Performance and Optimization of Capillary Tube Length In a Split Type Air Conditioning System

D.V.Raghunatha Reddy[1] Dr P.Bhramara[2] Dr K.Govindarajulu[3]

[1] Assit.Prof, Dept of ME, A.T.R.I.Uppal, Hyderabad-500039, A.P, India.

[1] Research Scholar, Dept of ME Dept., J N T U.A, Anantapur, A. P., India

[2]Assoc. Prof, Dept. Of ME, JNTUH College of Engineering Hyderabad A.P India

Professors, Dept of ME, JNTUA College of Engineering Ananthapur A.P, India

3

ABSTRACT

The objectives of this research were to evaluate the optimization of a capillary tube in a split- type air conditioning system and to determine the coefficient of performance (COP) of the system. The optimization was determined by mathematical calculation to evaluate COP of a split-type air conditioning system within 5 different sizes of capillary tube. Following this, the experimental equipment was designed and constructed to verify the COP data obtained from the calculation. The results found that from the theoretical analysis and experiment, the COP was changing in a direction contrary to the diameter of the capillary tube. When the capillary tube diameter is smaller, COP values tend to be higher.

KEYWORDS: Air-conditioning system, Optimization of Capillary tube, BAC Lab, Mathematical and Experimental Calculations, COP

I INTRODUCTION

Air conditioning and refrigeration systems play an important role in industry, infrastructure and households. The industrial sector includes the food industry, textiles, chemicals, printing, transport and others. Infrastructure includes banks, restaurants, schools, hotels and recreational facilities. Therefore, installation, repair and maintenance of equipment to function properly are important for the operations associated with those activities. At present reducing pressure valves used in air conditioning and refrigeration systems can be classified into two types: expansion valves and capillary tubes. The capillary tube is made from copper pipe, with a diameter around 0.5 mm to 5 mm and length around 0.5 m to 5 m. Its use depends on power and load capacity of the system. The capillary tube is often used with small cooling load or small changing load systems, such as refrigerators, water coolers and small air conditioners.

Problems from the blockage in the capillary tube results in lower injection of refrigerant into the evaporator, so there will be less cooling. Typically this problem can be solved by changing a new capillary tube. However, this also results in refrigerant being released from the system, which makes for higher cost and time wastage. Furthermore, the size of the replacement capillary tube must be the same and some sizes are difficult to source, which makes the maintenance cost even higher.

Taking into consideration these problems, the objective of this research is to determine the appropriate size of a new capillary tube that can replace the old blocked one and to construct an experimental equipment system with different capillary tubes to measure the real values. The resulting values will show which size of capillary tube can be used instead of the old one. This will be more convenient for maintenance and will save costs when fixing air conditioning and refrigeration systems.

1.1Objective:

1. To evaluate the performance of an air conditioner system for different capillary lengths, mathematically and experimentally.
2. To compare experimental and mathematical model and select best capillary length for the system

II Mathematical Solution for Capillary Tube:

Theoretically, the appropriate size of capillary tube can be calculated from the refrigerant effect, Coefficient of performance (COP) and others. The system is assumed to work as an isentropic process and there are five different sizes of capillary tubes in this calculation.
To undertake simulation with any value it is necessary to use the results from the previous test in the real work environment. The compressor information, RNB5522EXC, is from the compressor manufacturer and has been adjusted into the theoretical calculation to determine the value of the variables depending on the different size of capillary tubes by evaluating COP at the various states of capillary tubes in the isentropic process.
Theoretically, the appropriate size of capillary tube can be decided by evaluating coefficient of performance (COP) of the system for the different capillary lengths. Five different sizes of capillary tubes are considered for analysis.
To undertake simulation with any value it is necessary to use the results from the previous test in the real work environment. The compressor information, RNB5522exc, is from the compressor manufacturer and has been adjusted into the theoretical calculation to determine the value of the variables depending on the different size of capillary tubes by evaluating COP at the various states of capillary tubes in the isentropic process.

