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# Experimental Study on the Performance of Twisted Capillary Tube

Amr O. Elsayed
*Zagazig University*

# EXPERIMENTAL STUDY ON THE PERFORMANCE OF TWISTED CAPILLARY TUBE

**Amr O. Elsayed**

Zagazig University, Faculty of Engineering, Mech. Power Dept
Zagazig, Egypt
+2-055-3204997, Fax: +2-055-3204987, amro9992000@yahoo.com

## ABSTRACT

A novel capillary tube has been tested and evaluated experimentally in the refrigeration cycle of window type air conditioner. Three twisted capillary tubes have been demonstrated and evaluated to show the performance of these tubes and its ability in the depressurization process seeking for short capillary tube. The effect of twist angle and the number of twisted points on the refrigeration cycle performance have been investigated and compared with the performance of original straight capillary tube. Two twist angles and two different numbers of twisting points have been considered in this study. The results showed that the twist angle has a remarkable influence on the depressurization process and condensation temperature.

## 1. INTRODUCTION

The performance of adiabatic capillary tube has been extensively investigated because it's widely used as a simple expansion device in small refrigeration systems. The capillary tube performance depends upon many geometrical parameters such as inner diameter, inner surface roughness, tube length, and the tube configurations. Therefore, many researchers have been concerned with the performance of capillary tube and its behavior in the refrigeration cycle (e.g. Kuehl and Goldschmidt, 1990, Kim et al., 2002). Since the flow inside the capillary tube is very complex, another several investigators have been concerned with the flow of refrigerant and azeotropic mixture inside the tube (e.g. Chen et al., 1990, Choi et al., 2004, Melo et al., 2004). Theoretical modeling of refrigerant flow through the capillary tubes also received the attention of researchers (e.g. Kuehl and Goldschmidt, 1991, Fiorelli and Silvares, 2004). Among these researches, several empirical correlations and rating charts have been presented to predict the refrigerant mass flow rate inside the capillary tube (e.g. Choi et al., 2003).

In a vapor compression cycle using a capillary tube, the liquid refrigerant with slight degree of subcooling enters the capillary tube since the pressure decreases linearly along the tube length due to the wall friction. At the flash point (the first vapor bubble is formed) the pressure starts to decrease rapidly. Three regions can be described inside the capillary tube. Upstream the flash point, subcooled liquid region and metastabe liquid region exist. While downstream the flash point a two phase flow is established. The pressure gradients through the subcooled and two phase regions are proportional to their respective contributions to the overall flow resistance within the capillary tube (Bittle et al, 2001). From this point of view, the capillary tube configuration has been studied for material saving (e.g. Gorasia et al, 1991).

The main objective of this study is to test and evaluate the performance of twisted capillary tube and its ability in depressurization process, also to show the effect of twist angle and the number of twisted point on the refrigeration cycle performance. The motivation of this object is to produce a short capillary tube which has the ability to do the same job as the long one. As a first step of research, the examined twisted tubes and the original capillary tube are identical in outer and inner diameters, length and tube material.

## 2. EXPERIMENTAL APPARATUS AND PROCEDURES

A window type, 7kW nominal capacity, air conditioner using R-22 was used for testing the performance of three twisted capillary tubes. The vapor compression cycle of the conditioner was provided with controlling and measuring devices at the key locations of the refrigeration cycle. A schematic diagram of the experimental apparatus is shown in Figure 1.

