Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 14 (2012) 148 – 153

Energy Procedia

2011 2nd International Conference on Advances in Energy Engineering (ICAEE2011)

A review of development of micro-channel heat exchanger applied in air-conditioning system

Yanhui Han[a], Yan Liu[a], Ming Li[a]a*， Jin Huang[a]

College of Automotive Engineering, Jilin University, Chang Chun 130000, China

Abstract

Micro-channel heat exchanger(MCHX) has been increasingly applied in HVAC&R(Heating, Ventilation, and Air Conditioning & Refrigeration) field due to its higher efficiently heat transfer rate, more compact structure, lower cost. The characteristics of micro-channel heat transfer and fluid dynamics are summarized in this paper. The methods about optimizations (ie, geometry and thermodynamic performance) and the advantages and disadvantages of the MCHX are analyzed.

Keywords: Micro-channel Heat Exchanger; Flow characteristics; Heat Transfer Characteristics

1. Introduction

Heat exchanger with reliable and high performance has been the study focus of the refrigeration and air conditioning system. In recent years, with increasing demand for lightweight and rising copper prices, copper substitution is also a widespread concern. Under the premise of meeting the heat exchange remand, micro-channel heat exchanger can reduce equipment weigh, improve the device compact. The manufacturing costs can be reduced and the product competitiveness can be improved by using aluminums. Micro-channel heat exchanger has been extensive researched and applied in cooling of electronic equipment. Along with the improving of process technology, micro-channel technology is gradually used in household air conditioning and automotive air conditioning system.

The concept of micro-channel heat exchanger was first proposed and used by Tuckerman and Pease[1] in 1981.Micro-channel heat exchanger is defined by Mehendale.S.S as if the hydraulic diameter of heat

* Corresponding author. Tel.: 86-0431-85095196.
E-mail address: limingtiger@jlu.edu.cn.

doi:10.1016/j.egypro.2011.12.910

exchanger is less than 1mm. Micro-channel heat exchangers for heat exchanging between two different fluids was first developed out by the Swift in 1985[2].

To meet the rapid development of modern microelectronic mechanical requirements of heat transfer, micro-channel heat exchangers began to be used in cooling high-density electronic devices in the 1980s, then appeared in the MEMS(microelectronic mechanics system) industry in the 1990s. With studies on properties of micro-channel in depth and application in the promotion of electronic cooling,advantages of micro-channel heat exchanger which a traditional heat exchanger can not match gradually appear. And micro-channel heat exchanger began to enter the refrigeration and air conditioning industry. At present, the micro-channel heat exchanger has been applied in automotive air conditioning system. In household air conditioner field, technology of micro-channel heat exchanger applied in single-cold air-conditioner condenser has gradually matured, however, this technology face big challenges, such as complex gas-liquid two-phase uniform streaming[3]

2. Researches and advances in abroad

1.1 Researches in flow dynamics and heat transfer characteristics of micro-channel heat exchanger.

Compared with the conventional heat exchanger, micro-channel heat exchanger is very different in flow characteristics and heat transfer characteristics due to structural and other differences. Some phenomena and new laws in the emergence in Micro-channel can be attributed to scale effects. Reduced scale leads to enhance fluid compressibility effects[4]; the increased roughness leads to increase the drag coefficient[5,6]; as surface area to volume ratio increasing, the effects of the force associated with the area (surface forces, viscous forces, etc.) in micro-channel will be strengthened[7], and enhances the impact of axial heat conduction of micro-channel wall[8-10]. Many foreign scholars are on the exploratory investigation of heat transfer characteristics and flow characteristics in micro-channel heat exchanger.

