Journal of Engineering and Development, Vol. 17, No.6, December 2013 , ISSN 1813- 7822

Numerical Analysis Of Refrigerant Flow In Different Types Of Capillary Tubes Used R1270

Asst. Lecturer. Haider ali hussen

Department of Mechanical Engineering,University of Al-Mustansiriyah

E-mail : (haidereng25@yahoo.com)

Abstract :

The capillary tube is a common expansion device used in small sized refrigeration and air-conditioning systems. The main focus lies on the analysis of the refrigerant flow behavior in the along the capillary tube with different shapes (straight-coiled-serpentine) as well as using alternative (R1270) with different geometrical parameters by using a commercial code FORTRAN power station for the simulation. Capillary geometrical parameters will include diameter, coiled diameter, and curve diameter. Results showed that when capillary tube internal diameter increase from 1.4 mm to 1.8 mm. Straight tube length increases from (1.2978m) to (4.8738m) with ratio (73.37%) , Coiled tube length increases from (0.589m) to (1.958m) with ratio (69.91%) at coiled diameter (dd=10mm) ,and The serpentine tube length increases from (0.859m) to (2.671m) with ratio (67.84%) at curve radius ($R_C = 5mm$)or curve diameter (dr=10mm).. The ideal capillary tube type is coiled. Because length decrease with comparison straight and serpentine.

Key Words: Coiled, Serpentine, Capillary tube, Adiabatic, Refrigerants, Flow

تحليل عددي لجريان المائع في انواع مختلفة من الانابيب الشعرية باستخدام غاز R1270

م.م . حيدر علي حسين

قسم الهندسة الميكانيكية، كلية الهندسة ، جامعة المستنصرية

الخلاصة :

إنّ الإنبوبَ الشعريَ هو أداة توسّع مشتركة إستعملتْ في التبريد بحجم الصغير وتكييف الأنظمة. يهدف البحث على تحليل سلوك تدفق المبرّد على طول الإنبوب الشعري بالأشكال المختلفة (أفعوانية مستقيمة ملفوفة) بالإضافة إلى إستعمال البديل (R1270) مع مختلف المتغيرات الهندسية بإستعمال لغة فورتران للمحاكاة.. المتغيرات الهندسية للانبوب الشعري ستتضمن قطر، قطر اللفة ،قطر التقوس. أظهرت النتائج بأنّ عندما يزيد القطر الداخلي للانبوب الشعري من (1.4 مليمتر -1.8 مليمتر) طولَ الإنبوب المستقيم يَزِيدُ مِنْ (1.2978 m) إلى (4.8738 m) بالنسبة (73.37 %) ويزيد طول الإنبوب الملفوف مِنْ (0.589 m) إلى (1.958 m) بالنسبة (69.91 %) عند القطر الملفوف (dd =10 مليمتر) ويَزِيدُ طولَ الإنبوب الأفعواني مِنْ (0.859 m) إلى (2.671 m) بالنسبة (67.84 %) عند نصف قطر التقوس ($R_C = 5mm$) أَو قطر التقوس (dr=10mm). إنّ نوعَ الإنبوب الشعري المثالي هو ملفوفُ. لان الطول اقل بالمقارنة مع الانبوب المستقيم والأفعواني.

Nomenclature

Symbol	Definition	Units
A	Area	**m^2**
d	Capillary tube inner diameter	**m**
f	Friction factor	____
G	Mass velocity	**kg/m^2.s**
h	Specific enthalpy	**kJ/kg**
L	Length capillary tube	**m**
$\dot{m}$	Mass flow rate	**kg/s**
P	Pressure	**N/m^2 (Pa)**
r	Density	**kg/m^3**
Rc	Curve radius	**mm**
Re	Reynolds number	____
V	Velocity	**m/s**
υ	**Specific volume**	**m^3/kg**

Subscripts

f	Liquid phase
g	Vapour phase

1. Introduction

The capillary tube is widely used as a throttling device in the small-scale vapor-compression refrigeration equipment such as room air conditioners, household refrigerators and freezers. It is simple, reliable and inexpensive. A number of research works have been carried out since 1940 (ASHRAE 1998) [1]. Especially in the past 15 years or so, the capillary characteristics have been widely studied with alternative refrigerants. The following section describes some of these researches which are concerned with the present study.

Wei et al, (2001)[2], Studies the performance of coiled capillary tube for R-407C and R-22 with two coiled diameter (52 mm and 130 mm), length 1000 mm and inner diameter (1.0 mm) and also studies straight capillary tube with R-407C and R-22 this study with same inlet and outlet pressures, inner diameter and length. Results showed that the mass flow rate of coiled capillary tube is less than that of straight and evaluated the decrease ratio m coil/m straight.