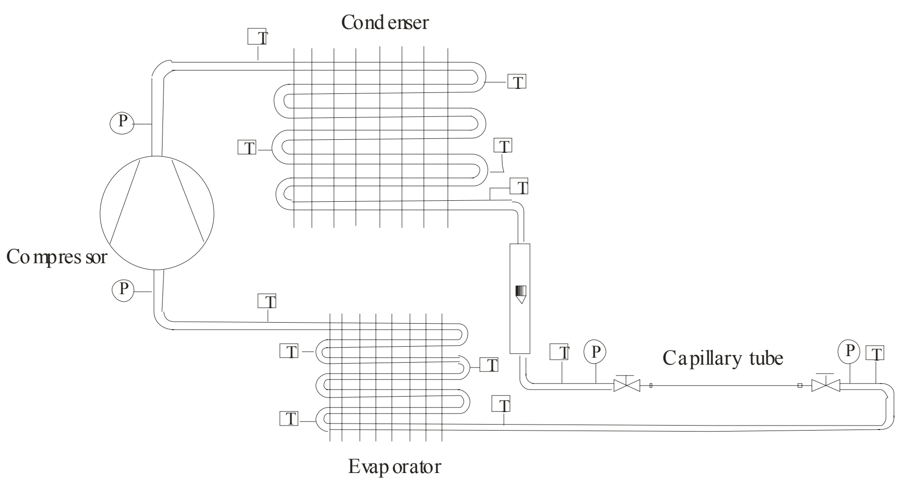


Figure 1: Schematic diagram of the experimental apparatus

The evaporator and condenser of the refrigeration unit were finned-plate air heat exchangers. The evaporator and condenser fans were employed to extract the room air and discharge it outside the room through foam ducts. An electric heater was installed in the path of entering air to the evaporator. The heater was connected with a variable capacity transformer to control the heater power. It is worth mentioning that the room temperature was maintained at 23- 24 ºC during the experiments.

The original capillary tube was placed in a horizontal and straight configuration between two shut-off valves and outside the conditioner cabin. An additional section of tubing was soldered at both ends of the capillary tube to facilitate the replacement of it. A service valve was installed at the compressor suction line for charging the refrigeration unit from a refrigerant accumulator. The original capillary tube was a standard drawn copper tube with 1.5 mm inner diameter and a length of 900 mm. All connections and additional tubes as well as the capillary tube were well insulated to guarantee that the steady state temperature along the wall is assumed equal to the refrigerant temperature.

The temperature was measured via a type-T thermocouple with a maximum uncertainty of ± 0.2 ºC. Thermocouples were placed at the inlet and outlet of the capillary tube, evaporator and condenser. Also, thermocouples were installed along the tube length of the evaporator and condenser to determine the condensation and evaporation temperatures. The thermocouple junctions were soldered at the outer surface of the tubes and the thermocouple wires were connected to a multi-channel temperature logging system.

The pressure at the capillary tube inlet and exit was measured by precision Bourdon type gages. Also, the compressor suction and discharge pressures were measured. The accuracy of the pressure gages was verified to be ±0.02 bar. The liquid refrigerant mass flow rate was measured by a calibrated flowmeter with a maximum uncertainty of ±0.5 kg/hr. A digital wattmeter with ±1% reading uncertainty was provided to measure the compressor power consumption.

All test runs for each of the four capillary tubes were performed in an identical manner and at the steady state condition. After installing the capillary tube, the refrigeration unit was evacuated and recharged again with the minimum refrigerant charge. Since the mass flow rate was increased by increasing the refrigerant charge. Ten percent of refrigerant under and overcharging can affect the cooling capacity of the refrigeration unit by 1- 9 % (Proctor, 1997 ). The minimum and maximum values of the refrigerant mass flow rate that were measure for the various capillary tubes are reported in the results.

## 3. TWISTED CAPILLARY TUBES

Three identical capillary tubes, similar to the original one, were modified to establish the twisting tubes. First, the entire length of the capillary tube was pressed to a required width to accommodate the oval configuration as shown in Figure 2. After that, the tube was fixed at one end to facilitate twisting. At the desired locations, the tube was twisted with the required angle. By this way, the number of twisted points and the twisting angle can be controlled and adjusted.

The twisted capillary tube #2 has a twist angle, θ = 90º and the number of twisted points (N) are 16 points with 50 mm apart. Second twisted capillary tube #3 has a twist angle, θ = 180º and the number of twisted points (N) are 8 with 100 mm apart. While the third twisted tube #4 has a twist angle of 180º and the number of twisted points (N) are 16 with 50 mm apart.

