International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 3, Issue 1, pp: (287-295), Month: April 2015 - September 2015, Available at: www.researchpublish.com

Review on Experimental and Performance Analysis of Domestic Refrigerator Using Helical Coiled Tube Condenser

CHANDRASHEKHAR M. BAGADE [1], S. A. BORIKAR[2]

[1]M.Tech IV semester, Heat Power Engineering, KITS Ramtek
[2]Assistant Professor, Mechanical Engineering Department, KITS Ramtek

Abstract: **Day by day there is increasing demand of refrigerating effect which increases the load on compressor. But sub cooling and superheating are the process used for getting maximum refrigerating effect, ultimately improve COP of the refrigerating system.**

Condenser plays an important role in any refrigeration system .it is use to remove heat from refrigerant vapour coming from compressor p-h and T-s diagrams clearly shows, the effect of sub cooling after condensate formation on COP. Now a day we are interested in improving COP of refrigeration system, without affecting compressor work. Sub cooling is one of the factors that can improve the COP of refrigeration system. Sub cooling is done in the condenser, thus condenser design is the key factor to improve the COP of domestic refrigerator.

Keywords: **Refrigerator, condenser, COP, sub cooling and superheating.**

1. INTRODUCTION

Now a days when we think about any refrigeration system our interest going towards the coefficient of performance of that system. In the same sense whenever we focused on domestic refrigerator we can observed there are two easy way to enhance the coefficient of performance. That is superheating of refrigerant after evaporator and another way is subcooling of refrigerant before entering into expansion device.

Effects of sub cooling and superheating of refrigerant on the refrigerating effect are clearly explained from p-h and t-s diagrams of refrigeration system.

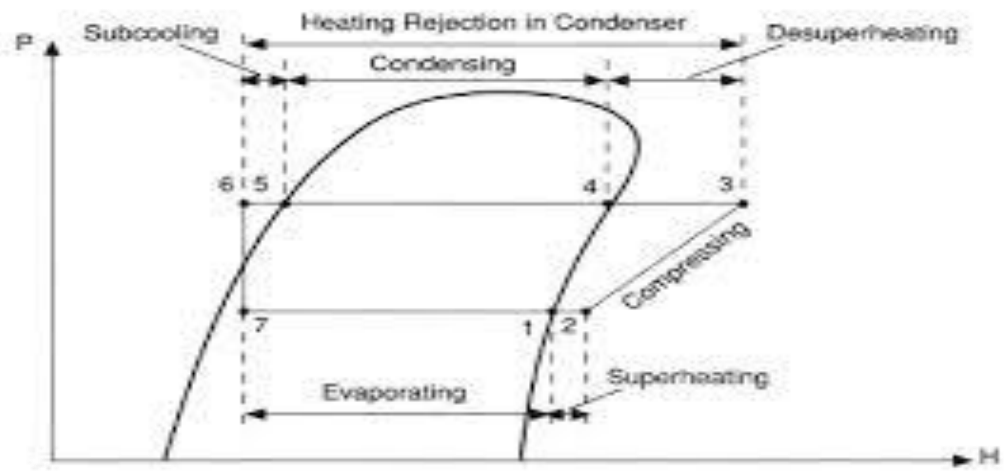


fig.1- p-h diagrams [19]