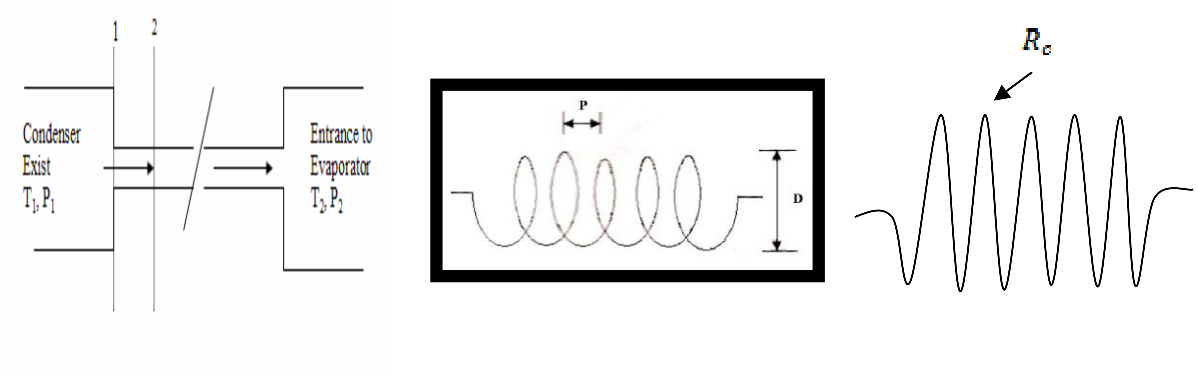
Kim S.G, S.T.Ro,M.S.Kim (2002)[3], compared experimentally the mass flow rates of coiled capillary tubes with different coiled diameters of 40, 120 and 200mm with those of straight tubes. They reported the mass flow rate of coiled capillary tube with coiled diameter of 40mm is approximately 9% less than that of straight tube.

Zhou and Zhang (2006)**[4]**, studied the performance of straight and coiled adiabatic capillary tubes with both numerically and experimentally. The test results show that mass flow rate increases with increase of coiled diameter. The mass flow rate of capillary tube with coiled diameter of 40 mm is approximately 10% less than that of the straight capillary tube. Therefore, with coiling effect considered, the tube length should be slightly shortened to match the required system mass flow rate.

Haider A. hussen (2011)**[5]**, Investigated theoretically and experimentally the evaluation the performance of adiabatic serpentine capillary tubes in different shapes with alternative refrigerant in a domestic refrigerator. The theoretical part has included a mathematical modeling and numerical solution for one dimensional steady flow, and in single phase or a homogenous mixture. The aim was to estimate the proper length of capillary tube, Reynolds number and friction factor. The governing equations (continuity, momentum and energy) were solved by using finite volume method .The work has covered different dimensions of tube length, tube curve radius (R_c), tube height (H) and internal tube diameter (d) for R-134a and R-600a. Theoretical results have showed an increase in capillary tube length when subcool degree of refrigerant or internal diameter of tube was increased. However, the length was decreased when mass flow rate of refrigerant was increased. Also as the height (H) or curve radius (R_c) of serpentine coil was increased, the tube length was also increased.

2. Capillary Tube Model

Figure (1) shows the representation of the capillary tube used for this modeling. For the analysis, the following assumptions were made: the mass flow rate ($\dot{m}$) is constant and adiabatic conditions prevailed in the capillary tube (ASHRAE handbook (2002), **[6]**).



a. Straight capillary tube **b. Coiled capillary tube** **c. Serpentine capillary tube**

Fig.(1) : Schematic Diagram of a Capillary Tube.

At steady state, since the mass flow rate ($\dot{m}$) was assumed to be constant therefore the mass flow equation can be written as , (the cross-sectional area was assumed to be constant).

$$\dot{m} = \frac{V_1 A}{\upsilon_1} = \frac{V_2 A}{\upsilon_2} \qquad (1)$$

$$or \qquad \frac{\dot{m}}{A} = G = \frac{V_1}{\upsilon_1} = \frac{V_2}{\upsilon_2} \qquad (1a)$$

Generally equation (1a) can be modified to give equation (2).

$$V = G\upsilon \qquad (2)$$

Where G= mass velocity

Since an adiabatic condition was assumed in the capillary tube, then an energy equation can be written as shown in equation (3), for a flow process, while the momentum equation is given by equation (4)(**Stoecker and Jones 1982** [7])

$$500\,h_1 + \frac{V_1{}^2}{4} = 500\,h_2 + \frac{V_2{}^2}{4} \qquad (3)$$

$$G(V_2 - V_1) = \left\{(P_1 - P_2) - f\frac{\Delta L\,G^2}{2\,d}\upsilon_m\right\} \qquad (4)$$

The required length L can be calculated from equation (4) in steps as given in equation (5) and **Figure 1**.

$$L = \sum_{i}^{n} \Delta L \qquad (5)$$

As could be seen in equation (4), the length (L) depends on pressure variation P, friction factor (*f*), flow velocity (V), and humid volume (*v*). Though, the enthalpy remains constant as a result of continuous flow of refrigerant (adiabatic situation) but there will be a progressive decrease in pressure. The humid volume of mixture can be calculated from the following equation (6).

$$\upsilon = \upsilon_f(1 - x) + \upsilon_g x \qquad (6)$$

The viscosity of mixture can be calculated from the following equation **[Stoecker and Jones 1982[7]]**.

$$\mu = \mu_f(1-x) + \mu_g x \qquad (7)$$

The Reynolds number is defined by:

$$Re = Vd/(\mu\, \upsilon) \qquad (8)$$

The friction factor equations developed by various researchers are given in **Table 1**

