rig is shown in figure (2).

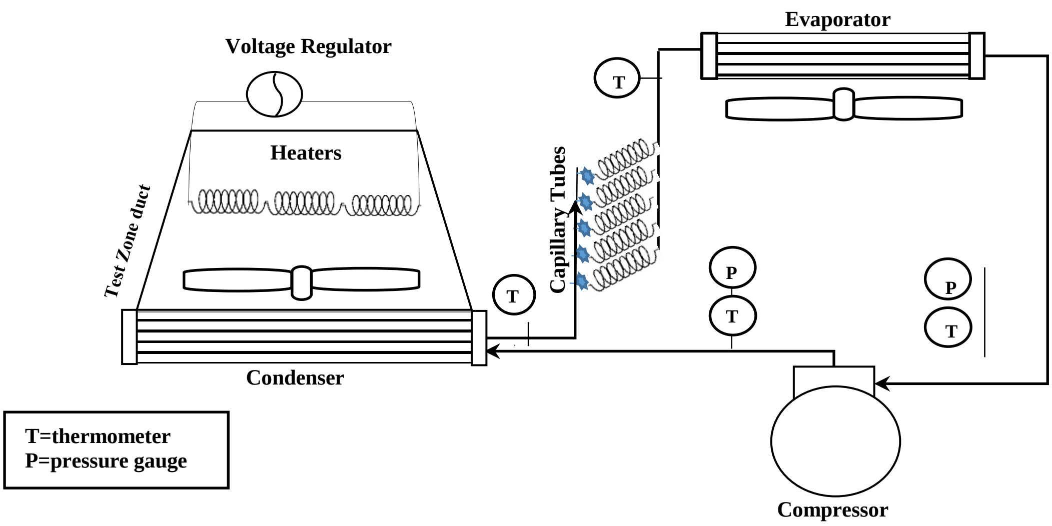

Figure (2) Sketch of test rig with measuring devices

4. Result and discussion:

4.1 Effect of capillary tube number on compressor work:

From Figure (3), the system working with any given capillary tube numbers has the same phenomena as the ambient air temperature increased the compressor work increased also. As the ambient temperature increased the refrigerant condenser – ambient air temperature difference will decrease and to overcome this reduction, the compressor tends to increase the condenser temperature by increasing in compressor pressure ratio Figure(4) .

In Figure(3), the system with one capillary tube has the highest compressor work due to the high tube-refrigerant obstruction that will produce more flashing gas (additional impediment) Fig(5). So the system with two capillary tube has less compressor work, due to the less pressure ratio as compared with the other number. And the ACS with the capillary tube more than two tubes have more compressor work also due to the increasing in the tube-refrigerant obstruction per unit mass of refrigerant pass that will produce more flashing gas (more obstruction) so increase the pressure drop over capillary length.