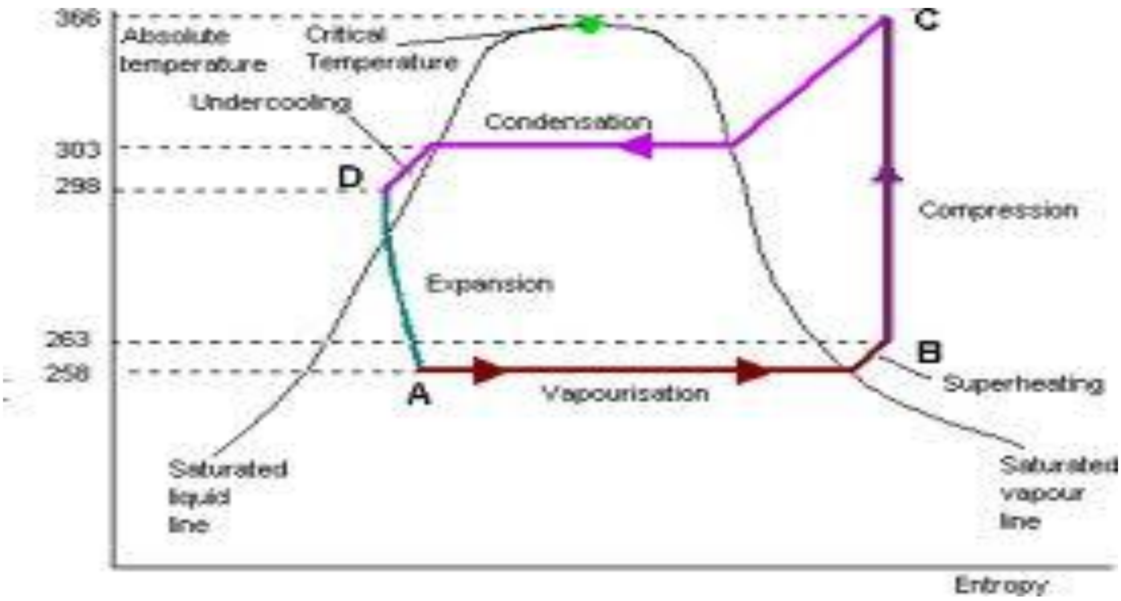


fig.2- t-s diagrams [20]

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system.

As per design concerned of domestic refrigerator, it is easy to change the design of condenser instead of evaporator design [10]. Earlier different types of condenser slides air cooled condenser, water cooled condenser is been used in a domestic refrigeration system. Air cooled condenser is most popular condenser for a refrigerator [1]. Many researches done in a past on the condenser, one of them wire-on-tube condenser where main tube is used in a spiral form with vertical wire having fins with different spacing. Heat transfer rate can be enhanced by using this type of condenser [12].

Helically coiled exchangers offer certain advantages as compare to straight tube condenser. Such as compactness of size, higher film coefficients, increased heat transfer rate, thermal performance these are some attractive features in case of helical coiled tube heat exchanger [2]. Due to flow resistance, there is more possibilities of pressure drop result in efficient and less-expensive designs [8].

The curved surface of helical coil is responsible for generation of the centrifugal force in outwards direction which create secondary flow inside the tube. These secondary flow increases the mass flow rate of the refrigerant ultimately heat transfer rate to the tube wall improved. Improvement of heat transfer rate shows the increment in COP of the refrigeration cycle [4, 6, 8].

It has been found that the secondary flow is turbulent flow. This turbulent flow must have sufficient intensity to enhance the heat transfer rate. Intensity of the turbulent flow is depends on diametric ratio. Diametric ratio is nothing but the ratio of diameter of helical coiled tube (D) to the outer diameter of the tube (d). Characteristics of flowing fluid through helical coiled tube is also determined from Dean number [i.e. De=Re$\sqrt{(\frac{d}{D})}$]. Where De is the Dean number and Re is the Reynolds number [6, 8].

Another most important parameter is the pressure drop across the helical coil tube. There is increasing in mass flow rate of flowing fluid with increase in pressure drop. Pressure drop is depends on the frictional factor. Friction coefficient (*f*) is given as,

$$f = \frac{\Delta P}{0.5 \times \frac{L}{d} \times \rho V^2}$$

Where L and d are length and diameter of the helical coil tube respectively

ΔP is the pressure drop, V is the velocity of flowing fluid [8].

The void fraction is use to find out flow regimes along the length of helical coiled tube. Calculation of the pressure drop and heat transfer coefficient are affected by the flow regimes hence flow regimes must be identified by considering void fraction with time it can be done by using densitometer. The void fraction is defined as the ratio of the vapour area to the total cross sectional areas [18].