Table 1: Friction Factor Equations

Shapes	Friction Factor	References
straight	$f = \frac{0.33}{Re^{0.25}}$	**Stoecker and Jones 1982[7]**
coiled	$f = \frac{0.192\,(d/D)^{0.5}}{[Re\,(d/D)^{2.5}]^{1/6}} \times \left\{1 + \frac{0.068}{[Re\,(d/D)^{2.5}]^{1/6}}\right\}$ Where D=coiled diameter	**Guobing and Yufeng, 2005[8]**
serpentine	$\ln\,(f * Re/64) = a + b(\ln\,(Re(d/2R_c))^2$ Where $R_c = curve\ radius$	**Popiel ,c.o. 2000[9]**

3. Properties of R1270 Calculation

The computation equations for properties of saturated refrigerant R-1270 applicable to a temperature range of $0\ C^o$ to 90 C^o will be used:**[present work]**

$$P = (\ 0.61909816 + 0.012654374 * t + \ 0.0003279709 * t^2) * 1000000 \qquad (9)$$

$$p_f = \ 538.65533 - \ 0.77906484 * t - \ 0.018163058 * t^2 \qquad (10)$$

$$v_g = \ 0.076915934 - 0.0016157397 * t + (\ 9.682025e - 06) * t^2 \qquad (11)$$

$$h_f = \ 203.17243 + 2.0662491 * t + \ 0.011415047 * t^2 \qquad (12)$$

$$h_g = \ 576.81924 + 1.2689988 * t - \ 0.027170885 * t^2$$

(13)

$$u_f = (\ 118.43379 - 0.94980785 * t + \ 0.00088059353 * t^2)/1000000.0 \qquad (14)$$

$$u_g = (\ 8.3643465 - 0.026178169 * t + 0.001442659 * t^2)/1000000.0 \qquad (15)$$

4. The main program

4.1 Computer Program

The modeling program was formulated in FORTRAN POWER STATION (4.0) language, which was written under Windows 7 environment on Pentium i5, 3.4 GHz of 8 GB ram. The execution time of each run is (1-2) minutes. The cycle modeling computer program consists of one main part that simulate the capillary tube length and pressure drop. Subroutines were built to serve the main program by calculating the necessary factors, represented in this study by refrigerant thermodynamic and thermo physical properties.

4.2 Description of The Program

The main goal of this program is to simulate the length of capillary tube in adiabatic flow case with the use of R1270 as refrigerant. The simulation procedure of the capillary tube consist of the following steps :

I. The program begin with known system information, which is represented by refrigerant mass flow rate, capillary tube inlet conditions (such as pressure and inside diameter), evaporator pressure and degree of sub cooling.

II. After that, the program starts to evaluate the length of single-phase flow region, which is considered to be the summation of the single-phase sub-cooled liquid flow region length.

III. After calculating the single-phase flow region length, a homogeneous flow model has been proposed in the two-phase flow region. An element approach is adopted here to model the refrigerant flow in a capillary tube, where the total temperature drops across the two-phase region is equally divided among a number of small temperature elements. The properties of the entrance at first element are known for its known saturation temperature and quality, which are the outlet refrigerant properties of the single-phase flow region. The assumed temperature drop across the element determines and evaluates the thermodynamic and thermophysical properties at element outlet depending on the assumed value of exit temperature.