2.1MATHEMATICAL CALCULATIONS:

Mass Flow Rate Equation:

$$m = C_1 + C_2 \times T_{evap} + C_3 \times T_{evap}{}^2 + C_4 \times T_{cond} + C_5 \times T_{cond}{}^2 + C_6 \times T_{evap} \times T_{cond} + C_7 \times T_{evap}{}^2 \times T_{cond} + C_8 \times T_{evap} \times T_{cond}{}^2 + C_9 \times T_{evap}{}^2 \times T_{cond}{}^2$$

Substituting the mass flow rate data in the above equation we have:
From above equation the constants we will get as:

C_{1}= 117.7158,
C_{2}= 2.7149,
C_{3}= -0.2007,
C_{4}= -0.8751,
C_{5}= 8.5×10^{-3},
C_{6}= 0,
C_{7}= 0.0197,
C_{8}= 3.3866×10^{-4},
C_{9}= 3.1417×10^{-4}
Substituting the constants in the equation (A) the mass flow rate equation can be written as follows:

$$m = 117.7158 + 2.714966\, T_{evap} - 0.20077\, T_{evap}{}^2 - 0.875139\, T_{cond} + 8.5913\times10^{-3}\, T_{cond}{}^2 + 0.019749\, T_{evap}{}^2\, T_{cond} + 3.38664\times10^{-4}\, T_{evap}\, T_{cond}{}^2 - 3.14175\times10^{-4}\, T_{evap}{}^2\, T_{cond}{}^2$$

substituting the various condenser and evaporator temperatures in the above equation we'll get the mass flow rate (kg/h) as below

Mass flow rate data of compressor RNB5522EXC

2.2 Mass Flow Rate (g/s)At Various Condenser And Evaporatortemperature:

Condenser Temperature(°C)	Mass flow rate(g/s)		
	Evaporator Temperature (°C)		
	0	5	10
40	26.793	31.917	38.243
45	26.542	31.286	37.475
50	26.510	31.455	36.438
55	26.547	31.278	34.735
60	26.704	31.148	33.553

Dimensions of five different capillary tubes used for calulations and experiment are
D = 1.524mm (0.06”). diameter is constant for all the lengths of the tube.
L_1 = 0.889m (35”)
L_2 = 0.8382m (33”)
L_3 = 0.762m (30”)
L_4 = 0.635m (25”), L_5 = 0.508m (20”).

2.3 Mass flow rate through the capillary tube can be evaluated from the equation below:

$$m = C_1 \times D^{C_2} \times L^{C_3} \times \mathrm{T}^{C_4} \times 10^{C_5 \times \mathrm{DSC}}$$

Where
m = Flow rate R-22 (g/s).
D= Diameter (mm)
L= *Length* (m)
T=Condenser Temperature.(^{O}C)

DSC=Degree of Sub cooling (^{O}C)
C_1= constant = 0.249029
C_2= constant = 2.543633
C_3= constant = -0.42753
C_4= constant = 0.746108
C_5= constant = 0.013922

Mass flow rate equation can be rearranged to get sub-cooled temperature:

$$DSC = \frac{1}{C_5} \log \frac{\mathrm{m}}{C_1 \times D^{C_2} \times L^{C_3} \times \mathrm{T}^{C_4}}$$

The above equation is valid for the single capillary system but the equation is modified for twin capillary system as follows:

$$DSC = \frac{1}{C_5} \log \frac{\mathrm{m}/2}{C_1 \times D^{C_2} \times (2 \times L)^{C_3} \times \mathrm{T}^{C_4}}$$

Substituting the values of mass flow rate and dimensions of the tube in the above equation sub-cooled temperatures can be shown follows

2.4 Model calculation for degree of sub-cooling(DSC) :

$$DSC = \frac{1}{0.013922} \log \frac{\frac{26.793}{2}}{0.249029 \times 1.524^{2.543633} \times (2 \times 0.889)^{-0.42753} \times 40^{0.746108}}$$

$$= 18.16$$

2.5 Degree of Sub-Cooling (°C) At Various Condenser And Evaporator Temperatures

Condensor Temperature (°C)	Evaporator Temperature (°C)	Degree of sub-cooling (°C)				
		Tube 1 (L_1=35”)	Tube 2 (L_2=33”)	Tube 3 (L_3=30”)	Tube 4 (L_4=25”)	Tube 5 (L_5=20”)
40	5	18.16	17.376	16.105	13.674	10.698
	10	23.801	23.016	21.745	19.314	16.338
45	5	14.797	14.012	12.741	10.310	7.334
	10	20.427	19.643	18.372	15.940	19.964
50	5	12.513	11.728	10.457	8.025	5.049
	10	17.099	16.315	15.044	12.612	9.636
55	5	10.118	9.333	8.062	5.631	2.655
	10	13.388	12.603	11.332	8.901	5.925
60	5	7.963	7.179	5.908	3.976	0.5005
	10	10.283	9.498	8.227	5.796	2.820