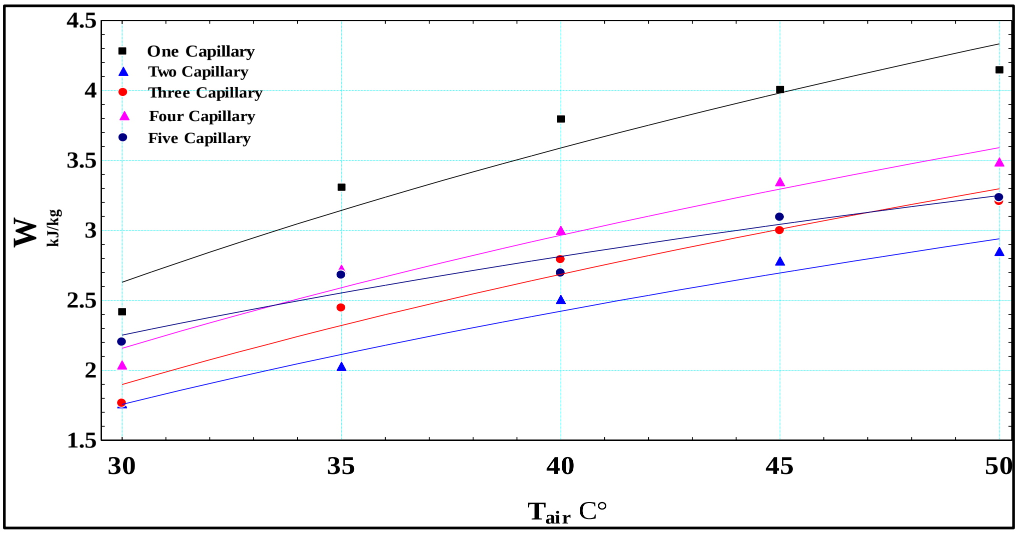

Figure (3) Compressor work vs. capillary tube number

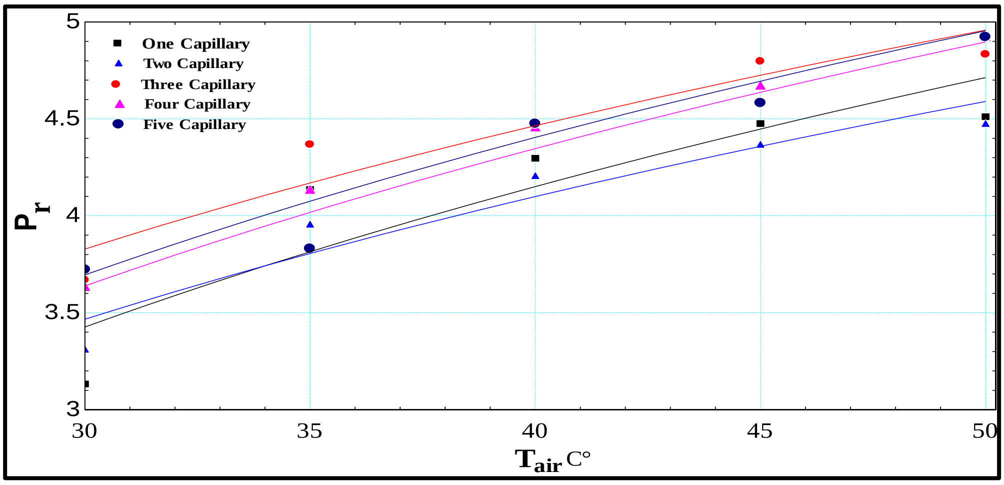

Figure (4) Compressor pressure ratio vs. capillary tube number

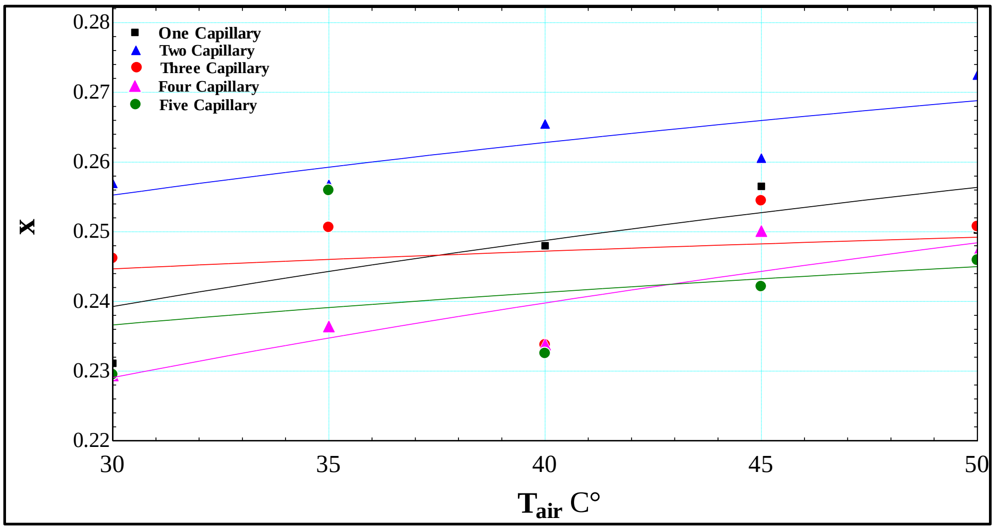

Figure (5) Flashing gas quality vs. capillary tube number

4.2 Effect of capillary tube number on condenser heat rejection:

From Figure (6) as the ambient temperature increased the condenser heat rejection decreased for any number of tested capillary tubes .The increasing in ambient temperature will reduce the refrigerant -air temperature difference that will decrease the refrigerant to air side heat transfer coefficient. So the compressor tends to increase the compression pressure ratio Figure (4)(the condensing temperature) but this does not overcoming the increasing in ambient temperature thus, the condenser heat rejection will decreased.