IV. Continue to the next element, where the outlet condition of element (i) is the inlet condition of element (i+1).

V. Add up all the lengths of the units so as to get the whole length of the capillary tube.

The program flowchart is shown in **Figure (2)**

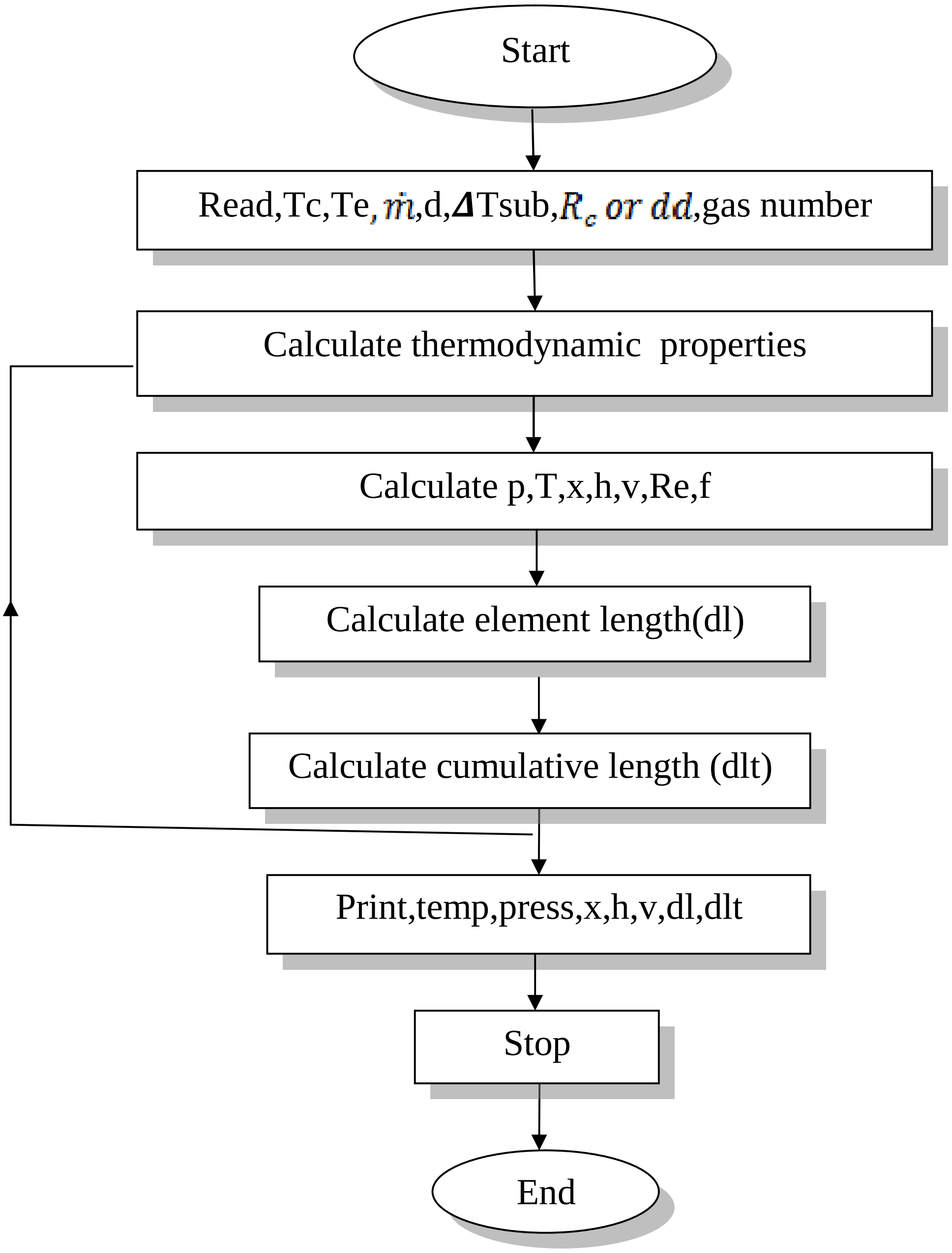


Fig.(2):Flow chart to design (straight-coiled-serpentine) capillary tube

5. Results and Discussions

The results of comparison of the investigated adiabatic capillary tube with different shapes (straight-coiled-serpentine) used refrigerant R1270 in the residential air-conditioning system are shown in **Figures. (3) to (8)**. **Figures (3) to (5)** show the change of velocity versus adiabatic capillary tube length with different shapes (straight-coiled-serpentine) used refrigerant R1270.**Figure(3)** shows the effect of internal diameter of straight capillary tube .When the internal diameter increases at constant temperature of condenser, the length of tube is also increases. Because the decrease in both friction factor and velocity, longer tube will be needed. The straight tube length increases from (1.2978m) to (4.8738m) with ratio (73.37%) between (1.4mm-1.8mm) for internal diameter .

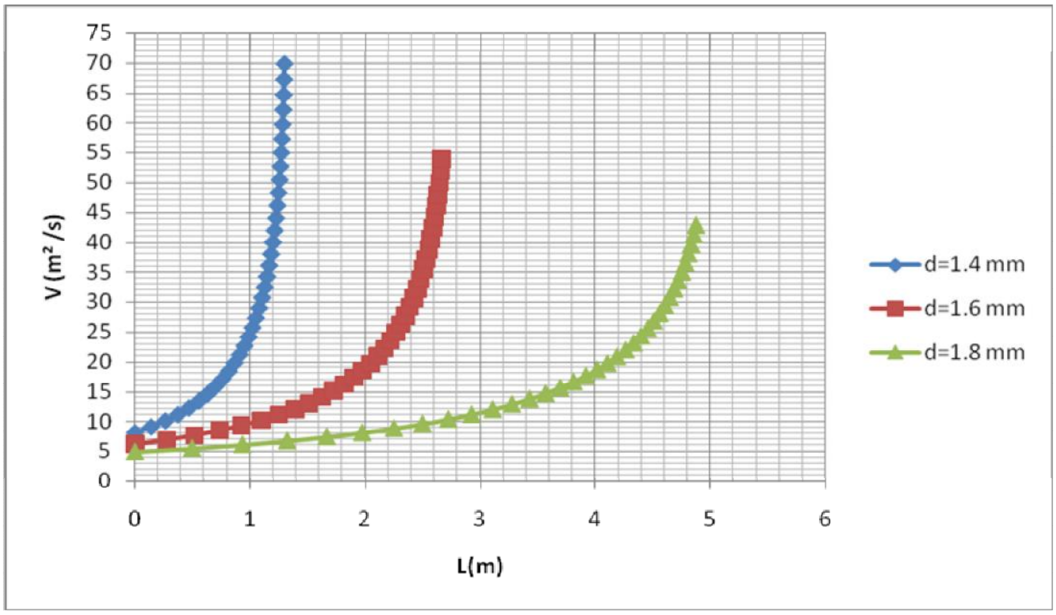


Fig.(3): Variation of velocity versus straight adiabatic capillary tube length with different diameter..(Tc=40,Te=5, ∆t sub=0, $\dot{m} = 6\ g/s$) for R1270

Figure (4) and (5) shows the same trend as illustrated above. **Figure (4)** shows the effect of internal diameter of coiled capillary tube. The coiled tube length increases from (0.589m) to (1.958m) with ratio (69.91%) between (1.4mm-1.8mm) for internal diameter at coiled diameter (dd=10mm). Figure (5) shows the effect of internal diameter of serpentine capillary tube. The serpentine tube length increases from (0.859m) to (2.671m) with ratio (67.84%) between (1.4mm-1.8mm) for internal diameter at curve radius ($R_c = 5mm$)or curve diameter (dr=10mm).