The values of degree of sub-cooling from the above table is used to calculate C.O.P’s by assuming 10°C of superheat at the inlet of the compressor

The C.O.P’s found out through the above mentioned procedure are tabulated as follows

C.O.P’S at various condenser and evaporator temperatures

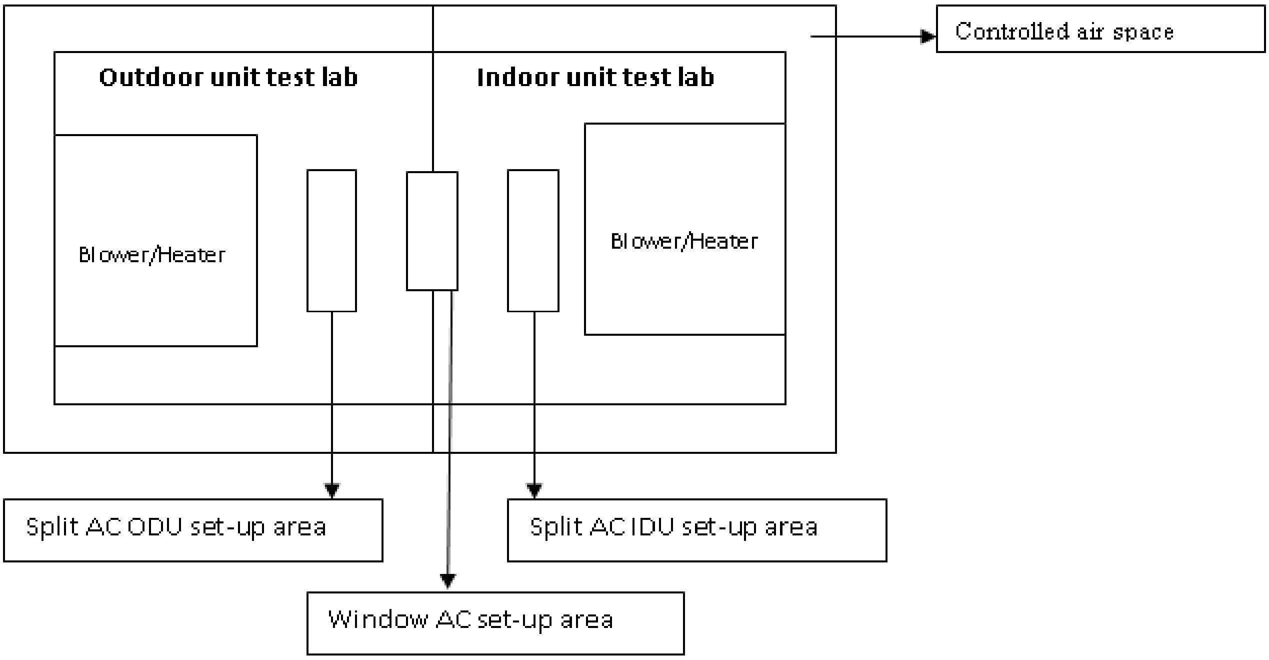
Condensor Temperature (°C)	Evaporator Temperature (°C)	C.O.P				
		Tube1 (L_1=35”)	Tube2 (L_2=33”)	Tube3 (L_3=30”)	Tube4 (L_4=25”)	Tube5 (L_5=20”)
40	5	7.326	7.286	7.220	7.095	6.780
	10	9.095	9.047	8.970	8.821	8.639
45	5	6.099	6.063	6.005	5.894	5.758
	10	6.633	6.596	6.536	6.421	6.28
50	5	5.164	5.132	5.080	4.980	4.858
	10	6.231	6.194	6.134	6.019	5.878
55	5	3.417	3.394	3.358	3.287	3.201
	10	4.150	4.123	4.080	3.999	3.897
60	5	3.326	3.302	3.264	3.191	3.101
	10	4.042	4.014	3.969	3.882	3.776

III EXPERMIENTAL PROCEDURE:

Experiments are conducted at Tecumseh products India pvt.ltd in the balance ambient calorimeter lab.