As heat transfer rate increases subcooling of refrigerant also increases when we using helical coiled tube condenser which gives maximum refrigerating effect ultimately coefficient of performance of domestic refrigerator will be enhanced. But due to space limitation I decided to use elliptical helical coiled tube condenser instead of circular helical coiled tube condenser.

2. LITERATURE REVIEW

The purpose of this literature review is to study the recent work carried out for design the condenser of domestic refrigerator and find out the better design to enhance the COP of domestic refrigerator without changing any components other than condenser.

Otto J. Nussbaum [1] studied all relevant type of condensers and investigate the effects of advantages and disadvantages of various condensers on performance of refrigeration systems. Air cooled condensers with small capacity i.e. 5 to 7.5 Hp is commonly used as indoor condensing unit. Selection of condensers is depends on the total heat rejection (THR) and quantity of flowing fluid.

Water cooled condensers is use for 0.25TR to 200TR. When we considering water circulating pump work, corrosive nature of water, make up water requirement air cooed condenser is best suitable for domestic refrigerator as compared to water cooled condenser.

An experimental investigation of N. D. Shirgire and P. Vishwan gives variation of overall heat transfer coefficient for strait tube and helical coil heat exchanger by keeping constant mass flow rate of hot water and varying the cold water mass flow rate. The graphs drawn in there research papers shows the increase in overall heat transfer rate with increase in mass flow rate [2]. Overall heat transfer coefficient is higher for helical coil heat exchanger as compared to straight tube heat exchanger.

There are various augmentation techniques which is used to improve heat transfer rate. Mainly three techniques i.e. passive, active and compound methods for heat transfer [3]. Insets required in passive technique while active technique required some external power input and in case of compound technique two or more active or passive techniques combined together for enhancement of heat transfer rate. After studying these three techniques passive technique is commonly used for enhancement of heat transfer rate.

B. Chinna Ankanna and B. Sidda Reddy [4] making some calculation by considering geometry and parameters of helical coils to calculate effectiveness and overall heat transfer coefficient.

First they set dimensional parameters and operating parameters for helical coil heat exchanger as given below.

Table 1. Dimensional parameters of Helical coil [4] (B. Chinna Ankanna and B. Sidda Reddy)

Sr. No.	Dimensional Parameters	Dimensions
1	Outer diameter of SS cylinder (D)	63.5mm
2	Inner diameter of SS cylinder (Di)	1.058Dmm
3	Thickness of SS cylinder (T)	3-5mm
4	outer diameter of SS end cap (Dco)	1.376Dmm
5	inner diameter of SS end cap (Dci)	1.162Dmm
6	thickness of the end cap (Tc)	6-9mm
7	Outer diameter of projected tube (Dto)	0.211Dmm
8	Inner diameter of projected tube(Dti)	0.145Dmm
9	Diameter of connecting tube(Dcp)	0.2Dmm
10	Diameter of CPVC pipe(Dcpvc)	0.3Dmm

Table 2. Operating parameters of Helical coil heat exchanger [4] (B. Chinna Ankanna and B. Sidda Reddy)

Parameters	Cold Water	Hot Water
Mass flow rate Mf	0.0625	0.166
Initial temperature (℃)	30	100
Outlet Temperature (℃)	60	70
Cp J/Kg ℃	4183	4216
Prandtl Number (Pr)	5.68	1.74
Thermal conductivity(K) (W/m2 ℃)	383	16.2
Viscosity (N-s/m2)	0.0008294	0.00028157
Density (kg/m3)	997.5	961

After setting dimensional parameters and operating parameters design procedure adopted for helical coil considering Reynolds number, Dean number, Nusult number, Prandtl number and there relation for finding heat transfer rate. After calculation and comparison of various parameters they conclude that helical coil heat exchanger provide more surface area for making fluid contact for long time, which may result in improvement of heat transfer rate as compared to straight tube heat exchanger.