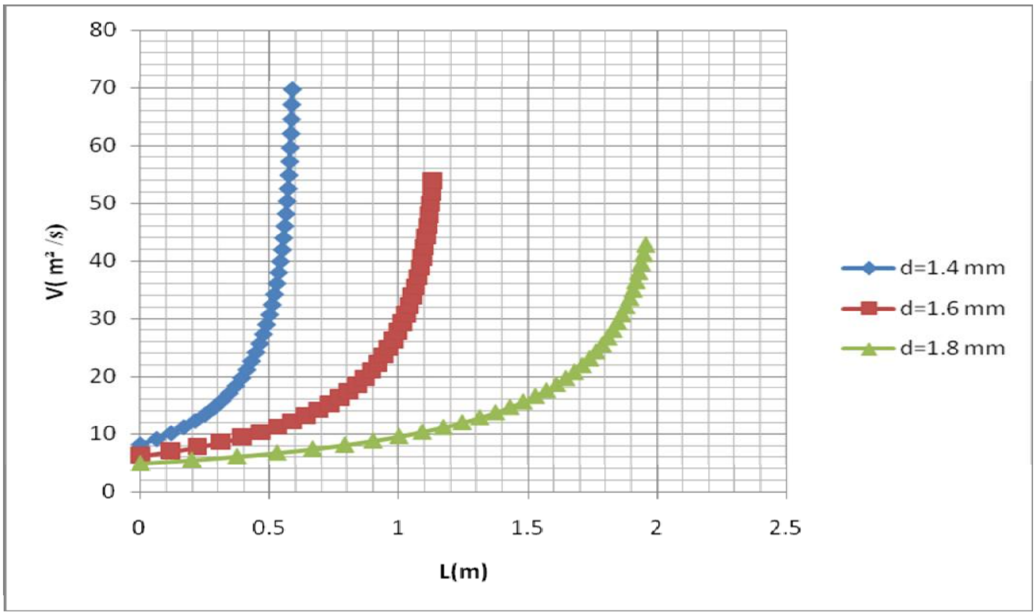


Fig.(4): Variation of velocity versus coiled adiabatic capillary tube length with different diameter..(Tc=40,Te=5,dd=10 mm, ∆t sub=0, $\dot{m} = 6\ g/s$) for R1270

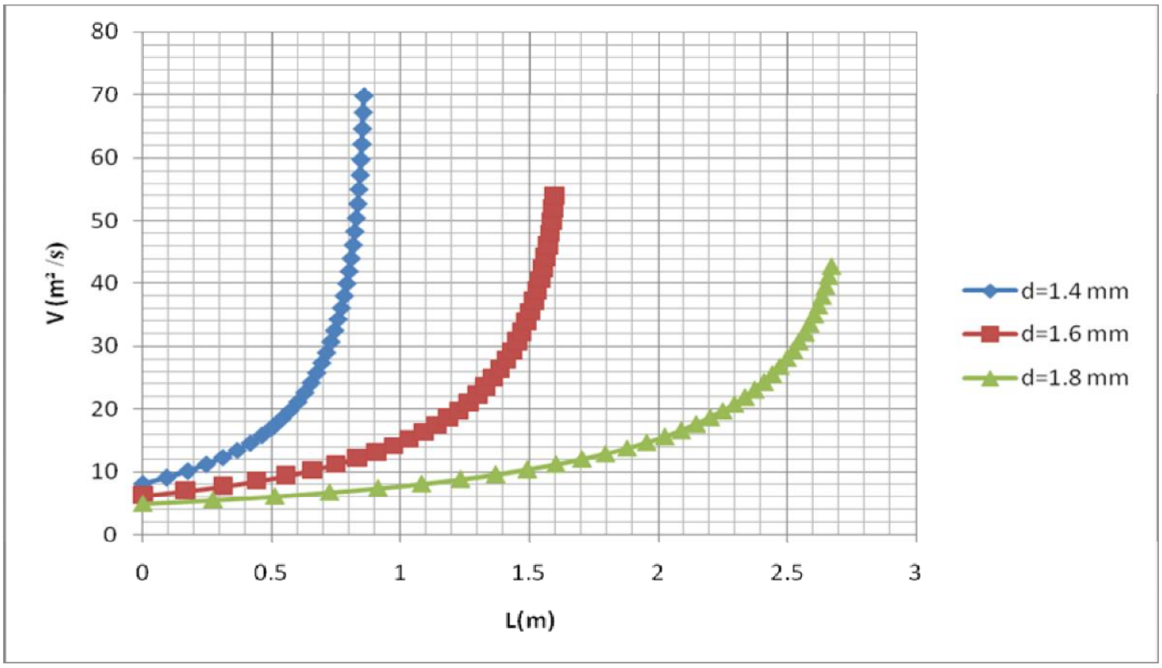


Fig.(5): Variation of velocity versus serpentine adiabatic capillary tube length with different diameter..(Tc=40,Te=5,dr=10mm, ∆t sub=0,$\dot{m} = 6\ g/s$) for R1270.