3.1BAC test lab

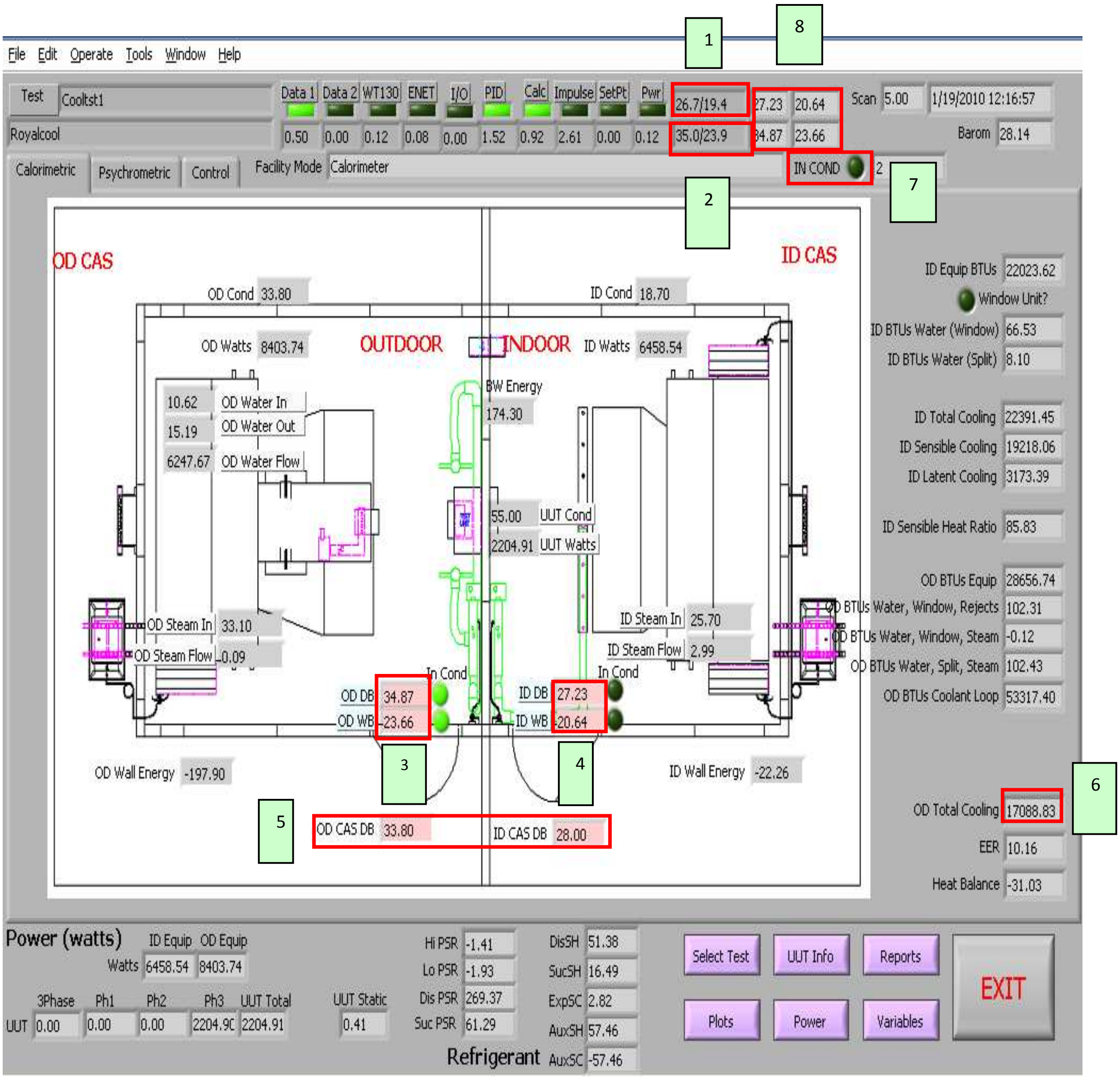
BAC lab was established to test the room air conditioning appliances (window and split type) as per different standards under balanced temperature conditions. The lab is divided into two test rooms namely indoor test room and outdoor test room. Each test room is enclosed by another chamber isolating the test rooms from the atmospheric influence by creating a space known as controlled air space. A constant dry bulb temperature equal to that of the dry bulb temperature inside the test room is maintained within the controlled air space shows the view of the balance ambient calorimeter (BAC) lab



