

Research Progress and Application Prospect Of Microchannel Heat Exchangers

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Abstract. A Micro-channel heat exchanger gradually replaces traditional heat exchanger with the advantages of high heat exchange efficiency, fast heating speed, good controllability, low noise, stable operation, good pressure bearing capacity and cost saving. The thesis summarizes the research progress and development prospects of the microchannel heat exchanger. Summarized and elaborated on the unparalleled advantages of microchannel heat exchangers compared to conventional sized equipment which is compared with the regular size equipment. Moreover application fields and prospects of the microchannel heat exchanger are analyzed from the point of energy saving and space occupancy. The thesis has some reference value for the research of micro heat exchangers.

Keywords: Microchannel; Heat exchanger; Heat transfer characteristics; Phase change.

1. Introduction

A Microchannel heat exchanger is a three-dimensional structural unit that can be used for heat transfer, manufactured with a solid matrix using special microfabrication technology. The current precise definition of microchannel heat exchangers is commonly and intuitively classified based on the size of their hydraulic equivalent diameter. Heat exchangers with a hydraulic equivalent diameter less than 1mm are commonly referred to as microchannel heat exchangers.

The heat exchanger of air conditioning has evolved from tube fin heat exchangers to tube belt heat exchangers and microchannel heat exchangers to improve the performance of air conditioning systems. Microchannel heat exchangers first appeared in the field of electronics. The degree of integration of electronic products is increasing and the heat dissipation of electronic components has become the most challenging problem with the advancement of technology and the updating of processing methods. Therefore, people have also applied micro technology to the field of heat sinks. Microtechnology can greatly improve the heat and mass transfer efficiency of process mechanical devices. Due to the fine scale, increased area to volume ratio and enhanced surface interaction, the transfer effect is significantly enhanced, which is 2~3 orders of magnitude higher than conventional scales.

Microchannel heat exchangers have emerged with the demand for high-performance, small volume electronic products. Microchannel heat exchangers have the characteristics of compact structure, high heat transfer efficiency, light weight and safe and reliable operation. Due to the unparalleled advantages of microchannel heat exchangers compared to many conventional sized equipment, research and application of microchannel heat exchangers have developed rapidly in recent years.

2. Development progress of microchannel heat exchangers

When it comes to phase change heat transfer, it is customary to refer to channels with an equivalent diameter of 3mm or less collectively as microchannels or microfine channels. We call it a microchannel heat exchanger when the channel of a heat exchanger is a microchannel.

American scholars Tuck erman and Pease reported a microchannel heat transfer structure as shown in Figure 1 as early as the 1980s. This structure is composed of materials with high thermal

conductivity such as silicon and its heat transfer process involves adding heat to the bottom and transferring it through the channel wall to the inside of the channel. Its heat transfer performance exceeds the level that traditional heat transfer methods can achieve, successfully solving the “thermal barrier” problem caused by large-scale and ultra large scale integrated circuits. Subsequently, Wu, Little, Pfahler, Choi and others analyzed and studied the single-phase flow in the channel. The microchannel heat exchanger used for heat exchange between two fluids was developed by Swift in 1985. Research has shown that the unit volume heat transfer of its microchannel heat exchanger can reach several tens of $\text{MW}/(\text{m}^2 \cdot \text{K})$. The Pacific North-West National Lab successfully developed micro devices and micro heat pumps that integrated combustion/gasification in the late 1990s. The Forschungszentrum Karlsruhe GmbH is also using devices that have undergone ultra fine turning with forming tools to connect them to form cross flow and counter flow micro heat exchangers.

Tuekennan D.B and Pease R.W. [1] developed a water-cooled ribbed heat sink to solve the heating problem of electronic components. The heat sink is made of silicon and features a rectangular channel with a width of $50\mu\text{m}$, deep $300\mu\text{m}$ and heat dissipation of $790\text{W}/\text{cm}$. Since then, many researchers have started researching microchannel heat sinks for electronic product cooling. The research mainly focuses on the following aspects: ① Research on the shape of heat exchangers: studying the influence of rectangles, triangles, single or multiple layers on heat transfer. ② Research on microscale heat transfer performance: studying the similarities and differences between microscopic and macroscopic heat transfer theories. ③ Research on the optimal size of microchannel heat exchangers.