Also from Figure(6) the ACS with three capillary tubes have the highest condenser heat rejection due to the highest condenseing temperature (highest pressure ratio) in addition to the high refrigerant mass flow rate "high refrigerant to air side heat transfer coefficient". while the ACS with one capillary tube have the lowest condenser heat rejection due to the highest obstruction of refrigerant –capillary tube that will reduce the amount of refrigerant mass flow rate which leads to decreasing the refrigerant to air side heat transfer coefficient.

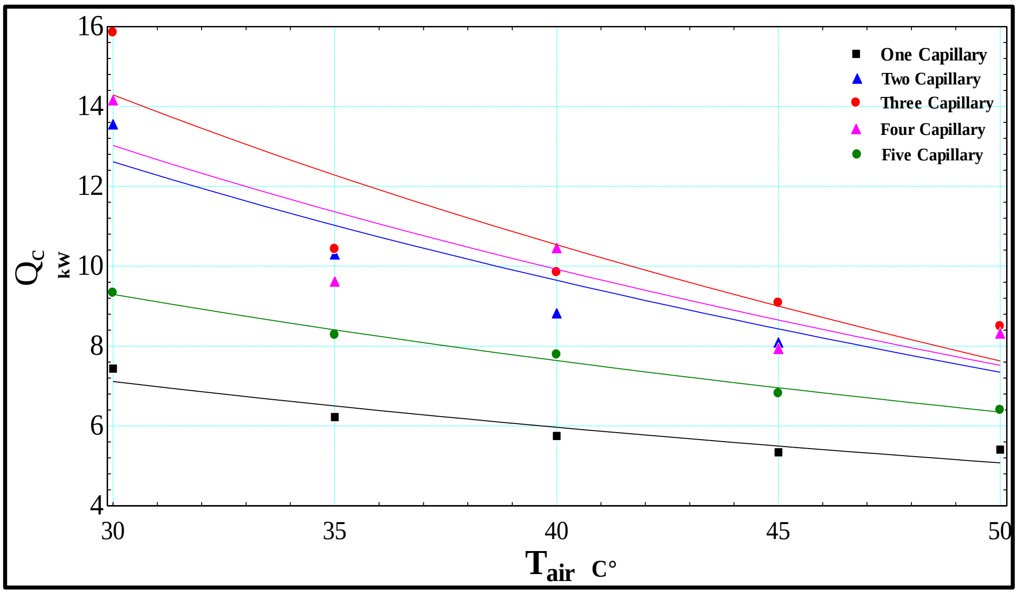

Figure (6) Condenser heat rejection vs. ambient air temperature

4.3 Effect of capillary tube number on refrigerating effect:

From Figure (7) as the ambient air temperature increased the ACS refrigerating effect with any tested capillary tube number will decrease due to the decreasing in the degree of sub cooling so the increasing in the amount of flashing gas as a result of decreasing in the amount of condenser heat rejection.

The ACS with three capillary tubes have the highest refrigerant effect, becaus of the highest heat rejection by condenser with more sub cooling "means less flashing gas " Figure (5). so the ACS with one capillary tube have the lowest refrigerant effect , because of the lowest heat rejection by condenser figure(5) which leads to reduce the degree of sub cooling and increase the amount of refrigerant flashing gas, this means that the portion of the latent heat will decrease by increasing vapor amount figure(8).

