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Selection of spiral capillary tube for refrigeration appliances

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Abstract:

Selection of spiral capillary tube for refrigeration appliances and the effect of changes in the parameters such as capillary tube dimensions i.e. capillary tube diameter, coil pitch, capillary tube length and inlet conditions of refrigerant to the capillary tube i.e. degree of subcooling, inlet pressure on the mass flow rate of the refrigerant, also investigation about the coiling effect of spiral capillary tube on mass flow rate of refrigerant for same cooling load is reviewed in this paper. The characteristics coiling parameter for a spiral capillary tube is the coil pitch; hence, the effect of the coil pitch on the mass flow rate of refrigerant for several spiral capillary tube test sections plays vital role in investigation of the performance.

The review is focused on the influence of tube diameter, tube length, coil pitch, and inlet condition on mass flow rate of refrigerant through spiral capillary tube, and also on investigation about the Coefficient of Performance (COP) of the system due to coiling effect of capillary tube. The use of spiral capillary tube reduces the space for the refrigeration system which is the need for more compact refrigeration system in the current trend. As the spiral capillary tube can be efficient in refrigeration appliances, it can also be employed in the air conditioning appliances.

Keywords: Spiral capillary tube, mass flow rate, coiling effect.

Introduction:

Capillary tubes are used to expand the refrigerant from the condenser pressure to the evaporator pressure in low capacity refrigerating machines such as domestic refrigerators and window type room air conditioners. It also controls the refrigerant mass flow rate and balances the system pressure in the refrigeration cycle. However, it has no provision to adjust the mass flow rate when load conditions changes. In spite of this fact, capillary tubes are preferred in small capacity refrigerating machines, where the load is fairly constant due to its several advantages such as simplicity, low cost, zero maintenance, and requirement of a low starting torque motor to run the compressor.

To overcome Ozone depletion and global warming problems, replacement of chlorofluorocarbon refrigerant like R 22 is required. The search for eco-friendly alternative of R-22 has brought out R-407C as the best promising ozone-safe substitute of R-22. If the refrigerants are changed in the existing VCRS system, the COP of the system will be affected thereby either reducing cooling effect or increasing the amount of compressor work. The review is divided in two parts. First one is selection of refrigerant and another one is select proper size of capillary tube.

A) Selection of refrigerant:

There is no general rule governing the selection of refrigerants. It depends upon thermo physical properties, technological and economic aspects, safety and environmental factor, the capacity required for household refrigerators, which have refrigerating capacities of 400-500 W and electrical power input within 100-150 W range. The energy efficiency is far from that achieved using vapour-compression systems.

After many years of testing and investigation, R407C is recognized as a suitable alternative refrigerant for R22 in medium and high temperature applications such as residential and light commercial air conditioning. R407C is a ternary blend of hydro fluorocarbon or HFC compounds, comprising 23% of R32 (Di-fluoro-methane, CF_2H_2), 25% of R125 (Penta-fluoro-ethane, CF_3CHF_2) and 52% of R134a (Penta-fluoro-ethane, CF_3CH_2F). It has no chlorine content, no ozone depletion potential, and only a modest direct global warming potential. ODP = 0, GWP = 1610.

B. G. Lee et al. (2005) concluded that ternary mixtures composed of HFCs and HCs can be used to develop the HCFC-22 alternative refrigerant mixtures. They selected HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, and HFC-236ea as HFCs, and propane and iso-butane as HCs. The simulator which could predict theoretically the performance of given refrigerant mixtures was developed and tested for various refrigerant systems. Nineteen different kinds of ternary mixtures were chosen for thermodynamic simulation. Among nineteen mixtures, six ternary refrigerant mixtures were selected as candidates for HCFC-22 alternatives. They were R-32/143a/600, R-32/152a/227ea, R-32/134a/236ea, R-

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2/143a/236ea, R-32/152a/236ea, and R-32/134a/600a. Performance of these mixtures was obtained experimentally by the thermodynamic calorimeter and was compared with that of HCFC-22, R-407C and R-410A.