Figure (6) show the change of velocity versus adiabatic capillary tube length with different shapes (straight-coiled-serpentine) used refrigerant R1270. The ideal capillary tube type is coiled. Because friction factor increases and this will lead to length decrease comparison with straight and serpentine. Table (2) presents a summary of the calculations near the entrance to the tube and as the temperature approaches the evaporating temperature of 5 C° .The cumulative length of the capillary tube required for the specified reduction in pressure is 1.134 m. Table show the change of in pressure ,velocity and friction factor .Friction factor increases because of the increase in velocity along capillary tube.

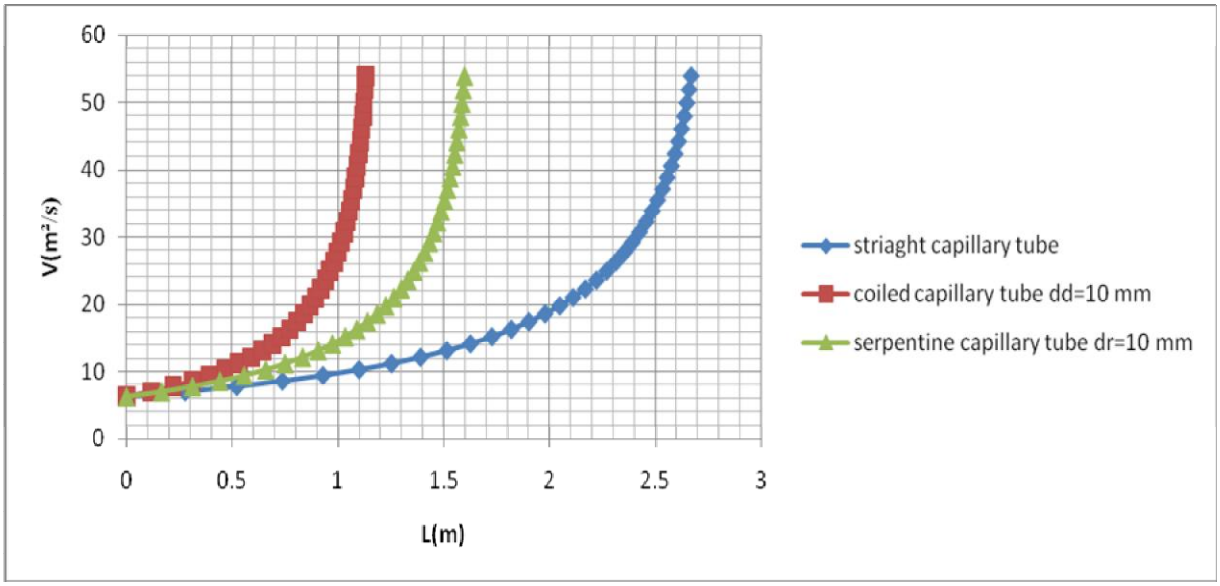


Fig. (6): Variation of velocity versus adiabatic capillary tube length with different shapes..(Tc=40,Te=5,d=1.6 mm ∆t sub=0,$\dot{m} = 6\ g/s$) for R1270

Figures (7) and **(8)** show the change of velocity versus adiabatic coiled capillary tube length with different coiled diameter used refrigerant R1270. Figure (7) shows the effect of coiled diameter of coiled capillary tube. The coiled tube length increases from (1.134m) to (2.051m) with ratio (44.7%) between (10 mm-30mm) for coiled diameter at internal diameter (d=1.6mm). **Figure.(8)** shows the effect of curve radius of serpentine capillary tube. The serpentine tube length increases from (1.597m) to (3.479m) with ratio (54.09%) between (dr=10mm-30mm) for curve diameter at internal diameter (d=1.6).