Table 3. Effectiveness [4] (B. Chinna Ankanna and B. Sidda Reddy)

Arrangements	Effectiveness (max.)
Helical coil in parallel configuration	0.631
Helical coil in counter configuration	0.671
Straight tube in parallel configuration	0.316
Straight tube in counter configuration	0.498

From above table effectiveness of counter helical coil heat exchanger is much higher than other arrangements.

Sanjeev Singh Punia and Jagdev Singh [5] conduct an experiment to investigate the effect of capillary tube length, capillary tube diameter and capillary coil diameter on the mass flow rate of refrigerant through helical coil tube. They used LPG as refrigerant in VCR system. In their experiment they set the range of tube length as 4.5 to 2.5 m and find out there is increment in the mass flow rate by an average 25% .

Also find that when inner diameter of helical coil tube increases from 1.12mm to 1.52mm mass flow rate increases by an average 106%.

They again investigate that when coil diameter of helix decreased from 190mm to 70mm mass flow rate also decreased by 13%, 7% and 9% for 1.12mm, 1.4mm and 1.52mm inner diameter of helical tube respectively.

After studying this paper I found that maximum COP can be obtained by using helical coil tube condenser but maximum pressure drop and frictional resistance are drawbacks of helical coil tube.

Rajesh Joshi and Dr. A. I. Khandwawala [7] gives experimental support to the research paper of Sanjeev Singh Punia and Jagdev Singh [5] Rajesh Joshi and Dr. A. I. Khandwawala used R134a refrigerant for their experiment. They noted all thermo-physical properties of R134a refrigerant at mean temperature of condenser i.e. at 60℃ as

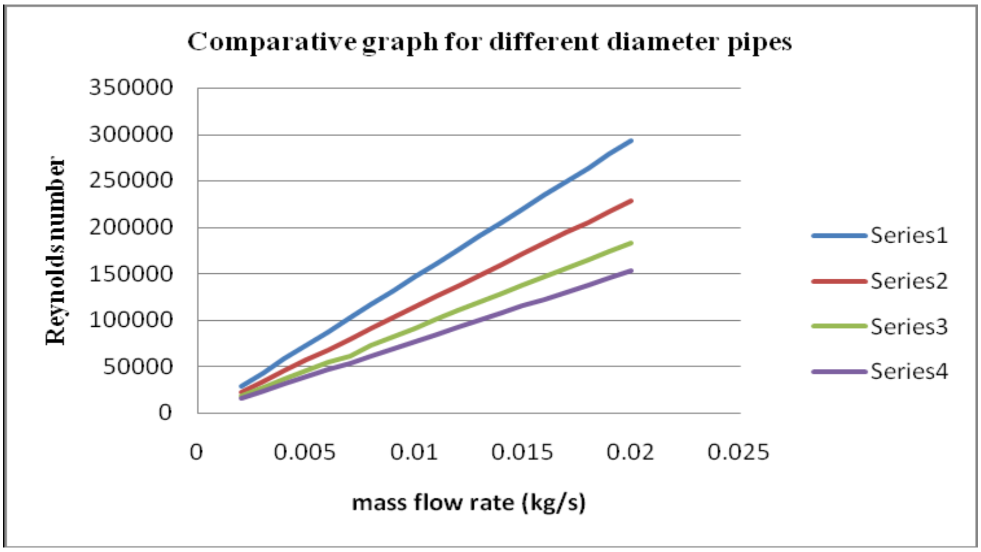
Liquid phase density = 1052.85 kg/ m^3 Vapour phase density= 87.719 kg/ m^3 Thermal conductivity of R134a K=0.01144W/m-k

Prandtl number for liquid= 0.769 Condensers inside diameters selected as 6.25mm, 8mm, 10mm and 12mm respectively. Mass flow rate of refrigerant varied from 0.002kg/s to 0.02 kg/s. in step of 0.001 kg/s.