L. B. Ortiz et al. (2001) investigated theoretically and experimentally, for an adiabatic flow in capillary tube covering R-22 and there three substitutes; two binary mixtures, R-32/ R-134a (30/70% by weight) and R-32/R-125(60/40%), and R-407c{R-32/R-125/ R-134a (23/25/52%)}.A comparison was carried out between experimental results and model predictions for one single length and two diameters. Result had showed similar performances for R-22 and R-407c. For particular geometry with large degrees of subcooling (above 12^0C), refrigerant mass flow rates were very similar. As the subcooling decreases, refrigerant R-407c mss flow rate becomes a fraction larger for different operating conditions (condensing temperature and degree of subcooling).

S. M. Sami et al. (2003) experimentally investigated the performance of new alternative refrigerant mixtures such as R-410A, R-507, R-407C, and R-404A under various conditions of magnetic field. The test results were obtained using an air-source heat pump set-up with enhanced surface tubing under various magnetic field conditions. Performance tests were conducted according to the ARI/ASHRAE Standards. The test results demonstrated that as magnetic field force increases, compressor head pressure and discharge temperature slightly increase as well as less liquid refrigerant is boiling in the compressor shell. This has a positive effect in protecting the compressor. The effect of magnetic field on mixture behavior varies from one mixture to another depending upon the mixture's composition and its boiling point. Furthermore, the use of magnetic field appears to have a positive influence on the system COP as well as thermal capacities of condenser and evaporator.

Hira lal Sachdev et al. (2004) carried out experimental analysis along with energy analysis of vapour compression refrigeration cycle for R-22 and its alternate refrigerant R407C, R410A and R417A has been carried out by varying evaporator temperature between -38 °C to 7°C and condenser temperature between 35 °C to 60°C, with the help of Engineering Equation Solver (EES). The parametric investigation such as coefficient of performance, volumetric cooling capacity, pressure ratio, exergy destruction ratio, exergetic efficiency, and efficiency defect in individual components for R-22, R-407C, R-410A and R-417A have been carried out theoretically and have been compared with the experimental available data. The results indicate that evaporating and condensing temperatures have pronounced effect on exergy destruction in the air-conditioner components such as compressor, condenser, and throttle valve where as in the evaporator it is negligible. The exergetic efficiency and COP of the cycle change to large extent with the variation in evaporator and condenser temperatures. The computational analysis has allowed the determination of the best energetic and exergetic performances of R-22 and its substitute refrigerant R-407C, R410A and R417A.

B) Selection of capillary tube:

Several combinations of length and bore are available for the same mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system, the mass flow rate through it will vary in such a manner that the total pressure drop through it matches with the pressure difference between condenser and the evaporator. Its mass flow rate is totally dependent upon the pressure difference across it; it cannot adjust itself to variation of load effectively. Most of the studies in coiled capillary tubes have been performed with helically coiled capillary tubes, as the helically coiled capillary tubes can be accommodated in a small space. Hence relatively little information in open literature is available on the flow characteristics of refrigerants in a spiral capillary tube.

M. K. Mittal et al. (2009) investigated the effect of coiling on the flow characteristics of R-407C in an adiabatic spiral capillary tube. The characteristic coiling parameter for a spiral capillary tube is the coil pitch. The effect of the coil pitch on the mass flow rate of R-407C was studied on several capillary tube test sections. They observed that the coiling of the capillary tube significantly reduced the mass flow rate of R-407C in the adiabatic spiral capillary tube. In order to quantify the effect of coiling, they conducted experiments for straight capillary tube and observed that the coiling of the capillary tube reduced the mass flow rate in the spiral tube in the range of 9–18% as compared with that in the straight capillary tube. A generalized non dimensional correlation for the prediction of the mass flow rates of various refrigerants was developed for the straight capillary tube on the basis of the experimental data of R-407C, 134a, R-22, and R-410A measured by other researchers. Additionally, a refrigerant-specific correlation for the spiral capillary was also proposed on the basis of the experimental data of R-407C.