In 2003, Qu et al[11] from Purdue University developed an annular flow model, made a measurement of the saturated flow boiling heat transfer coefficient in water-cooled micro-channel heat sinks, and captured the trend by the experimental data that heat transfer coefficient decreasing with increasing vapor quality in the low vapor quality region of micro-channels. In 2004, Re'mi Revellin et al[12] from Ljubljana University made researches on two-phase flow characteristics of R-134a as refrigerant in 0.5mm channel, and summed up the relationship between mass flow and vapor quality in four different flow patterns. In the same year, G. Hetsroni[13] from Israel respectively compared some different laboratory condition, such as compressible fluid and single-phase gas, smooth wall and rough wall, laminar and turbulent conditions to analyze the flow characteristics of liquid and gas flow in micro-channels under conditions of a small Knudsen and Mach numbers. Gian Luca Morini[14] from the University of Bologna, Italy, found that in the previous literatures, a good agreement was achieved between the experimental data of friction coefficient f and Nusaier number Nu of Single-phase flow experimental and traditional theory calculations, but there were inconsistencies between the f and Nu. In 2005, MJ Kohl et al[15] from Georgia Institute of Technology conducted experiments about straight channel test sections under conditions of channel hydraulic diameters ranging from 25 to 100 μm, and obtained the pressure drop experimental data that $6.8 < Re < 18814$ of compressible fluid, $4.9 < Re < 2068$ of incompressible fluid. In 2009, Harirchian et al[16] from Purdue University conducted experiments with a perfluorinated dielectric fluid (Fluorinert FC-77) as working medium, and parallel micro-channels whose widths ranging from 100 to 5850 μm, all with a depth of 400 μm, and the experiment results shown that the width over 400 μm, the heat transfer coefficient was almost invariant with channel size. In the same year, Licheng Sun[17] from Kyoto University in Japan analyzed 13 kinds predicted correlation of saturated flow boiling heat transfer in micro-channel, and made a comparison with the latest 2009 data in the database, found that the Lazarek–

Black correlation and the Kew–Cornwell correlation were of best two methods. By introducing Webber number, he modified the Lazarek–Black correlation, made its applicability extended and the error domain reduced. In 2010, Cristiano Bigonha Tibiriçá[18] from University of Sáo Paulo, Philippines, choose standard stainless steel pipe with 2.3mm diameter, and R134a and R245fa as working fluid, conducted experiments at high-speed film flow pattern. The experimental results shown that heat transfer coefficient increasing with increased the heat flux, mass velocity, and saturation temperature.

1.2 Micro-channel heat exchanger optimization

The traditional heat transfer performance can be improved by using the micro-channel structure. The micro-channel geometry and size have significant impact on the performance of heat exchanger. Therefore, there will be great significance to explore the optimal structure of micro-channel during the micro-channel heat exchanger design.

In1991 and 1992, RW Knight[19,20] optimized the structure of micro-channel heat exchanger by reducing the maximum thermal resistance under conditions of given pressure drop. Then 1998 Haim H. Bau[21] from Pennsylvania University, in 2004 Professor Sung Jin Kim[22] from institute of Science and Technology of Korea, also developed the thermal resistance minimizing method to optimize the thermal resistance, and to minimize micro-channel heat exchangers. In 2005, Kandlikar et al[23] from United States Rochester Institute of Technology optimized micro-channels by minimizing the pressure drop index analysis, Jang et al[24] optimized micro-channels by developing a new software to calculate the parameters, Kwasi Folid[25] from Honda Research Institute optimized micro-channels by CFD(computational fluid dynamics) and analytic solutions. In 2006, Waqar Ahmed Khan et al[26] from University of Waterloo in Canada, optimized micro-channel heat exchanger by entropy production reducing method. Before 2006, most majority studies were focus on the isolation of heat exchanger equipment optimization, from 2006 Madhusudan Iyengara et al[27] from Purdue University explored to optimize the entire system including the micro-channel heat exchangers, pumps, air flow baffles, fins, fans or blowers etc. In 2007, T.Bello-Ochende[28] from University of Pretoria obtained the optimal geometry (the aspect ratio and the optimal channel shape) by using the Finite Element Modeling (FEM) method. In the same year, K. Hooman[29] referred to Darcy-Brinkman flow model, and optimized heat transfer, pressure drop, entropy production problem in saturated porous rectangular tube. In 2009, Afzal Husain[30] from Inha University applied response surface approximation to optimize the micro-channel heat exchanger, and obtained the optimal aspect ratio and channel geometry. In the same year, Laxmidhar Biswal[31] from Indian proposed a systems analysis method (mathematical analytic method) to design and optimize laminar single-phase liquid cooled micro-channel heat exchanger.