Table (2): Capillary Tube Calculation

(Tc=40,Te=5,d=1.6mm,dd=10 mm, Δt sub=0,$\dot{m} = 6\ g/s$) for R1270

n	temp	pressure	x	h	velocity	dl	dlt	Re	*f*
0	40	1650027	0	304.086	6.2405	0	0	58363.41	0.04997
1	39	1611463	0.0097	304.082	6.9793	0.118	0.118	58241.35	0.04999
2	38	1573554	0.0191	304.076	7.7513	0.104	0.222	58120.06	0.05001
3	37	1536302	0.0284	304.069	8.557	0.092	0.313	57999.43	0.05003
4	36	1499706	0.0374	304.062	9.3968	0.081	0.394	57879.39	0.05005
5	35	1463766	0.0462	304.053	10.2713	0.073	0.467	57759.82	0.05007
6	34	1428481	0.0549	304.043	11.1806	0.065	0.532	57640.65	0.05009
7	33	1393853	0.0633	304.032	12.1253	0.058	0.59	57521.77	0.05011
8	32	1359880	0.0716	304.02	13.1055	0.053	0.643	57403.09	0.05013
9	31	1326564	0.0797	304.006	14.1217	0.048	0.691	57284.55	0.05015
10	30	1293903	0.0876	303.991	15.1741	0.043	0.734	57166.05	0.05017
11	29	1261899	0.0953	303.974	16.263	0.039	0.773	57047.52	0.05019
12	28	1230550	0.1029	303.955	17.3886	0.036	0.808	56928.88	0.05021
13	27	1199857	0.1103	303.934	18.5512	0.032	0.841	56810.05	0.05023
14	26	1169820	0.1175	303.911	19.7509	0.029	0.87	56690.99	0.05025
15	25	1140439	0.1246	303.886	20.988	0.027	0.897	56571.63	0.05027
16	24	1111714	0.1316	303.858	22.2628	0.025	0.921	56451.93	0.0503
17	23	1083645	0.1384	303.828	23.5753	0.022	0.944	56331.83	0.05032
18	22	1056232	0.1451	303.795	24.9259	0.021	0.964	56211.3	0.05034
19	21	1029475	0.1516	303.76	26.3147	0.019	0.983	56090.33	0.05036
20	20	1003374	0.158	303.721	27.7419	0.017	1	55968.87	0.05038
21	19	977928.8	0.1643	303.679	29.2078	0.016	1.016	55846.92	0.0504
22	18	953139.5	0.1704	303.634	30.7124	0.014	1.031	55724.47	0.05042
23	17	929006.1	0.1765	303.586	32.2562	0.013	1.044	55601.53	0.05044
24	16	905528.8	0.1824	303.533	33.8393	0.012	1.056	55478.11	0.05047
25	15	882707.3	0.1882	303.477	35.462	0.011	1.067	55354.23	0.05049
26	14	860541.8	0.1939	303.417	37.1245	0.01	1.077	55229.91	0.05051
27	13	839032.1	0.1995	303.352	38.8272	0.009	1.086	55105.2	0.05053
28	12	818178.5	0.205	303.283	40.5704	0.008	1.094	54980.14	0.05055
29	11	797980.8	0.2104	303.209	42.3545	0.008	1.102	54854.78	0.05058
30	10	778439	0.2157	303.13	44.1798	0.007	1.109	54729.21	0.0506
31	9	759553.2	0.2209	303.046	46.0468	0.006	1.115	54603.49	0.05062
32	8	741323.3	0.2261	302.956	47.956	0.006	1.121	54477.71	0.05064
33	7	723749.4	0.2311	302.861	49.9079	0.005	1.126	54351.96	0.05067
34	6	706831.4	0.2361	302.759	51.9029	0.005	1.13	54226.36	0.05069
35	5	690569.3	0.241	302.651	53.9419	0.004	1.134	54101.02	0.05071

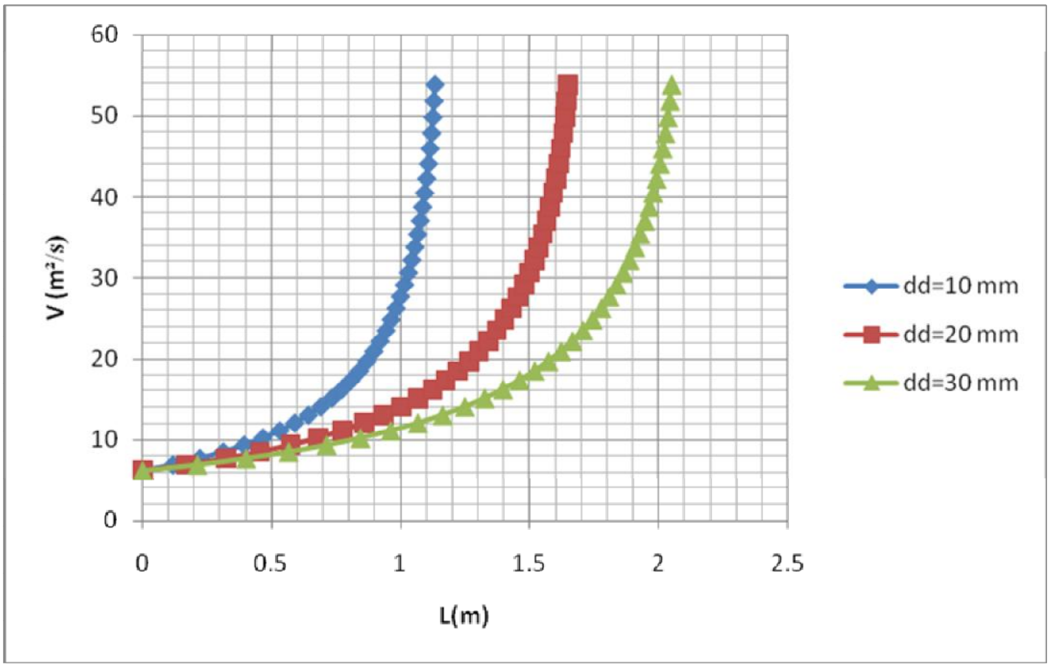


Fig.(7): Variation of velocity versus coiled adiabatic capillary tube length with different coiled diameter..(Tc=40,Te=5,d=1.6 mm, ∆t sub=0, $\dot{m} = 6\ g/s$) for R1270