They experimentally noted the result as effect of variation of inside diameter of condenser tube and mass flow rate on heat transfer coefficient in common domestic refrigerator which is given below,

Table 4 Comparative performance with Reynolds number [7] (Rajesh Joshi and Dr. A. I. Khandwawala)

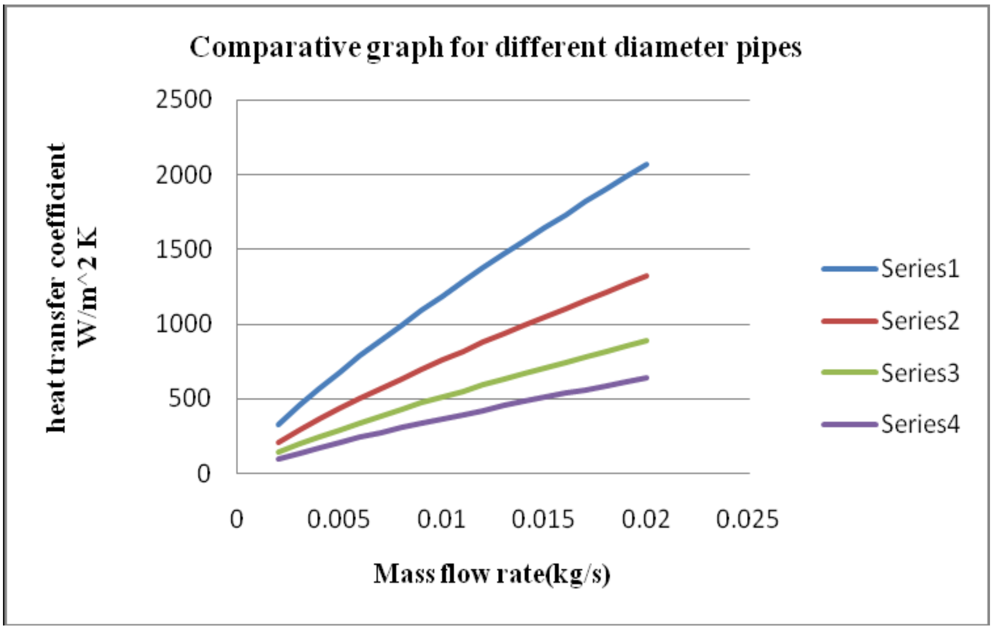
Mass flow rate (kg/s)	Reynolds number			
	Pipe dia. 6.25mm	Pipe dia. 8mm	Pipe dia. 10mm	Pipe dia. 12mm
0.002	29300.2	22890.78	18312.6	15260.5
0.003	43950.2	34336.17	27468.9	22890.7
0.004	58600.3	45781.56	36625.2	30521.0
0.005	73250.4	57226.95	45781.5	38151.3
0.006	87900.5	68672.33	54937.8	45781.5
0.007	102550.7	80117.72	60944.1	53411.8
0.008	117200.8	91563.11	73250.4	61042.0
0.009	131850.9	103008.5	82406.8	68672.3
0.01	146501	114453.9	91563.1	76302.5
0.011	161151.1	125899.3	100719	83932.8
0.012	175801.2	137344.7	109875	91563.1
0.013	190451.3	148790.1	119032	99193.3
0.014	205101.4	160235.4	128188	106823
0.015	219751.5	171680.8	137344	114453
0.016	234401.6	183126.2	146501	122084
0.017	249051.7	194571.6	155657	129714
0.018	263701.8	206017	164813	137344
0.019	278351.9	217462.4	173969	144974
0.02	293002	228907.8	183126	152605



Graph 1. Comparative effects mass flow rate on Reynolds number for different diameters of pipe [7] (Rajesh Joshi and Dr. A. I. Khandwawala)

Table 5 Comparative performance with heat transfer coefficient [7] (Rajesh Joshi and Dr. A. I. Khandwawala)