M.K. Khan et al. (2008) experimentally investigated the flow of R-134a inside an adiabatic spirally coiled capillary tube. The effect of various geometric parameters like capillary tube diameter, length and coil pitch for different capillary tube inlet subcooling on the mass flow rate of R-134a through the spiral capillary tube geometry has been investigated. It has been established that the coil pitch significantly influences the mass flow rate of R-134a through the adiabatic spiral capillary tube. The effect of providing pressure taps on the capillary tube surface has a negligible effect on the mass flow rate through the capillary tube. It has been concluded that the effect of coiling of capillary tube reduces the mass flow rate by 5–15% as compared to those of the straight capillary tube operating under similar conditions. The data obtained from the experiments are analyzed and a semi-empirical correlation has been developed. The proposed correlation predicts more than 91% of the mass flow rate which is in agreement with measured data in an error band of ±10%.

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1430-1434 ISSN: 2249-6645

P.K. Bansal et al. (1998) worked for homogeneous two-phase flow model, CAPIL, which was designed to study the performance of adiabatic capillary tubes in small, vapour compression refrigeration systems, in particular household refrigerators and freezers. The model was based on the fundamental equations of conservation of mass, energy and momentum that are solved simultaneously through iterative procedure and Simpson's rule. The model uses empirical correlations for single-phase and two-phase friction factors and also accounts for the entrance effects. The model uses the REFPROP data base where the Carnahan-Starling-De-Santis equation of state is used to calculate the refrigerant properties. The model includes the effect of various design parameters, namely the tube diameter, tube relative roughness, tube length, level of subcooling and the refrigerant flow rate. The model is validated with earlier models over a range of operating conditions and is found to agree reasonably well with the available experimental data for HFC-134a.

Jongmin Choi et al. (2003) developed a generalized correlation for refrigerant flow rate in adiabatic capillary tubes by implementing dimensionless parameters based on extensive experimental data for R-22, R-290, and R-407C. Dimensionless parameters are derived from the Buckingham- π theorem, considering the effects of tube inlet conditions, capillary tube geometry, and refrigerant properties on mass flow rate. The generalized correlation yields good agreement with the present data for R-22, R-290, and R-407C with average and standard deviations of 0.9 and 5.0%, respectively. Approximately 97% of the present data are correlated within a relative deviation of ±10%. Further assessments of the correlation are made by comparing the predictions with measured data for R-12, R-134a, R-152a, R-410A, and R-600a in the open literature. The correlation predicts the data for those five refrigerants with average and standard deviations of ±0.73 and 6.16%, respectively.

P.K. Bansal et al. (1996) provided new selection charts for selecting the capillary tube size from the refrigerant mass flow rate and flow condition or for predicting the refrigerant mass flow rate through adiabatic capillary tubes from a given capillary tube size and flow condition. The mathematical model is developed from the homogeneous flow model and the governing equations are based on the basis of conservation of mass, energy, and momentum. The selection charts and flow correction factors are proposed for practical use. The developed selection charts are verified by comparing them with the limited available experimental data.

Chang Nyeun Kim et al. (2000) experimentally investigated the capillary tube performance for R-407. The experimental setup is a real vapor compression refrigerating system. Mass flow rate is measured for various diameters and lengths while inlet pressure and degree of sub cooling are changed. These data are compared with the results of numerical model. The mass flow rate of the numerical model is about 14% less than the measured mass flow rate. They found that mass flow rate and length for R-407C are less than those for R-22 under same conditions. They used the numerical method for finding the diameter and length by using the continuity equation, momentum equation and energy equation.