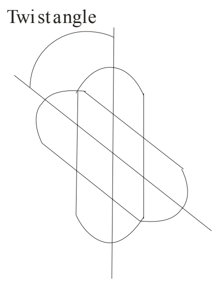


Figure 2: Capillary tube twisting

## 4. EXPERIMENTAL RESULTS AND DICUSSION

As well known, the capillary tube keeps the pressure difference between the condenser and evaporator during the cycle operation. Therefore to facilitate viewing of twisting effect and the influence of twisted point's number, the depressurization process in the various capillary tubes is presented in Figure 3. This figure shows the variation of measured pressure drop across the tubes as a function of refrigerant mass flow rate. It is seen from this figure that the capillary tube # 4 (θ = 180º & N = 16) has the greatest pressure drop, as expected, due to the restriction of flow. The pressure drop of the capillary tube #4 is higher by about 42 % than that for the original capillary tube #1. However, for capillary tubes #2 (θ = 90º & N = 16) and #3 (θ = 180º & N = 8) the increase of $\Delta P$ is about 8 % and 34 % respectively compared with the original tube #1.

The high pressure difference caused by the twisted capillary tubes, especially tubes #3 and #4, leads to increase in the condensation temperature. This is shown in Figure 4. From this figure, it can be observed that the condensation temperature increases by about 20 % for tube #4 and by about 16 % for tube #3 than that for the original tube #1 at the same refrigerant flow rate. This increase in condensation temperature reflects the influence of the twisting angle. For capillary tube #2 that θ = 90º and N = 16 nodes the increase of condensation temperature is about 4 % at $m_{ref}$ = 86 kg/hr, while at $m_{ref}$ = 107 kg/hr the condensation temperature reaches close to the condensation temperature of the original capillary tube.

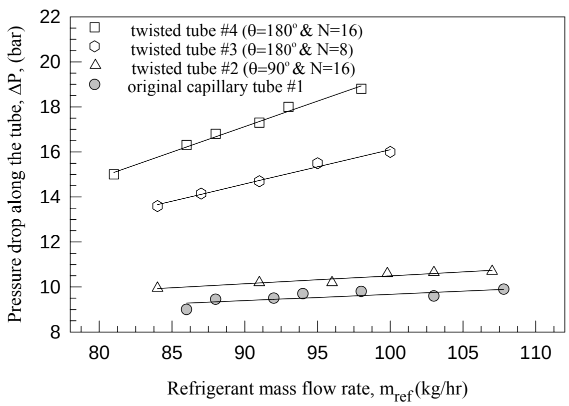


Figure 3: Variation of pressure drop as a function of refrigerant mass flow rate.

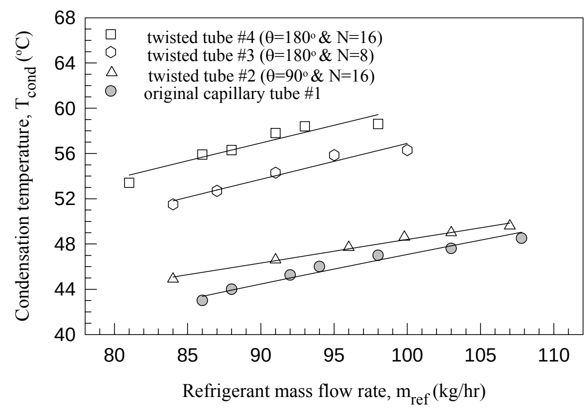


Figure 4: Measured condensation temperature for the various capillary tubes.