2 Research and development in China

Foreign scholars have conducted many experiments on micro-channel heat exchanger, and obtained numerous experiment data of different conditions. Theoretical studies about micro-scale heat transfer and flow mechanism also have been developed. Researches in China about micro-channel heat exchangers are less and later, however， researchers from Tsinghua University have some more in-depth researches on micro-scale heat transfer theory.

In 2000, Professor Guo[32] from Tsinghua University proposed matters needing attention when exploring scale effect, and documented the mechanism of micro-scale heat conduction, micro-scale flow and micro-scale convection. Dongxing Du[4] from Tsinghua University analyzed the impacts of compressibility on gas flow and heat transfer characteristics in micro-channel and documented the resistance characteristics in micro-roughness incompressible pipe flow. In 2002, Luo[33] from Tsinghua

University obtained the numerical results of natural convection in a rectangular structure under the conditions of considering the radiation heat transfer at room temperature. In 2003, Wang Wei et al[6] obtained results of the numerical calculation by simulation laminar flow between rough surface micro-scale plate, explored the impacts of the density and the layout of roughness elements on fluid flow. Tsinghua University, Li and Guo[34] expounded the physical mechanism of micro-scale flow and heat transfer on the scale effects during 2003 micro-nano manufacturing technology symposium. In 2009 Huiyong Zhang et al[35] from Tsinghua University analyzed the prediction accuracy about the existing heat transfer and pressure drop correlation, summed up the various factors impacted on performances of louver fin micro-channel heat exchanger.

In 2004, Fuqin Ma[36] from The Zhongyuan Institute of Technology, combined with theory of trans-critical cycle and the heat transfer characteristics inside the heat exchanger, estimated design load of micro-channel heat exchanger used in CO2 vehicle air conditioner. Then she[37] combined with micro-channel characteristics and CO2 characteristics, proposed design philosophy about heat exchanger size, material selection, dehumidifier etc. huanling Liu[38] from Xidian University to established three-dimensional micro-channel heat transfer model, analyzed the micro-channel flow field and temperature field, then proposed a correction method based on macro-theory by comparing simulation results with existing experimental data. In 2007, Shangmei Su[39] from Shandong University, in 2008 Haiming Yang et al[40] from China Electronics Technology Group Corporation, in 2009 Xiaoguang Xu[41] from Nanjing University conducted experiments on heat transfer characteristics of fluid flow characteristics of micro-channel heat exchangers. In 2009, Rao[42] from Guangzhou U.S. Air Wing Water Company, conducted experimental studies by ETL Enthalpy Room, explored how the Air flow and flow path design effect on the micro-channel heat exchanger heat transfer quantity of air conditioning system, and verified the impacts of the whole design of the ventilation on micro-channel heat exchanger.

The analysis mentioned above shows that technologies of micro-channel heat exchanger developed rapidly in China and international. However, many studies are concentrated on the differences of heat transfer mechanism between micro-channel and macro channel(size> 1mm) and the analysis of flow and heat transfer characteristics. Although exploratory development of influencing factor (channel shape, wall roughness, fluid quality, the surface over heat, the mean free path and the channel size ratio[39], etc.) of the micro-channel heat exchanger have gradually increased, but the comprehensive study of micro-channel flow and heat transfer is still in early stages, the theoretical system has not yet formed completely and maturely. The analysis of experimental results about similar issues and similar phenomena has not been uniform. Meanwhile, the application conditions of acquired predicted correlation has been restricted, and the amendment problems have not yet resolved, while universal and extensive-use predicted- correlation has not appeared yet.

3 Conclusions

In recent years, micro-channel heat exchanger has been more widely applied in the refrigeration and air conditioning industry and researches related to such theory and problem has attracted the world-wide attention. Before designing the micro-channel, the pressure loss and heat transfer characteristics must be accurately predicted, while the theoretical basis which can accurately guide the design is not yet mature and there is no uniform industry standard in manufacturing. However, it is believed that with the study of micro-channel heat exchanger performances in-depth, optimization of heat transfer structure and existing problems in manufacturing and applications will be resolved, micro-channel heat exchanger will be more widely used.

Acknowledgements

The authors gratefully acknowledge the financial support from the Basic Research Foundation from Jilin University under the grant No. 201103173.