Dongsoo Jung et al. (2006) modeled pressure drop through a capillary tube in an attempt to predict the size of capillary tubes used in residential air conditioners. They provided simple correlating equations for practicing engineers. Stoecker's basic model was studied with the consideration of various effects due to subcooling, area contraction, and different equations for viscosity and friction factor, and finally mixture effect. McAdams' equation for the two-phase viscosity and Stoecker's equation for the friction factor yielded the best results among various equations. With these equations, the modified model yielded the performance data that are comparable to those in the ASHRAE handbook. After the model was validated with experimental data for CFC12, HFC134a, HCFC22, and R407C, performance data were generated for HCFC22 and its alternatives such as HFC134a, R407C and R410A under operating conditions such as condensing temperature (40, 45, 50,55 ^{0}C), subcooling (0, 2.5, 5 ^{0}C), capillary tube diameter (1.2±2.4 mm), and mass flow rate (5±50 g/s).These data showed that the capillary tube length varies uniformly with the changes in condensing temperature and subcooling. Finally, a regression analysis was performed to determine the dependence of mass flow rate on the length and diameter of a capillary tube, condensing temperature, and subcooling. Simple practical equations yielded a mean deviation of 2.4% for 1488 data obtained for two pure and two mixed refrigerants.

S. G. Kim et al. (2002) developed a dimensionless correlation on the basis of the experimental data of adiabatic capillary tubes for R22 and its alternatives, R407C R32/125/134a, 23/25/52 wt. %) and R410A (R32/125, 50/50 wt.%). Several capillary tubes with different length and inner diameter were selected as test sections. Mass flow rate through the capillary tube was measured for several condensing temperatures and various degrees of subcooling at the inlet of each capillary tube. Experimental conditions for the condensing temperatures were selected as 40, 45 and 50 ^{0}C, and the degrees of subcooling were adjusted to 1.5, 5 and 10 ^{0}C. Mass flow rates of R407C and R410A were compared with those of R22 for the same test conditions. The results for straight capillary tubes were also compared with those of coiled capillary tubes. A new correlation based on Buckingham-π theorem to predict the mass flow rate through the capillary tubes was presented based on extensive experimental data for R22, R407C and R410A. Dimensionless parameters were chosen considering the effects of tube geometry, capillary tube inlet conditions, and refrigerant properties. Dimensionless correlation predicted experimental data within relative deviations ranging from -12% to +12% for every test condition for R22, R407C and R410A. The predictions by the developed correlation were in good agreement with the results in the open literature.

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1430-1434 ISSN: 2249-6645

M. A. Akintunde et al. (2008) investigated the effects of various geometries of capillary tubes based on the coil diameters and lengths alone, with no particular attention placed on the effect of coil pitch. This paper examined the effects of pitches of both helical and serpentine coiled capillary tubes on the performance of a vapor compression refrigeration system. Several capillary tubes of equal lengths (2.03 m) and varying pitches, coiled diameters and serpentine heights were used. Both inlet and outlet pressure and temperature of the test section (capillary tube) were measured and used to estimate the COP of the system. In the case of helical coiled geometries, the pitch has no significant effect on the system performance. In the case of serpentine geometries, both pitch and height affects the system performance. Performance improves with both increase in the pitch and the height. Correlations were proposed to describe relationships between straight and coiled capillary tube and between helical coiled and serpentine coiled capillary tubes. The COP obtained was 0.9841 for mass flow rates of helical and serpentine with straight tubes, 0.9864 and 0.9996 for mass flow rates of serpentine and helical coiled tube respectively. This study investigated the performance of capillary tube geometries having R-134a as the working fluid.

M.A. Akintunde et al. (2007) concluded that some parameters such as friction factor, dryness fraction and Reynolds number affect the required length and diameter of a capillary tube for a given refrigeration capacity. The friction factors were based on the dryness fraction ranges between 0.05 - 0.85% and 0.5 - 1.9% above that of ASHRAE under the same conditions. Furthermore, both McAdams' and Duckler's equations for two-phase viscosity were employed so that the deviation in the estimated lengths could be compared. The tube lengths generated by combining various friction factor models with McAdams' equation are much closer to that of ASHRAE standard than those of Duckler's equation. The estimated lengths using McAdams' and Duckler's equations exceeded ASHRAE standard by 1.65% and 4.13% respectively. The required capillary tube length for a specified condenser condition depends on both Reynolds number and dryness fraction and not on either alone and these two factors should not be in exponential form. The generated lengths approach the ASHRAE requirement as the degree of sub cooling is increased.