The inlet subcooling level of the refrigerant has an influence in the flash point location and there by the metastable liquid region length (Koizumi and Yokoyama 1980). Therefore, the measured subcool level versus condensation temperature is presented in Figure 5 for the different capillary tubes. It can be seen form this figure that the subcool level curve for the capillary tube #2 is similar in shape to the curve of the original capillary tube #1. The subcool level of tube #2 is higher by about 3 ºC. For capillary tubes #3 and #4 the trend of the curves are different, when compared with the other tubes. Also, high subcool level is achieved by these tubes as shown in Figure 5. This high level of subcooling occurs at high condensation temperatures, since the value of latent heat that is required to be rejected from the condenser decreases as the condensation temperature increases. At the same time, it should be mentioned that the entering air temperature to the condenser was approximately 24 ºC during the experiments.

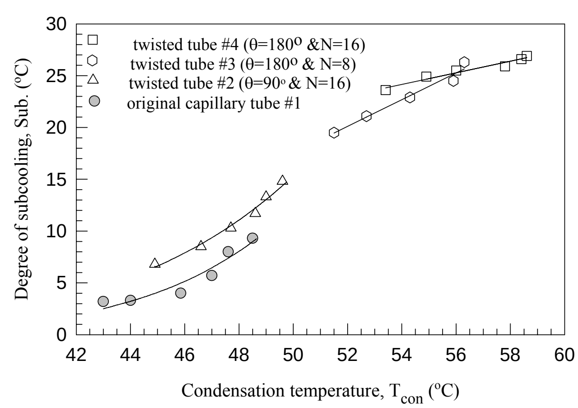


Figure 5: Measured subcooling level versus condensation temperature.

The high level of the subcooling leads to an increase in the metastable liquid region length and improves the quality of the outlet refrigerant from the capillary tube (Bittle et. al. 2001). This fact can be seen in Figure 6. This figure reveals that the beast refrigerant qualities are achieved by capillary tubes #3 and #4 which have 180 º twisting angle. So it can be said that more liquid refrigerant entering to the evaporator and more cooling duty can be done. This is shown in Figure 7, which presents the plot of cooling duty of the evaporator at the different values of mass flow rate

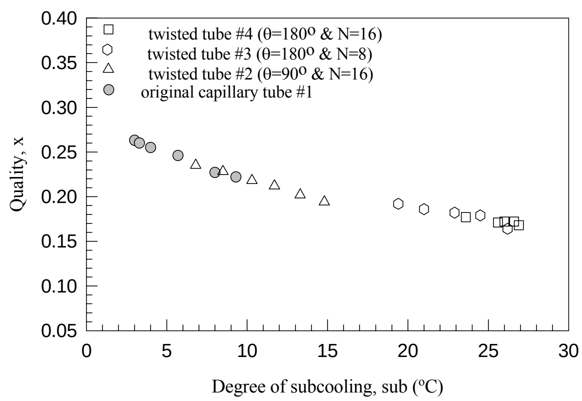


Figure 6: The quality of outlet refrigerant as a function of subcooling degree.

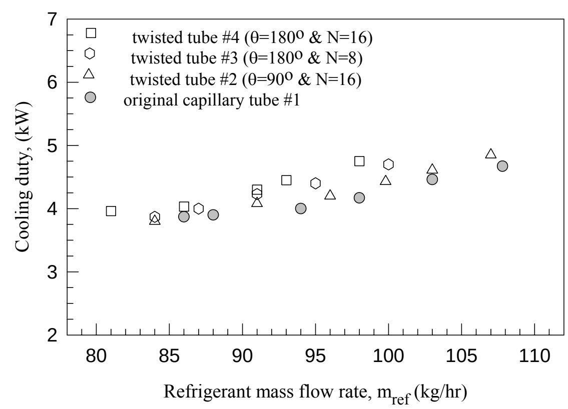


Figure 7: The evaporator cooling duty in the vicinity of the different capillary tubes.