Mass flow rate (kg/s)	Heat transfer coefficient (w/m2-K)			
	Pipe dia. 6.25mm	Pipe dia. 8mm	Pipe dia. 10mm	Pipe dia. 12mm
0.002	328.05	210.36	140.77	101.39
0.003	453.74	290.96	194.71	140.24
0.004	571.17	366.25	245.10	176.53
0.005	682.8	437.84	293.00	211.03
0.006	790.02	506.59	339.01	244.17
0.007	893.7	573.08	383.51	276.21
0.008	994.46	637.69	426.75	307.36
0.009	1092.72	700.7	468.91	337.73
0.01	1188.82	762.32	510.15	367.43
0.011	1283.01	822.72	550.57	396.54
0.012	11375.56	882.03	590.26	425.12
0.013	1466.46	940.36	629.29	453.24
0.014	1556.03	997.79	667.73	480.92
0.015	1644.33	1054.4	705.62	508.21
0.016	1731.46	1110.2	743.01	535.14
0.017	1817.51	1165.4	779.93	561.73
0.018	1902.54	1219.9	816.43	588.02
0.019	1986.64	1273.9	852.52	614.01
0.02	2069.86	1327.2	888.23	639.73



Graph 2. Comparative effects mass flow rate on Heat transfer coeficeint for different diameters of pipe [7] (Rajesh Joshi and Dr. A. I. Khandwawala)

From above readings and graphs I can easily observed that for given mass flow rate, when pipe diameter increases value of Re decreases and form given to diameter heat transfer rate increases with increase in mass flow rate.

Spiral capillary tube condenser is another possible replacement for straight tube condenser. Nishant P. Tekade and Dr. U. S. Wankhede [12] studied various papers related to the spiral tube heat exchanger. They noted that selection of refrigerant is depends on thermo-physical properties and technological and economical aspects.

Suitable combination of length and diameter of tube affect the mass flow rate and pressure drop. Use of spiral capillary tube improve COP of refrigeration system but heat transfer rate in case of spiral tube heat exchanger is difficult to calculate as compare to helical coil tube heat exchanger, because there is complex and interfering heat transfer nature from centre to outward direction. Also there is maximum value of centrifugal force in tangential direction which produce greater frictional resistance to the flow of fluid and greater turbulence occurs inside the tube which may result in higher uncontrolled pressure drop across the two ends of condenser tube which increases load on compressor.

Possible drawing of Helical coil tube condenser is as below

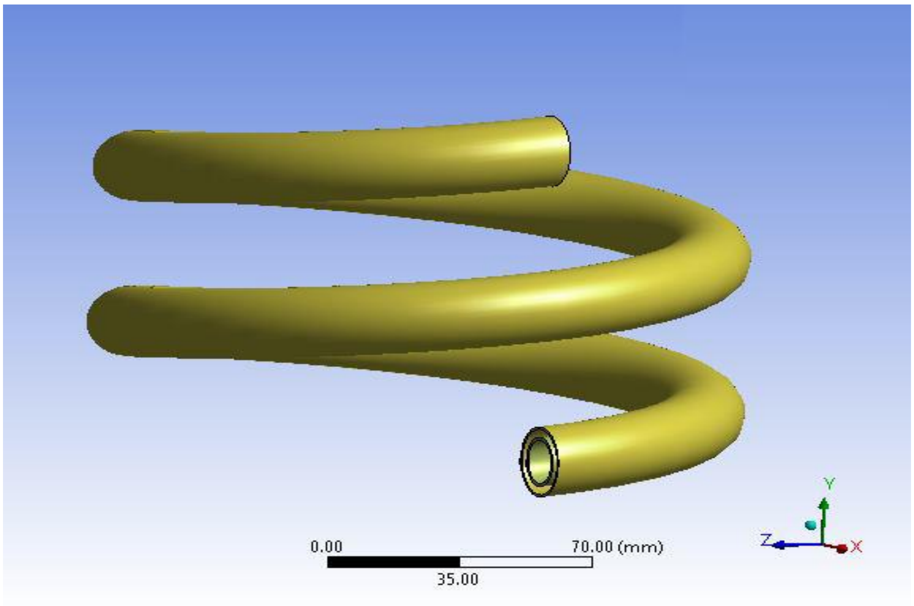


Diagram 1. Helical coil tube condenser [14] (Soby P. Sunny, Siddharth D. Mhaske and Yash B. Parikh)