BAC lab view

Each test room consists of the following equipment

- **Chillers:** Used to maintain the ambient temperatures.
- **Blowers:** Used to distribute the air inside the test room in order to maintain equilibrium.
- **Steamers:** Used to maintain the relative humidity.
- **Heaters :** Used to maintain the dry bulb temperature
- **Temperature sensors:** Used to measure temperature inside the room
- **Energy meter:** Used to calculate power consumption of appliance and lab equipment.
- **Temperature controllers :** Used to maintain dry bulb and wet bulb temperatures
- **Computer:** The lab is pre-programmed, controlled and monitored by software called as Lab view. The software automates the lab avoiding manual intervention reducing error levels.



Test Cooltst1

Royalcool

0.50 0.00 0.12 0.08 0.00 1.52 0.92 2.61 0.00 0.12

26.7/19.4

35.0/23.9

7.23 20.64

4.87 23.66

Scan 5.00

1/19/2010 12:16:57

Barom 28.14

Facility Mode Calorimeter

IN COND 2

OD Cond 33.80

ID Cond 18.70

OD Watts 8403.74

ID Watts 6458.54

BW Energy 174.30

10.62 OD Water In

15.19 OD Water Out

6247.67 OD Water Flow

55.00 UUT Cond

2204.91 UUT Watts

OD Steam In 33.10

OD Steam Flow -0.09

ID Steam In 25.70

ID Steam Flow 2.99

OD DB 34.87

OD WB 23.66

ID DB 27.23

ID WB 20.64

OD Wall Energy -197.90

ID Wall Energy -22.26

OD CAS DB 33.80

ID CAS DB 28.00

ID Equip BTUs 22023.62

ID BTUs Water (Window) 66.53

ID BTUs Water (Split) 8.10

ID Total Cooling 22391.45

ID Sensible Cooling 19218.06

ID Latent Cooling 3173.39

ID Sensible Heat Ratio 85.83

OD BTUs Equip 28656.74

OD BTUs Water, Window, Rejects 102.31

D BTUs Water, Window, Steam -0.12

OD BTUs Water, Split, Steam 102.43

OD BTUs Coolant Loop 53317.40

OD Total Cooling 17088.83

EER 10.16

Heat Balance -31.03

Power (watts)

	ID Equip	OD Equip
Watts	6458.54	8403.74

	3Phase	Ph1	Ph2	Ph3	UUT Total
UUT	0.00	0.00	0.00	2204.9C	2204.91

UUT Static 0.41

Hi PSR -1.41

Lo PSR -1.93

Dis PSR 269.37

Suc PSR 61.29

Refrigerant

DisSH 51.38

SucSH 16.49

ExpSC 2.82

AuxSH 57.46

AuxSC -57.46

- Total OD cooling capacity indicator
- Stabilization indicator
- Outdoor and indoor unit test rooms dry bulb and wet bulb temperatures
- Once the standard is defined in the program the temperatures defined in the standard are maintained inside the test rooms with the aid of steamers, blowers, heaters and chillers through an automated process.
- The unit starts running the varying dry bulb and wet bulb temperatures can be monitored on the calorimetric screen

- The dry bulb and wet bulb temperatures are stabilized over the defined values the in-condition light turns and a report is generated.
- The report generated narrates the complete test summary. Therefore the judgment can be made basing in the cooling capacity and EER obtained from the report.

3.1Results from Experiment:

Measurement position	Symbol	Unit	Capillary tube				
			Tube 1 (L_1=35”)	Tube 2 (L_2=33”)	Tube3 (L_2=30”)	Tube 4 (L_2=25”)	Tube 5 (L_2=20”)
Compressor pressure	P_1	Bars	4.481	4.495	4.757	4.964	5.067
	P_2	Bars	22.0632	21.787	20.546	20.063	19.987
Compressor temperature	T_1	°C	14.78	14.96	15.23	15.39	15.5
	T_2	°C	87.1	86.7	85.9	86.2	86.6
Condenser temperature	T_3	°C	53.46	53.67	54.29	55.08	55.28
Evaporator temperature	T_4	°C	8.2	9.5	9.9	10.2	10.5
C.O.P’S	C.O.P’S	-	2.318	2.254	2.178	2.151	2.096

IV RESULTS AND DISCUSSIONS:

The performance of 1.5tonn split type air conditioning system is evaluated mathematically and experimentally. The results from mathematical model and experiments are discussed in the following sections:
Mathematical model:
Mathematically C.O.P’S are evaluated at various condenser and evaporator temperatures by considering the sub-cooled temperature and assuming the 5°C of superheat at the inlet of compressor.