On the other hand, high condensation temperature causes increasing in the compressor power consumption. This can be observed in Figure 8 which presents the measured power consumption as a function of the refrigerant mass flow rate for the different capillary tubes. In this figure the capillary tube #2 increases the compressor power consumption by about 2 % than the consumed power in the vicinity of the original tube #1. While at $m_{ref}$ = 95 kg/hr, capillary tubes #3 and #4 increase the power consumption by about 12 % and 18 % respectively compared with the power consumption in the vicinity of the original tube #1.

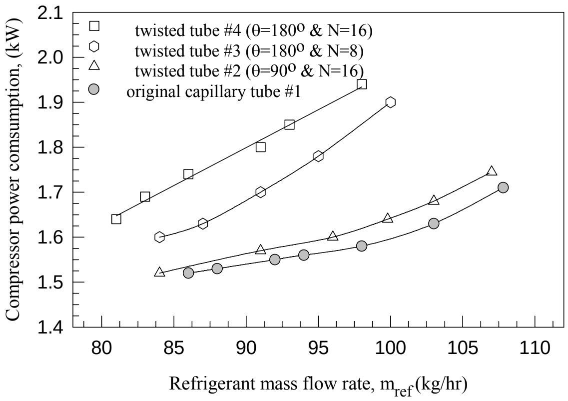


Figure 8: Measured power consumption at the various values of refrigerant flow rate.

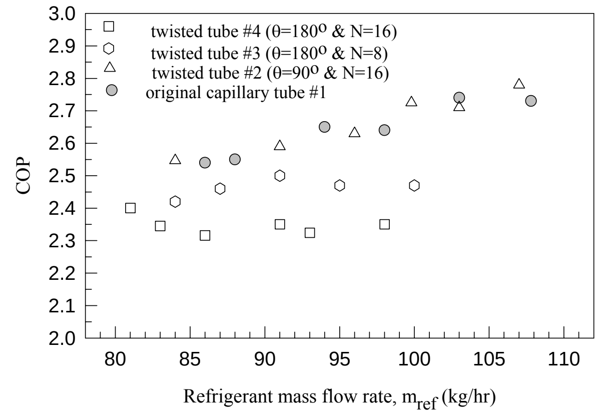


Figure 9: COP of the air conditioner in the vicinity of various capillary tubes.

The coefficient of performance, COP, of the refrigeration cycle is plotted in Figure 9 to evaluate the performance of various capillary tubes. It is seen from this figure that the COP of the refrigeration cycle decreases when using capillary tubes #3 and #4 that have 180º twisting angle in spit of the achievement of best quality values at the tube outlet. This means that the increase of evaporator cooling duty which occurred by these capillary tubes does not match the increase in power consumption. For capillary tube #2 ($\theta$ = 90º & N = 16 nodes), the COP of the cycle is approximately equal to that of the original capillary tube #1.

## 5. CONCLUSIONS

Performance characteristics of twisted capillary tube have been presented and compared with the original capillary tube of window type air conditioner using R-22 as a refrigerant. Three twisted capillary tubes with the same inner diameter and length, as the original capillary tube, have been tested experimentally. The effect of twist angle and the number of twisted points on the refrigeration cycle performance have been investigated and discussed.
From the experimental results in this article, it can be concluded that:

- The twist angle has a remarkable influence on the depressurization process and condensation temperature.
- The twisted capillary tube with 90º twisting angle and 16 twisted points shows a similar behavior as the original straight capillary tube; however, this twisted tube leads to more power consumption (by about 2%) and similar COP of the refrigeration cycle.
- High level of subcooling and best refrigerant qualities at the tube outlet are achieved by capillary tubes that have 180º twisting angle. While, on the other side, the compressor power consumption is higher and the COP of the refrigeration cycle is lower than those for the original capillary tube.

From the above conclusions it can be deduced that the control of the capillary tube length can be done by selecting the suitable number of twisted points with correct choice for the twist angle to obtain the required pressure drop across the capillary tube.

Future experimental investigations are needed to correlate the capillary tube length and diameter with different twist angles at various numbers of twisted points for alternative refrigerants in different refrigeration cycles.

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