Temperature drop in case of helical coil tube condenser is higher than the straight tube condenser because of curvature nature of the helical coil which shows the enhancement of heat transfer rate [14].

From Numerical analysis and CFD modelling it can be seen that whenever there is increase in velocity of flowing fluid decreases the ratio of pressure drop to the heat removed for greater pitch as compared to the smaller pitch. This shows better heat transfer characteristics for larger pitch as compared to smaller pitch [15].

Under the turbulent flow condition of refrigerant inside the helical coil tube condenser overall heat transfer coefficient is more. Because of calculation of heat transfer coefficient is based on the inlet and outlet temperature of flowing refrigerant which affected by an intensity of turbulence [16]. Fin spacing also affect the discharge pressure and heat transfer coefficient, which is higher in case of higher fin spacing [17].

3. CONCLUSIONS

After studying many papers I conclude that there is possibility to change the condenser design to improve the heat transfer rate which gives easy subcooling of refrigerant after condensation. This is further responsible for increment in the refrigerating effect of any refrigeration system. Increment in the refrigerating effect indicates that improvement in COP of refrigeration system.

There are numbers of condenser design available for domestic refrigerator to enhance its COP. But I noted that Helical coil tube condenser gives better heat transfer rate, maximum mass flow rate, minimum frictional losses with minimum coil length.

Due to curvature shape of helical coil tube refrigerant flowing with higher turbulence nature which indicates that more frictional resistance to the flow of refrigerant which increases the load on compressor.

REFERENCES

[1] Otto J. Nussbaum, 2009 Condensers, Service Application Manual SAM Chapter 620-32A Section 5B

[2] N. D. Shirgire and P. Vishwanath Kumar, 2013 Review on Comparative Study between Helical Coil and Straight Tube Heat Exchanger, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 8, Issue 2 (Jul. - Aug. 2013), PP 55-59

[3] Manoj Hajare, Chetan Deore, Kavita Kharde, Pushkar Rawale and Vivek Dalvi, April 2014 Review Of Heat Transfer Augmentation Techniques, A Peer Reviewed International Journal, Vol.2., Issue.2., 2014

[4] B. Chinna Ankanna and B. Sidda Reddy, 22nd March 2014 Performance Analysis of Fabricated Helical Coil Heat Exchanger, International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print),Volume No.3 Issue No: Special 1, pp: 33-39

[5] Sanjeev Singh Punia and Jagdev Singh, Dec 2012 Experimental Investigation on the Performance of Coiled Adiabaticcapillary Tube with LPG as Refrigerant, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), ISSN 2249-6890,Vol. 2, Issue 4 Dec - 2012 73-82

[6] Pramod S. Purandare, Mandar M. Lele and Rajkumar Gupta, October – 2012 Parametric Analysis of Helical Coil Heat Exchanger, International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 8, October – 2012, ISSN: 2278-0181

[7] Rajesh Joshi and Dr. A.I. Khandwawala, February 2014 A Comparative Study of the Effect of Variation of Inside Diameter of Condenser and Mass Flow Rate on the Heat Transfer Coefficient in a Domestic Refrigerator, Rajesh Joshi et al Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 4, Issue 2(Version 1), February 2014, pp.514-518

[8] Yordam Kocatepe, Hojin Ahn, Cafer Aydın and Aydın Karacasu, 2009 Experimental Investigation of a Heat Exchanger with a Helical Coil Made of Corrugated Tubes, ULIBTK'09 17. Ulusal Isı Bilimi ve Tekniği Kongresi 24-27 Haziran 2009, SİVAS