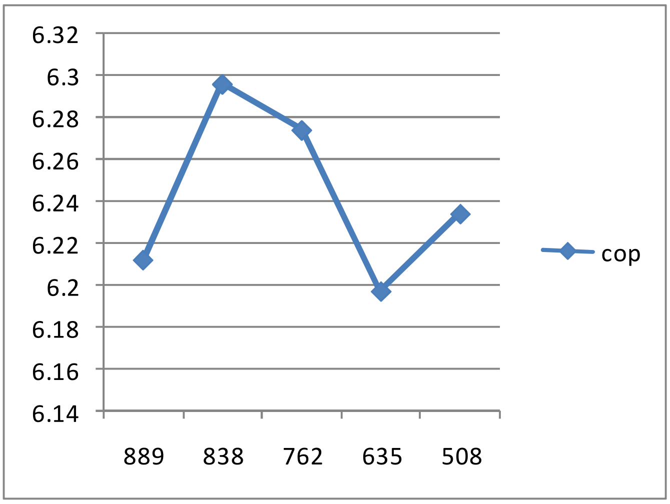
4.1 The Results Are Tabulated in Table C.O.P’S evaluated at Various Evaporator and Condenser Temperatures:

Condensor Temperature (°C)	Evaporator Temperature (°C)	C.O.P				
		Tube1 (L_1=35”)	Tube2 (L_2=33”)	Tube3 (L_3=30”)	Tube4 (L_4=25”)	Tube5 (L_5=20”)
40	5	7.326	7.286	7.220	7.095	6.780
	10	9.095	9.047	8.970	8.821	8.639
45	5	6.099	6.063	6.005	5.894	5.758
	10	6.633	6.596	6.536	6.421	6.28
50	5	5.164	5.132	5.080	4.980	4.858
	10	6.231	6.194	6.134	6.019	5.878
55	5	3.417	3.394	3.358	3.287	3.201
	10	4.150	4.123	4.080	3.999	3.897
60	5	3.326	3.302	3.264	3.191	3.101
	10	4.042	4.014	3.969	3.882	3.776

4.2 Mathematical results by changing Condenser temperature and Evaporator temperature:

Capillary tubes	Mathematical results		
	Condenser Temperature (^{0}c)	Evaporator Temperature (^{0}c)	COP
Tube 1	53.46	8.2	6.212
Tube 2	53.67	8.9	6.296
Tube 3	54.29	9.3	6.274
Tube 4	55.08	9.5	6.197
Tube 5	55.28	9.9	6.234

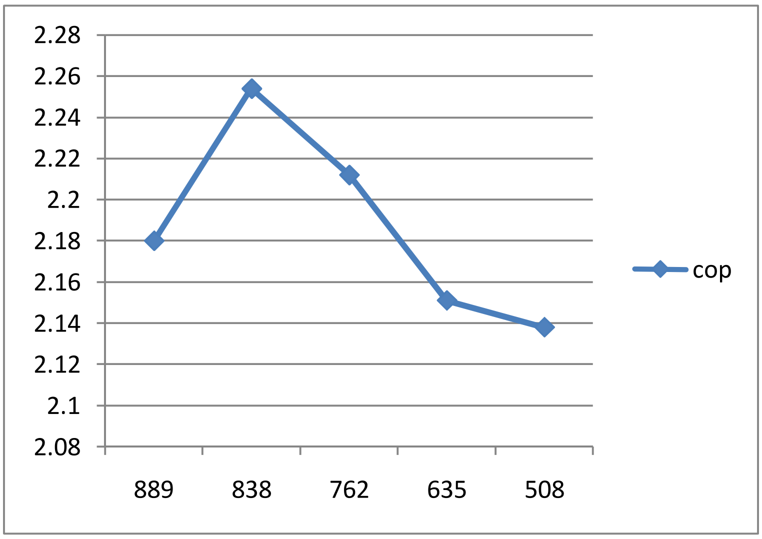
Length Of The Capillary Vs C.O.P (Mathematical Model):