Chun-Lu Zhang et al. (2004) had done parameter analysis, an insight into the flow characteristics of capillary tubes. Based on the approximate analytic solutions, influences of geometrical parameters (inner diameter and length) and inlet operating parameters (pressure, subcooling or quality) on the mass flow rate through an adiabatic capillary tube have been intensively studied in this work. Some simple theoretical relations were developed. The relations show that the mass flow rate is the power function of the geometries. Experimental data was supplemented by numerical data for R22, R410A and R407C.

Worachest et al. (2006) provided new selection charts for the sizing of adiabatic capillary tubes operating with alternative refrigerants. The mathematical model is based on conservation of mass, energy, and momentum of fluids in the capillary tube. After the developed model is validated by comparison with the experimental data reported in literature, selection charts that contain the relevant parameters are proposed for sizing adiabatic capillary tubes. The selection charts are presented for some alternative refrigerants and a wide range of operations. These newly developed selection charts can be practically used to select capillary tube size from the flow rate and flow condition or to determine mass flow rate directly from a given capillary tube size and flow condition.

M.K. Khan et al. (2008) developed a mathematical model to predict the performance of a helical capillary tube under adiabatic flow conditions. The proposed model can predict the length of the adiabatic helical capillary tube for a given mass flow rate or the mass flow rate through a given length of capillary tube. The effect of parameters like condensing pressure, degree of subcooling, pitch of helix and the coil diameter has been studied for the flow of refrigerant R-I34a through the adiabatic helical capillary tube. A capillary tube selection chart has been developed, using the proposed model, to predict the mass flow rate of refrigerant R-l 34a through a capillary of size 1.07 mm diameter and 2 m length.

S. M. Sami et al. (2001) experimentally investigated the capillary tube behavior, using various new alternatives under different geometrical parameters. Capillary geometrical parameters include length, diameter, as well as entrance conditions. The results clearly showed that the pressure drop across the capillary tube is significantly influenced by the diameter of the capillary tube, inlet conditions to the capillary and refrigerant type. The data demonstrated that the capillary pressure drop decreases with the increase of the capillary diameter and the alternatives of R-22 had higher pressure drop than that of R-22.

C. Melo et al. (1999) discussed the effect of capillary length, capillary diameter, refrigerant subcooling, condensing pressure and type of refrigerant on the mass flow-rates through the capillaries. The experiments were performed with three refrigerants such as CFC-12, HFC-134a and HC-600a, and at different condensing pressures and levels of subcooling under choked flow conditions. Eight capillaries with different combinations of lengths, diameters and tube roughness's were used, and extensive data was collected. A conventional, dimensional analysis was performed to derive correlations to predict the mass flow rates for different refrigerants.

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Conclusions

Earlier studies have shown that use of alternative refrigerants play an important role in forming problems such as global warming and ozone depilation. The coefficient of performance of refrigeration appliances improves in case of retrofitting with the spiral capillary tube. It is possible to obtain the effective size (diameter, length & coil pitch) of capillary tube by using of experimental techniques and by maintaining proper pressure equalization between condenser and evaporator. It is possible to predict about mass flow rate of refrigerant in spiral capillary tube. The influence of degree of subcooling, pressure and geometric parameters such as diameter, length, and coil pitch on the performance i.e. COP of the system and mass flow rate of refrigerant through capillary tube was reviewed in this paper.