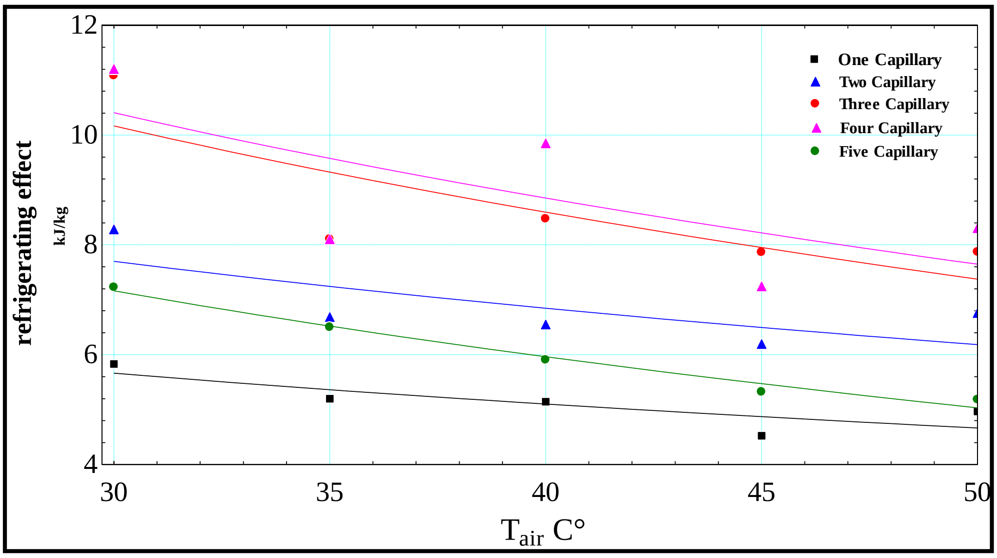

Figure (7) Refrigerating effect vs. ambient air temperature

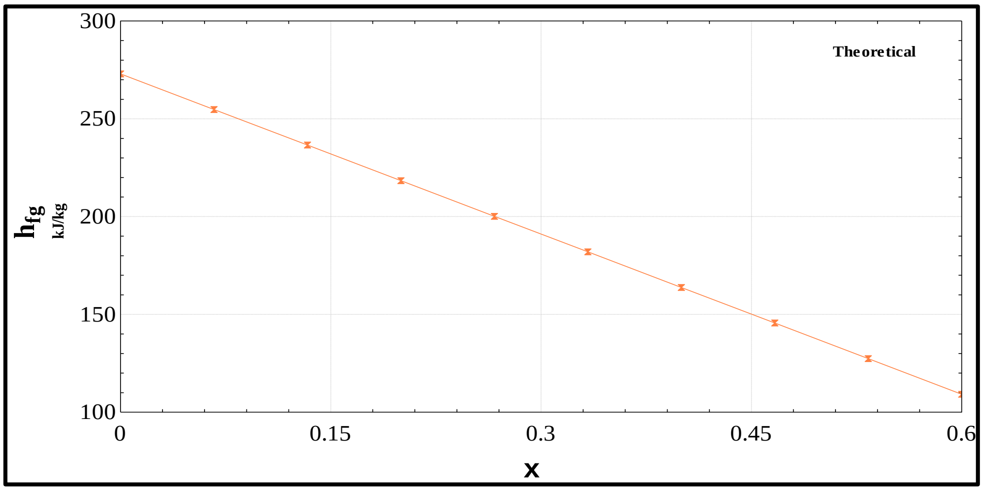

Figure (8) Refrigerating latent heat vs. amount of refrigerant flashing gas

4.4 Effect of capillary tube number on refrigerant mass flow rate:

From Figure (9) as the ambient air temperature increased the refrigerant mass flow rate over capillary tube number will decrease. because of , as the ambient air temperature increased the compressor tends to overcome this increasing by increase the condensing temperature (increasing the pressure ratio), this lead to decrease the compressor volumetric efficiency as shown in Figure(10), so the compressor mass flow rate.