4.3 Comparison between the Mathematical Results And Experimental Results

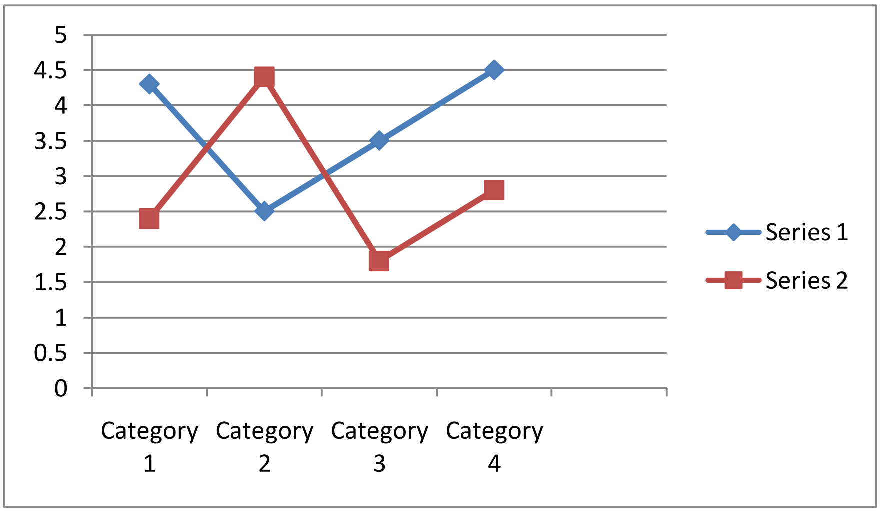
From the mathematical and experimental models it is found that Tube 2(largest length) has the maximum C.O.P'S 6.296 and 2.254 respectively. The experimental results correspond with the results from calculation (mathematical model) or at least they show the same trend. From the above graphs it is apparent that when the capillary tube length is increased C.O.P is higher.

Length of the Capillary Vs C.O.P (From Experiments)



Capillary tube length in mm

Comparison between Experimental and Mathematical Results

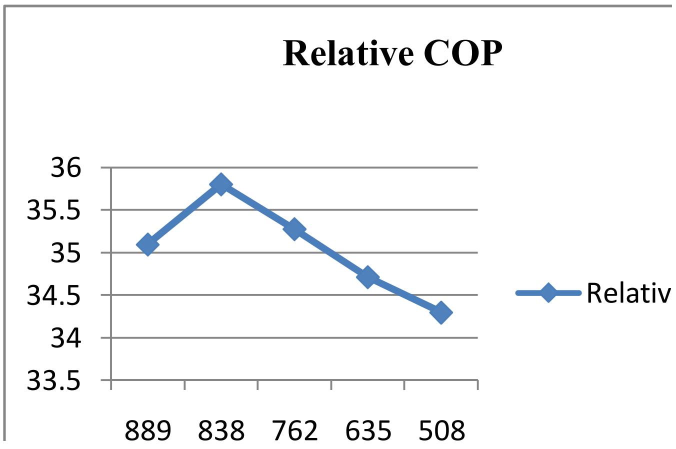


Graph shows the comparison between experimental and mathematical values. Around 30-35% of deviation was noticed between mathematical and experimental values. This deviation in the mathematical and experimental values might be due to the following reasons:

- Frictional losses in the compressor were not considered in analysis.
- Electrical losses are also not considered.
- Fan motor efficiency is also not considered

V Relative COP:

The ratio of the actual COP to theoretical COP is known as Relative COP



VI NOMENCLATURE:

A	cross-sectional area (m^2)
D	diameter (m)
H	specific enthalpy (kJ/ kg-1)
K	Boltzmann's constant
L	length (m)
M	mass flow rate (kg /s)
P	pressure (kPa)
s	entropy (kJ/ kg K)
T	temperature (°C)
V	velocity (m/s)
v	specific volume (m3/ kg)
x	vapor quality (dimensionless)
Cp	specific heat (kJ/ kg K)
Dc	capillary tube diameter (m)
Ds	suction line diameter (m)
g	gravitational acceleration (m/ s2)
h	specific enthalpy (J/ kg)
Q	heat transfer rate (W)
s	specific entropy (J/kg K)
T	temperature (K)
U	overall heat transfer coefficient (W/m2 K)
V	velocity (m/ s)
Hc	heat transfer coefficient in capillary tube (W/m2 K)
Hs	heat transfer coefficient in suction line (W/m2 K)
Lf	final length of capillary tube (m)
Lhx	heat exchange region length (m)
Lin	initial length of capillary tube (m)
Lsp	single-phase flow length (m)
Ltp	two-phase flow length (m)
m	mass flow rate (kg/sec)
z	position (m)