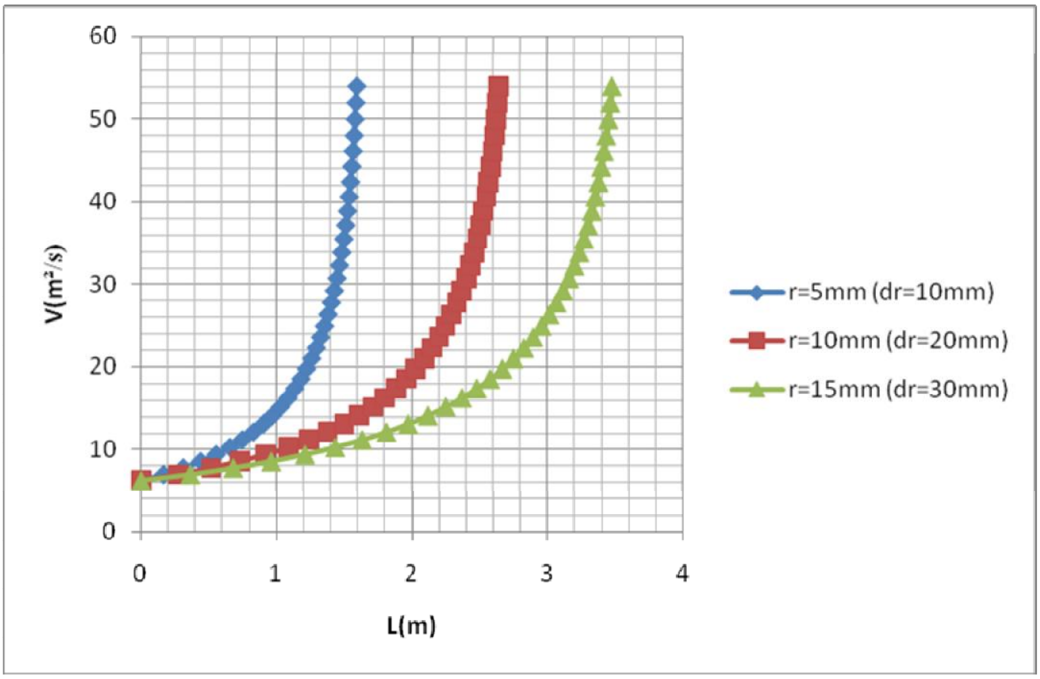


Fig.(8): Variation of velocity versus serpentine adiabatic capillary tube length with different curve diameter..(Tc=40,Te=5,d=1.6mm, ∆t sub=0, $\dot{m} = 6\ g/s$) for R1270

6. Conclusion

The present study examined the generated capillary tube lengths based on friction factors and viscosity equations for two-phase flow, which is prevalent in the capillary tube. The lengths generated by various friction factors under stated conditions and compared with (straight-coiled-serpentine) capillary tube. It was clearly shown that the required capillary tube length for a specified condenser condition depends on both velocity and friction factor and not on either alone.When capillary tube internal diameter increase from 1.4 mm to 1.8 mm. Straight tube length increases from (1.2978m) to (4.8738m) with ratio (73.37%) , Coiled tube length increases from (0.589m) to (1.958m) with ratio (69.91%) at coiled diameter (dd=10mm) ,and The serpentine tube length increases from (0.859m) to (2.671m) with ratio (67.84%) at curve radius ($R_C = 5mm$)or curve diameter (dr=10mm). The ideal capillary tube type is coiled. Because friction factor increases and this will lead to length decrease compare with straight and serpentine.

References

1. **ASHRAE. ASHRAE handbook— refrigeration. Atlanta, CA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1998; chapter 45**
2. **Wei, C. Z.; Lin, Y. T.; Wang, C. C.; and Lev, J. S., 2001, "An Experimental Study of The Performance of Capillary Tubes for R – 407C Refrigerant", ASHRAE, Transaction ,pp.(634 – 638).**
3. **Kim S.G, S.T.Ro,M.S.Kim,2002" Experimental Investigation of The Performance of R-22,R-407C and R-410a in Several Capillary Tube for Air Conditioner ",International Journal of Refrigeration , pp.(521-531).**
4. **Zhou Guobing and Zhang Yufeng, 2006, "Numerical and experimental investigations on the performance of coiled adiabatic capillary tubes". Applied Thermal Engineering, Vol. 26, pp. (1106-1114).**
5. **Haider A. hussen (2011),'' Evaluation of the Performance of Adiabatic Serpentine Capillary Tubes With Alternative Refrigerant in a Domestic Refrigerator''. ". M.Sc. Thesis, University of Mustansiriyah.**
6. **ASHRAE 2002. *ASHRAE Handbook: Refrigeration*. Chapters 49.7 and 45.26. “Adiabatic Capillary Tube Selection Procedure”.**
7. **Stoecker, W.F., and Jones, J.W., 1982, "Refrigeration and Air Conditioning". Mc Graw Hill, New York.**
8. **Guobing Z and Zhang Yufeng,2005, "Numerical and Experimental Investigation on The Performance Coiled Adiabatic Capillary Tubes". Applied Thermal Engineering, vol. 26, pp, (1106-1114).**
9. **Popiel, c.o. (2000),"friction factor in u-type undulated pipe flow",trans of the asme ,vol 122,pp(262).**