References

[1] D. B. Tuckerman and R. F. W. Pease, "High-performance heat sinkingfor VLSI," IEEE Electron Device Lett., vol. EDL-2, no. 5, pp. 126–129,May 1981.

[2]Swift; Migliori ; Wheatley, CONSTRUCTION OF AND MEASUREMENTS WITH AN EXTREMELY COMPACT CROSS-FLOW HEAT EXCHANGER ,Heat Transfer Engineering, v 6, n 2, p 39-46, 1985

[3]H.Y.Zhang, M.J.Li, B.X.Wang, application of microchannel heat exchanger in the household air-conditioning, Heating Ventilating And Air Conditioning(HV &AC) 2009 ,Volume 39(9)

[4]X.D.Du, Affect of compressibility and roughness on the micro-pipe flow and heat transfer, PhD thesis, Tsinghua University,2000

[5]Guo Z Y, Li Z X， size effect on single-phase channel flow and heat transfer at microscale, Int.J Heat and Fluid Flow.2003,(24):284-298

[6]W.Wang, Z.X.Li, Z.Y.Guo, Numerical Analysis of Rough surface effect on the microscale flow, Journal of Engineering Thermophysics 2003，24(l):85-87

[7] Guo Z Y, Characteristics of microscale fluid flow and heat transfer MEMS. Proceeding of the international conference on Heat and Transport phenomena in microscale, Banff Canada ,2004:24~31

[8]Li Z X ,Wang W, Guo Z Y. Effects of axial heat conduction in wall on convection inmicrotubes.Conf.on Microchannels and Minichannels, April24-25,2003,Rochester,New York ,USA,2003:327~333

[9]Mori S,Sakakibara. Steady heat transfer to laminar flow in a circular tube with conduction in tube wall. Heat Transfer-Jpn.Res,1974,3(2):27-46

[10]Shah R K, London A Laminar flow forced conduction in ducts. Advances in Heat Transfer ,Acadernic Press,New York,San Francisco,London,1978

[11] Weilin Qu, Issam Mudawar ,Flow boiling heat transfer in two-phase micro-channel heat sinks—II. Annular two-phase flow model, International Journal of Heat and Mass Transfer 46(2003) 2773-2784

[12]Remi Revellin, Vincent Dupont,Characterization of diabatic two-phase flows in microchannels: Flow parameter results for R-134a in a 0.5 mm channel,International Journal of Multiphase Flow 32 (2006) 755–774

[13]G. Hetsroni *, A. Mosyak,Fluid flow in micro-channels G，International Journal of Heat and Mass Transfer 48 (2005)

[14] Gian Luca Morini, Single-phase convective heat transfer in microchannels: a review of experimental results, International Journal of Thermal Sciences 43 (2004) 631–651

[15] M.J. Kohl, S.I. Abdel-Khalik, S.M. Jeter, D.L. Sadowski,An experimental investigation of microchannel flow with internal pressure measurements, International Journal of Heat and Mass Transfer 48 (2005) 1518–1533

[16] Tannaz Harirchian, Suresh V. Garimella, Effects of channel dimension, heat flux, and mass flux on flow boiling regimes in microchannels, International Journal of Multiphase Flow 35 (2009) 349–362

[17] Licheng Sun, Kaichiro Mishima, An evaluation of prediction methods for saturated flow boiling heat transfer in mini-channels, International Journal of Heat and Mass Transfer 52 (2009) 5323–5329

[18] Cristiano Bigonha Tibiriçá, Gherhardt Ribatski,Flow boiling heat transfer of R134a and R245fa in a 2.3 mm tube, International Journal of Heat and Mass Transfer 53(2010)2459-2468

[19] R. W. Knight, J. S. Goodling, and D. J. Hall, "Optimal thermal design of forced convection heat sinks-analytical," J. Electron. Packaging, vol. 113, no. 3, pp. 313–321, 1991.

[20] R. W. Knight, D. J. Hall, J. S. Goodling, and R. C. Jaeger, "Heat sink optimization with application to micro-channels," IEEE Trans. Compon. Hybrids Manuf. Technol., vol. 15, no. 5, pp. 832–842, Aug. 1992.