VII CONCLUSIONS:

From the experimental work, the following conclusions are drawn for a capacity of 1.5 Tons Split type Air-Conditioning system, at Tecumseh at Hyderabad.
All the parameters are at standard test conditions as per IS 10617 for R-22 Refrigerant.
Condenser Temperature: 50-55°C
Evaporator Temperature: 7- 10°C
INDOOR UNIT CONTIONS:
Dry Bulb Temperature (DBT) - 27°C
Wet Bulb Temperature (WBT) - 19°C
OUTDOOR UNIT CONTIONS:

Dry Bulb Temperature (DBT) - 35°C
Wet Bulb Temperature (WBT) - 24°C
Capillary Tube size: 0.06"×33"×2 nos.

1. When the diameter is held constant and lengths of the capillary tube is varied, the length 33"(838 mm) gives the maximum COP of the system.
2. When the length of capillary tube decreases, as the refrigeration effect also decreases. When the capillary tube diameter is kept constant.
3. The Degree of sub cooling increases as the length of the tube increases. Practically, maximum degree of sub-cooling that can be achieved is 15°C. Because, compressor work will also increases as the degree of sub cooling increases.
4. Compressor work will be minimum in between the range of evaporator temperature 8 -10 °C for using Air-Conditioning system
5. Normally the Actual COP to theoretical COP (i.e. Relative COP) is 32-35%. For Split type Air-Conditioning system.

Comparison between the standard size and recommended capillary tube size:

S.NO	Capillary tube size	COP	Relative COP
1	0.06"×27"×2 no's	2.1645	34.9993
2	0.06"×33"×2 no's	2.254	35.801

REFERENCES:

1. Akkarat Poolkrajang and Nopporn Preamjai Optimization of capillary tube in air conditioning system, Asian Journal on Energy and Environment.
2. C.P Arora, Refrigeration and Air conditioning. Tata McGraw-Hill Book Company.
3. Balance Ambient Test Facility Lab manual (BATAF) Tecumseh Products India Pvt. Ltd.
4 Stocker, W.F. and Jones J.W. (1982), Refrigeration & Air Conditioning**.** McGraw- Hill Book Company, Singapore.
5 Jung, D., Park, C. and Park B. (1999). Capillary tube selection for HCFC22 Alternatives, Department of Mechanical Engineering, Inha University, Inchon, Korea
6. ASHRAE (2001**).** 2001 Ashrae Handbook Fundamentals SI Edition. Atlanta, USA.
7. A Text book of Refrigeration and Air conditioning by R.S.Khurmi and J.K.Gupta.

Authors

D.V.Raghunatha Reddy B.Tech. (ME) from JNT University College of Engineering, Hyderabad M.Tech.(R&A.C) from JNTUAnantapur, working as a Assistant Professor in ME Dept, Aurora's Technological Research and Institute Uppal, Hyderabad, and pursuing Ph.D from JNTUniversity, Anantapur His current research interests are in the areas of simulation of refrigeration systems in different techniques.

P.Bhramara, B.Tech. (ME) from JNT University College of Engineering, Hyderabad M.Tech.(R&A.C) from Coimbatore Engineering College Coimbatore, and completed Ph.D.(Heat Transfer) from JNTU, Hyderabad in . She has one year of Industrial experience and 12 years of teaching experience. Presently she is working as Associate Professor, JNTU College of Engineering, JNTUH, Kukatpally, Hyderabad. Her research interests in Two Phase Heat Transfer, Instrumentation & Data acquisition Refrigeration & Air Conditioning, Computational Fluid Dynamics.

K.Govindarajulu B. Tech. (Mechanical) S.V.U. Tirupati, M. Tech. (Heat Power) JNTU, Hyderabad and Ph.D. (Boiling Heat Transfer), I.I.T., Rookee, Professor in Mechanical Engineering from JNTU Ananthapur He has 30 years of teaching experience. He has many research publications in various international and national journals and conferences, and he has received as a **BEST TEACHER AWARD IN THE YEAR 2012**