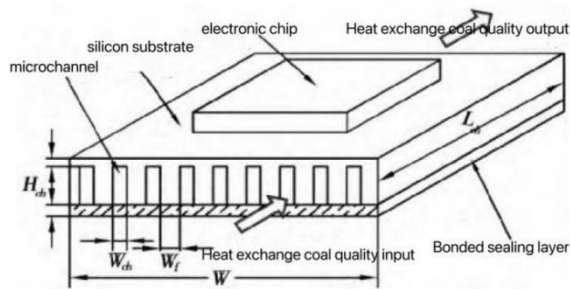


Fig.1 Basic structure of microchannels

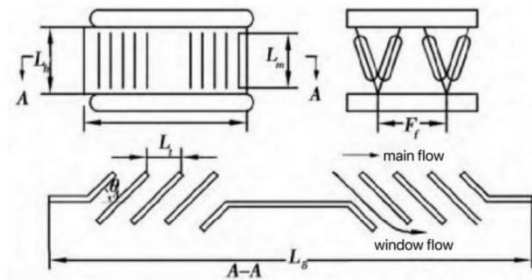


Fig.2 Schematic diagram of louver structure

Bao Tao et al. [2] established a mathematical model for a parallel flow condenser with corrugated louver fins with discontinuous extended surfaces on the air side and non circular microchannel porous aluminum flat tubes with small hydraulic diameters on the refrigerant side, using heat transfer and pressure drop correlation equations suitable for this microscale enhanced heat transfer structure and conducted numerical simulations under certain operating conditions. The result analysis shows that during the condensation process of refrigerant in non circular cross-section microchannels, the surface tension has a significant strengthening effect on the surface coefficient; The flow cross-section during the condensation process can be adjusted to achieve the effect of adjusting the flow rate by changing the number of processes and tubes, thereby maintaining a higher condensation heat transfer coefficient and lower flow pressure drop. It has significant advantages compared with conventional heat exchangers.

Zhang Xingqun et al.[3] conducted theoretical and experimental analysis on the thermal performance of parallel flow condensers, identified the factors that affect the thermal performance of parallel flow condensers and it is believed that there exists a critical wind speed for condensers with a certain structure. The air side resistance increases sharply and the heat transfer tends to be constant when the wind speed exceeds the critical wind speed; Reducing the height of the fins can increase the heat transfer of the heat exchanger within a certain range; Reducing the spacing between fins increases the heat transfer area and enhances the heat transfer capacity of the condenser but increases the resistance on the air side at the same time; A reasonable distribution of the number of flat tubes between processes can increase the heat transfer of the condenser while

reducing the pressure drop on the air side; Any optimization measures are not unilateral and must consider their impact on other parameters.

Deng D, Wan W, Tang Y, et al.[4] established a microchannel heat exchanger model, calculated the heat transfer coefficient and pressure drop on the refrigerant side and air side and compared the calculation results with experimental data under 48 different operating conditions. The results showed that the calculation error of the heat transfer performance of the model was within 2% and the error of the refrigerant side pressure drop was also within the allowable range.

Sahar A M, Wissink J, Mahmoud M M, et al.[5] conducted experimental research on the convective heat transfer coefficients of transcritical carbon dioxide flow in horizontal and vertical microchannel circular tubes. The heat transfer performance of microchannel circular tubes with different inner diameters was experimentally measured under different pressures, temperatures and mass flow rates. A new Nusselt number correlation equation suitable for microchannels was created based on experimental data.

Liang Yuanyuan, Xu Bo, Chen Jiangping[6] conducted experimental and numerical simulations on the microchannel condenser and tube fin condenser of a household split air conditioning system using R410A. The two condensers in the study have the same shape, windward area, volume and fin spacing. Comparing different condensers used in the same system, it was found that the cooling capacity of the system using microchannel condensers increased by 3.4% and the operating energy efficiency of the system increased by 13.1% compared to COP when the indoor temperature is 26.7°C and the outdoor temperature is 35.0°C. The condensation temperature of the system decreased by 2.5°C due to the increase in heat transfer area on the refrigerant side and air side of the microchannel condenser. In addition, the refrigerant side pressure drop of the microchannel condenser has decreased from 166kPa to 57kPa due to the increase in the cross-sectional area of refrigerant flow and the shortening of the process.

3. Application fields of microchannel heat exchangers

3.1 Application of Microchannel Heat Exchanger in Automotive Air Conditioning

Microchannel heat exchangers are used in the condensers and evaporators of automotive air conditioners at present. Its lightweight, high heat transfer coefficient and corrosion resistance perfectly meet the demand for high-performance heat exchangers in automotive air conditioning.

The operating environment of car air conditioning is quite special and the operating conditions are relatively harsh. At the same time, the heat exchanger of car air conditioning must have characteristics such as compact structure, high heat transfer efficiency, light weight, low resistance on the refrigerant and air sides, easy installation, durability and safe and reliable operation due to factors such as internal space and installation and maintenance. The structure of automotive air conditioning condensers has gone through main structural forms such as tube and strip and parallel flow. The parallel flow heat exchanger was originally a patented product of Modin Corporation in the United States, used to replace the tubular condenser of automotive air conditioning. Later it was called a multi-component parallel flow condenser after Japanese companies such as Showa Aluminum added baffles in the two end headers to form different circuits. The pressure drop on the refrigerant side of the advection condenser decreases by only 20% to 30% of that of the tube and strip condenser under the same windward area. The overall heat transfer performance is more than 30% higher than that of the tube and strip type.

3.2 The application of microchannel heat exchangers in household air conditioners

Microchannel heat exchangers can be applied to household air conditioners in various structural forms. Heat exchange tubes generally use strip shaped aluminum tubes with multiple microchannels, and there are various forms of ribs: plate shaped ribs, slotted ribs, staggered ribs and louver ribs. The louver microchannel heat exchanger has received the most attention at present and its structural diagram is shown in Figure 2.