[9] Mrunal P.Kshirsagar, Trupti J. Kansara and Swapnil M. Aher, April-May 2014 Fabrication and Analysis of Tube-In-Tube Helical Coil Heat Exchanger, International Journal of Engineering Research and General Science Volume 2, Issue 3, April-May 2014 ISSN 2091-2730

[10] C. Inan, T. A. Newell and A. N. Egrican, May 2000 Heat and Mass Transfer through a Domestic Refrigerator and Evaluation of Evaporator Performance under Frosted Conditions, Air Conditioning and Refrigeration Center University of Illinois Mechanical & Industrial Engineering Dept. 1206t Green Street Urbana, IL 61801 (217) 333-3115

[11] Khan M. K., Sahoo P.K. and Kumar R., 2007 Flow Characteristics of HFC-134a in an Adiabatic Helical Capillary Tube, 5th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics Sun City, South Africa Paper number: KM1

[12] Nishant P. Tekade and Dr. U. S. Wankhede, May-June 2012 Selection of Spiral Capillary Tube for Refrigeration Appliances, International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.3, May-June 2012 pp-1430-1434, ISSN: 2249-6645

[13] Ramachandra K. Patil, B. W. Shende and Prasanta K. Ghosh, Dec 1982 Designing a helical-coil heat exchanger, Designing an HCHE, Chemical engineering Dec 13, 1982

[14] Soby P. Sunny, Siddharth D. Mhaske and Yash B. Parikh, 2014 Numerical Simulation of a Tube in Tube Helical Coiled Heat Exchanger using CFD, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 9, Number 18 (2014) pp. 5209-5220, © Research India Publications.

[15] R. Thundil Karuppa Raj, Manoj Kumar S., Aby Mathew C. and T. Elango, March 2014 Numerical Analysis of Helically Coiled Heat Exchanger using CFD Technique, ARPN Journal of Engineering and Applied Sciences, VOL. 9, NO. 3, MARCH 2014, ISSN 1819-6608

[16] Pablo Coronel and K.P. Sandeep, 2008 Heat Transfer Coefficient in Helical Heat Exchangers under Turbulent Flow Conditions, International Journal of Food Engineering, Vol. 4 [2008], Iss.1, Art. 4

[17] Vivek Shahu, PoojaTiwari, K. K. Jain and Abhishek Tiwari, 2013 Experimental Investigation of the Refrigerator Condenser by Varying the Fins Spacing of the Condenser, International Journal on Mechanical Engineering and Robotics (IJMER) ISSN (Print): 2321-5747, Volume-1, Issue-1, 2013

[18] Ahmed Mohamed Elsayed, Sep2011 Heat Transfer in Helically Coiled Small Diameter Tubes for Miniature Cooling Systems, University of Birmingham Research Archive e-theses repository, B15 2TT, Sep2011

[19] http://www.google.co.in/imgres?imgurl=http://www.thermopedia.com/content/5507/REFRIGERATION_FIG5.gif&imgrefurl=http://refrigerationtoday.blogspot.com/2014/02/refrigeration-p-h.html&h=309&w=508&tbnid=n53MHVPGTEBNBM:&zoom=1&docid=Wiu3eQAtdIyY8M&ei=S-sOVJ2VL8mfugSws4DQBg&tbm=isch&ved=0CCYQMygKMAo

[20] http://www.google.co.in/imgres?imgurl=http://mamic.8k.com/sys5.gif&imgrefurl=http://refrigerationtoday.blogspot.com/2014/06/absorption-refrigeration-t-s-diagram.html&h=295&w=441&tbnid=f8kD2sItaa3WkM:&zoom=1&docid=x3G23Jen5dgC0M&ei=S-sOVJ2VL8mfugSws4DQBg&tbm=isch&ved=0CEIQMygcMBw