Also from Figure(9)the ACS with two capillary tubes have the highest mass flow rate becouse of it has the lowest pressure ratio so the highest volumetric efficiency Figure(10). on the other hand the ACS with more than two capillary tube have the lowest mass flow rate this due to the increasing in capillary-refrigerant obstruction per number of capillary tube , in addition the higher pressure ratio increase the amount of refrigerant flashing gas (the flashing gas bubbles obstruct the refrigerant flow through capillary tubes)

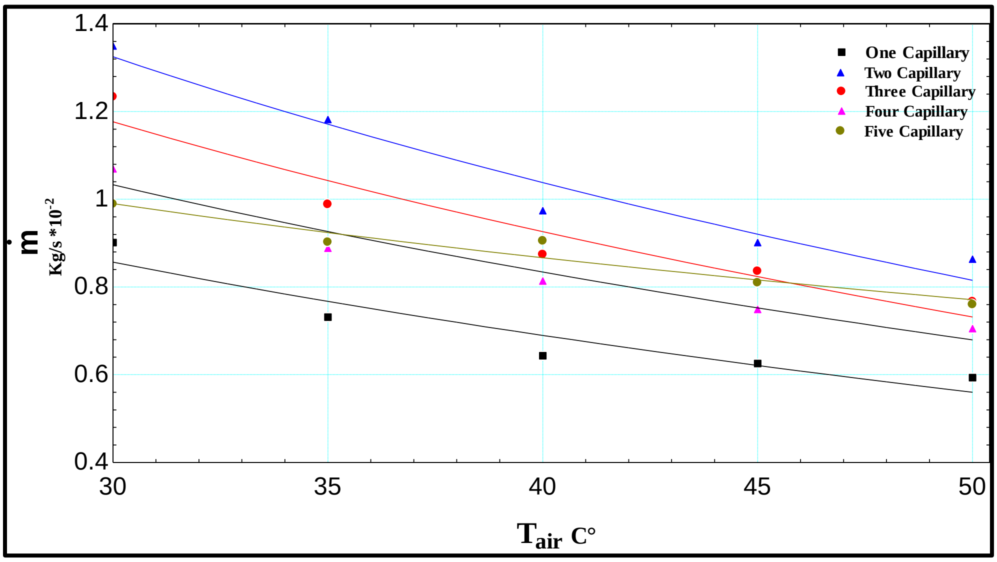

Figure (9) Refrigerant mass flow rate vs. ambient air temperature

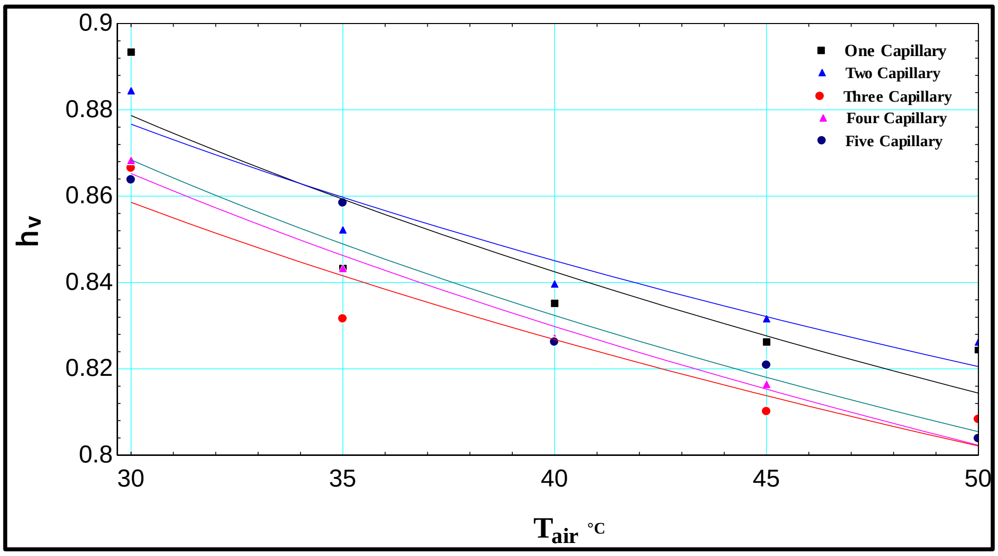

Figure (10) Compressor volumetric efficiency vs. ambient air temperature

4.5 Effect of capillary tube number on the coefficient of performance:-

In the light of paragraph 4.1,4.2 for all tested capillary tube numbers as the ambient air temperature increase the compressor work will increase Figure(3) ;while the refrigerating effect will decrease Figure (6),consequently the coefficient of performance will decrease as the ambient air temperature increase Figure (11)