[21]Haim H. Bau， Optimization of conduits' shape in micro heat exchangers， International Journal of Heat and Mass Transfer 41 (1998) 2717-2723

[22] Sung Jin Kim ,Methods for Thermal Optimization of Micro-channel Heat Sinks, Heat Transfer Engineering Volume 25, Issue 1, 2004, Pages 37 - 49

[33] S. G. Kandlikar and H. R. Upadhye, "Extending the heat flux limit with enhanced microchannels in direct single-phase cooling of computer chips," in Proc. IEEE 21st Annu. Symp. Semiconductor Thermal Meas. Manage., Mar. 15–17, 2005, pp. 8–15.

[24]KwasiFoli,TatsuyaOkabe,MarkusOlhofer,YaochuJin,BernhardSendho.Optimization of micro heat exchanger :CFD, analytical approach and multi-objective evolutionary algorithms. International Journalof Heat and Mass Transfer49(2006)1090¨C1099

[25] S. P. Jang and S. J. Kim, "Fluid flowand thermal characteristics of a microchannel heat sink subject to an impinging air jet," J. Heat Transfer, vol. 127, no. 7, pp. 770–779, 2005.

[26]Waqar Ahmed Khan, J. Richard Culham, Optimization of Microchannel Heat Sinks

[27]Madhusudan Iyengarand and Suresh Garimella，DESIGN AND OPTIMIZATION OF MICROCHANNEL COOLING SYSTEMS

[28]T.Bello-Ochende,L.Liebenberg,J.P.Meyer.Constructalcoolingchannelsformicro-channelheatsinks. InternationalJournalofHeatandMassTransfer50(2007)4141—4150

[29]K. Hooman, H. Gurgenci, Heat transfer and entropy generation optimization of forced convection in porous-saturated ducts of rectangular cross-section，International Journal of Heat and Mass Transfer 50 (2007) 2051–2059

[30] Afzal Husain，Kwang-Yong Kim，Thermal Optimization of a Microchannel Heat Sink With Trapezoidal Cross Section，J. Electron. Packag. 131, 021005 (2009)

[31]Laxmidhar Biswal, Suman Chakraborty, and S. K. Som，Design and Optimization of Single-Phase Liquid Cooled Microchannel Heat Sink，IEEE TRANSACTIONS ON COMPONENTS AND PACKAGING TECHNOLOGIES, VOL. 32, NO. 4, DECEMBER 2009

[32]Z.Y.Guo, International Heat Transfer Introduction - micro-scale heat transfer, Journal of Mechanics 30（1），2000.2.25

[33]X.B.Luo, Flow and heat transfer in Micro inertial fluid device and application, PhD thesis, Tsinghua University，2002

[34]Z.X.Li,Z.Y.Guo, The scale physical mechanism of Micro-scale flow and heat transfer effects of and its application, Micro-nano manufacturing technology seminar，2003:151~161

[35] H.Y.Zhang, M.J.Li, B.X.Wang, application of microchannel heat exchanger in the household air-conditioning, Heating Ventilating And Air Conditioning(HV &AC) 2009 ,Volume 39(9)

[36]F.Q.Ma,J.B.Wu,J.wang, CO2 car air conditioning theory with compact design of heat exchanger, ISSN1005—9180(2OO4)04 一 OO69—04

[37] F.Q.Ma,J.B.Wu,J.wang, CO2 car air conditioning with micro-channel heat exchanger design technical，Journal of Nanyang Normal University,2004 3(9)

[38]H.L.Liu, Study on Microchannel heat exchanger, Xi'an University of Electronic Science and Technology Master thesis,2004.1

[39]S.M.Su, Y.N.Zhang, Characteristics analysis and application prospects of micro-channel heat exchanger, District Heating 2007.5

[40]H.M.Yang,K.Z.Zhang,J.Y.Zhnag Study on flow and heat transfer characteristics of Microchannel heat exchanger, Low-temperature technology, 36 (10)

[41]Xiaoguang Xu, Experimental and Theoritial Investigation on Pressure Drop and Heat Transfer Flow Boiling in Microehannel Nanjing University of Science & Teehnology 2009.6

[42]Rongshui Rao,Junwei Cheng， Applied Research of Microchannel heat exchanger on the air conditioner，REFRIGERA TION AND AIR - CONDITIONING 2009 09(4)