References

1. B. G. Lee, J. Y. Park, J. D. Kim, and J. S. Lim, "A study on the performance of alternative refrigerant mixtures for HCFC-22CFC," Alternatives research center, Korea Institute of Science and Technology (KIST), Cheongryang, Seoul, South Korea, (2005), pp. 130-150.
2. L. B. Ortiz, S. Y. Motta, S. L. Braga, 2001 "Experimental analysis of adiabatic flow of non- azeotropic mixture R-407c through a capillary tube" Engenharia Termica, No. 1, pp. 41-46.
3. S. M. Sami, Shawn Aucoin, "Effect of magnetic field on the performance of new refrigerant mixtures," Int. J. Energy Res. 2003, 27, pp. 203–214.
4. Hira lal Sachdev, Akhilesh Arora, B.B.Arora, 2004, "Performance analysis of R-22 and its alternate refrigerants," M. Tech Thesis, Department of Mechanical Engineering, Delhi College of Engineering, University of Delhi.
5. M. K. Mittal, R. Kumar, A. Gupta, "An Experimental Study of the Flow of R-407C in an Adiabatic Spiral Capillary Tube," Journal of Thermal Science and Engineering Applications, Vol. 1, DECEMBER (2009), pp. 041003-041011.
6. Mohd Kaleem Khan, Ravi Kumar, Pradeep K. Sahoo, "An experimental study of the flow of R-134a inside an adiabatic spirally coiled capillary tube," International Journal of Refrigeration 31(2008), pp.970-978.
7. P. K. Bansal, A. S. Rupasinghe, "An Homogeneous Model for Adiabatic Capillary Tubes," Applied Thermal Engineering Vol. 18, No's 3-4(1998), pp. 207-219.
8. Jongmin Choi, Yongchan Kim, Ho Young Kim, 2003, "A generalized correlation for refrigerant mass flow rate through adiabatic capillary tubes," Int. J. Refrig., 26, pp. 881–888.
9. P. K. Bansal, A. S. Rupasinghe, "An empirical model for sizing capillary tubes," International Journal of Refrigeration, Volume 19, Issue 8, November (1996), pp. 497-505.
10. Chang Nyeun Kim & Young Moo Park, " Investigation on the Selection of Capillary Tube for the Alternative Refrigerant R-407C," International Journal of Air-Conditioning and Refrigeration Volume 8, May (2000), pp.40-49.
11. Dongsoo Jung, Chunkun Park, Byungjin Park, "Capillary tube selection for HCFC22 alternatives," International Journal of Refrigeration 22, (2006), pp. 604-614.
12. Kim, S. G., Ro. S. T., and Kim, M. S., 2002, "Experimental Investigation of the Performance of R22, R407C and R410A in Several Capillary Tubes for Air-Conditioners," Int. J. Refrig., 25, pp. 521–531.
13. M.A. Akintunde, Ph. D., "Effect of Coiled Capillary Tube Pitch on Vapor Compression Refrigeration System Performance," The Pacific Journal of Science and Technology Volume 9. Number 2. November (2008), pp. 284-294.
14. M.A. Akintunde, Ph. D., "The Effects of Friction Factors on Capillary Tube Length," The Pacific Journal of Science and Technology, Volume 8, Number 2, November (2007), pp. 273-281.
15. Chun-lu Zhang, Guoliang Ding, 2004, "Approximate analytic solutions of adiabatic capillary tube," Int. J. Refrig., 27, pp.17–24.
16. Worachest, Pirompugd, Wongwises, Somchai, 2006, "Capillary tube sizing charts for fluorine-based refrigerants," ASHRAE Transactions.
17. Khan. M.K., R. Kumar, and P.K. Sahoo. 2008, "A homogeneous flow model for adiabatic helical capillary tube," ASHRAE Transactions 114(1), pp.239-49.
18. S. M. Sami, P.E., H. Maltais and D. E. Desjardins, "Influence of Geometrical Parameters on Capillary Behavior with New Alternative Refrigerants," M.Tech Thesis, Department of Mechanical Engineering, School of Engineering University of Moncton, Moncton, NB, E1A 3E9.
19. Melo, C., Ferreira, R. T. S., Neto, C. B., Goncalves, J. M., and Mezavila. M.M., 1999, "An Experimental Analysis of Adiabatic Capillary Tubes," Appl. Therm. Eng., 19(6), pp. 669–684.