From Figure (11) the ACS with one capillary tube have the lowest COP from other because of this system have the highest compressor work (denominator of COP) with the lowest refrigerating effect (numerator of COP). The ACS with three capillary tubes have the highest COP from all tested capillary number this due to the portion of refrigerating effect increasing is much more effect than that of compressor work increasing.

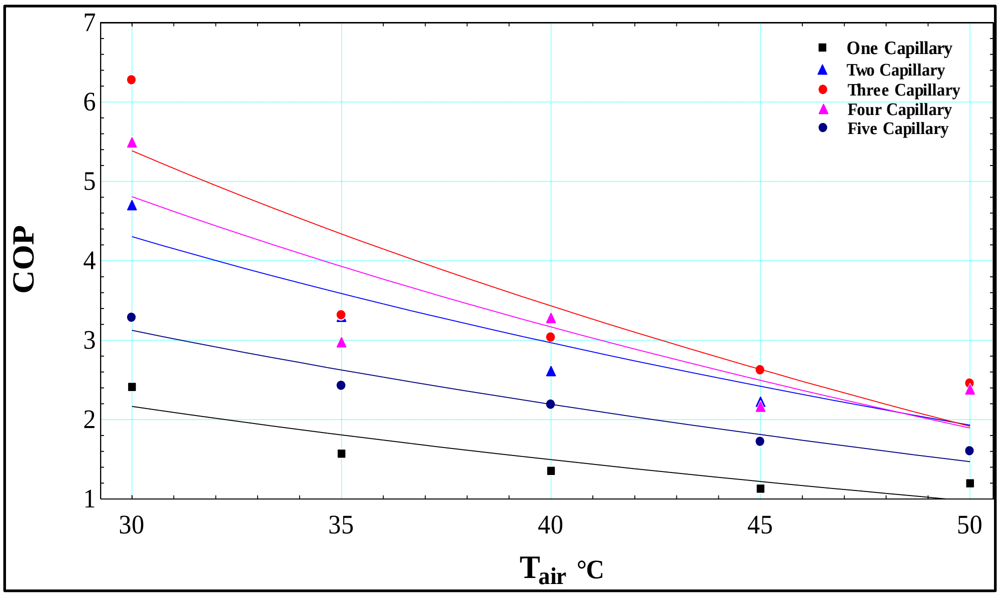

Figure (11) COP vs. ambient air temperature

5. Conclusions:

1. The compressor work of air conditioning system will increase as the number of capillary tube increased more than 2 due to the portion of refrigerant flash gas increasing which acts as additional obstruction to flow of refrigerant with copper tube inside wall .
2. As the ambient temperature increased the condenser heat rejection decreased for any number of tested capillary tubes. Also as the ambient air temperature increased the refrigerating effect with any tested capillary tube number will be decreased.
3. The air conditioning system with three capillary tubes has the highest refrigerant effect because of the highest heat rejection by condenser with more sub cooling "means less flashing gas.
4. The increasing in capillary tubes more than two will increases the refrigerant obstruction per number of capillary tube in addition the higher pressure ratio increase the amount of refrigerant flashing gas this will reduce the refrigerant mass flow rate through capillary tube.
5. The window type air conditioning system with three capillary tubes has the highest COP from all other tested capillary tubes number with 14% increasing from base case of two tubes.

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Symbols	Description	Unit
COP	Coefficient Of Performance	
q_c	Heat rejected by condenser	kJ/kg
w_{scom}	Compressor Specific work	kJ/kg
q_e	Refrigerating effect	kJ/kg
h	Enthalpy of refrigerant	kJ/kg
ACS	Air Conditioning System	

NOMENCLATURE