Liu X, Zhang H, Zhu C, et al[7] compared the performance of room air conditioners using R22 as refrigerant when using microchannel condensers and tube fin condensers respectively. The research results indicate that compared with tube fin condensers, microchannel condensers have a unit volume heat flow rate that is 14% -33% higher. The refrigerant usage, condenser volume and condenser weight of the microchannel heat exchanger were reduced by 35%, 55% and 35% respectively at the same time.

Deng D, Chen L, Wan W, et al.[8] experimentally tested the performance of split type air conditioners using microchannel heat exchangers and spin fin heat exchangers, respectively, with R22 as the refrigerant and a cooling capacity of 10.5 kW. The experimental results show that using a microchannel heat exchanger reduces the windward area by 23% and the refrigerant volume by 32%. Using microchannel heat exchangers increases the COP of the system by 1% to 6% in refrigeration mode.

Gu Jiayang [9] conducted comparative experiments by installing an all aluminum microchannel heat exchanger and a conventional copper tube aluminum fin heat exchanger on the outdoor unit of AADS-040 split unit air conditioning. The weight and refrigerant usage of microchannel heat exchangers are only 1/4 and 1/2 of those of conventional heat exchangers respectively under the same cooling capacity. In summary the application of microchannel heat exchangers in household air conditioning can effectively improve heat transfer efficiency, reduce volume and weight, reduce refrigerant usage and improve overall air conditioning performance.

The technology of using microchannel heat exchangers for the condenser of single cooling air conditioners has become mature but microchannel evaporators are not yet mature due to the uniform separation of gas-liquid phases and the removal of defrosting water under heat pump conditions in household air conditioners.

3.3 Application of microchannel heat exchangers in CO₂ transcritical refrigeration systems

The gas cooler in the carbon dioxide transcritical cycle has gone through a development process from tubular to microchannel heat exchangers. Scientists have discovered the phenomenon of thermal short circuit in tubular air coolers in the research process of carbon dioxide transcritical cycle. Zeng S, Lee P S [10] from the Norwegian University of Science and Technology proposed the use of microchannel heat exchangers in transcritical carbon dioxide systems To overcome the weakness of finned air coolers. The microchannel heat exchanger is a compact and efficient heat exchanger composed of flat tubes and fins, which increases the refrigerant side area by about three times compared to the traditional round tube flat fin design. The pressure drop on the air side is reduced, the air side wind speed is increased and the air side heat transfer coefficient is increased due to the streamlined shape of the flat tubes.

The weakness of microchannel heat exchangers is the presence of significant flow resistance, but due to the low viscosity of CO₂, the pressure drop generated by the lower viscosity is smaller, allowing for a larger mass flow rate of CO₂ to be designed. On the other hand, microchannels are also more suitable for higher operating pressures, which is consistent with CO₂ high-pressure refrigeration systems. Higher operating pressures can withstand significant pressure drops and have little impact on changes in evaporation temperature.

3.4 The application of microchannel heat exchangers in the petrochemical industry

Microchannel heat exchangers have small channel sizes and much higher heat exchange efficiency than traditional heat exchangers. They can be made smaller, saving equipment space and making them easy to maintain and replace. Therefore, microchannel heat exchangers are widely used in the petrochemical industry, greatly improving the efficiency and safety of the petrochemical process. The main applications include heating and cooling, evaporation and condensation and temperature control during reaction process.

3.5 Application of microchannel heat exchangers in other fields

The excellent performance of microchannel heat exchangers has rapidly expanded their application areas. The heat exchanger of compressed condensing units is still a tube fin heat exchanger and the energy efficiency of the system is not high in the field of industrial refrigeration, resulting in serious energy waste in the entire industry. Applying microchannel heat exchangers to compression condensing units can not only improve the energy efficiency ratio of the units, enhance product competitiveness, but also save industrial refrigeration energy consumption and promote energy conservation in the refrigeration and air conditioning industry. It is widely used in microelectronics, aerospace, medical, chemical and biological engineering, materials science, cooling of high-temperature superconductors, thermal control in thin film deposition, cooling of high-power laser mirrors and other occasions with special requirements for the size and weight of heat exchange equipment; especially in the trial operation of micro nuclear reactors, the trial navigation of fuel cell powered submarines, the application of micro turbine machinery and micro chemical instruments, miniaturized heat exchange devices have played an important role as equipment for corresponding systems.

4. Conclusion and Outlook

With the development of micro electromechanical systems and micro chemical mechanical systems, traditional heat exchange devices can no longer meet the basic requirements of application systems at present. The development of miniaturization of heat exchange devices has become an urgent requirement and inevitable trend. In addition with the increasing prominence of energy issues, it is also required to minimize equipment volume as much as possible while meeting heat exchange requirements, that is, to improve equipment compactness, thereby reducing equipment weight, saving materials and correspondingly reducing footprint.

Although there are still many difficulties in the design, manufacturing, assembly, sealing technology and parameter measurement (non-contact measurement technology) of microchannel heat exchangers, with a large number of experiments and numerical simulations to improve and optimize their structure, performance, and design research, microchannel heat exchangers will become increasingly mature and a new type of equipment with broad application prospects.

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