CFD SIMULATION OF COMPACT TYPE MINI CHANNEL HEAT EXCHANGER BY USING WATER – A REVIEW

P.J.Pan*

N.S.Patel**

Abstract

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In the conventional heat exchangers, pipes are larger in size which makes heat exchanger bulky. But in some typical applications such as closed loop gas turbine heat exchangers, cryogenic applications, heat exchangers used in PWR power plants, nuclear submarines, etc., size and weight are critical design constraints on the heat exchanger. Also for high pressure applications tubes are subjected to high bending stresses. To overcome these difficulties, compact heat exchangers can be employed. Mini channels heat exchanger is a type of compact heat exchanger in which mini channels are machined on metal plates and then such plates are bonded together. Such an arrangement provides high strength so that it can be used for high pressure applications. It has been observed that in mini channels, convective heat transfer coefficient is more than the tubes used in conventional heat exchangers. Hence, the length for same heat transfer is greatly reduced which results in reduced overall size and weight of the heat exchanger. Electronic device are in heavy demand for computer processor applications and generate large amount of heat. These high power device can be cooled off very effectively by either liquid or gas coolant flowing through micro or mini channels. Continuous research work is ongoing for developing high speed processor which

* M.E. Student, Department of Mechanical Engineering, Government Engineering College, Dahod,, Gujarat, India

** Assistant Professor, Department of Mechanical Engineering, Government Engineering College ,Dahod, Gujarat, India

generate high amount of heat. Cooling of such particular systems requires high amount of mass flow rate and compactness is also required. In present work, a mini channel heat exchanger is designed with assuming inlet and outlet of hot temperature, inlet of cold water temperature and also the mass flow rates of cold and hot water. This compact heat exchanger can be used for cooling purpose of electronics device like silicon chip which would be used for microprocessor. In order to cool down silicon chip, it is kept in place of hot fluid plate. Cooling of silicon chip is required to prevent from damage and subsequently failure. The heat exchanger is designed for 10°C temperature drop of hot fluid.

.***Keywords***–*Thermal energy, Size & Weight, Cooling purpose of microprocessor, Silicon chip.*

1. Introduction

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions.

In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak .Such exchangers are referred to as direct transfer type, or simply recuperate. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching.

Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. Common examples of heat exchangers are shell and tube exchangers, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers.

The convection and conduction principle of heat transfer is mainly employed in the design and manufacturing of a heat exchanger. One of the most common examples of a heat exchanger is the radiator in a car where the hot fluid in the radiator gets cooled by the flow of air over the radiator surface.

Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors. Heat transfer in the separating wall of a recuperator generally takes place by conduction. However, in a heat pipe heat exchanger, the heat pipe not only acts as a separating wall, but also facilitates the transfer of heat by condensation, evaporation, and conduction of the working fluid inside the heat pipe. In general, if the fluids are immiscible, the separating wall may be eliminated, and the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger.

A heat exchanger consists of heat transfer elements such as a core or matrix containing the heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually, there are no moving parts in a heat exchanger; however, there are exceptions, such as a rotary regenerative exchanger (in which the matrix is mechanically driven to rotate at some design speed) or a scraped surface heat exchanger.

The heat transfer surface is a surface of the exchanger core that is in direct contact with fluids and through which heat is transferred by conduction. That portion of the surface that is in direct contact with both the hot and cold fluids and transfers heat between them is referred to as the primary or direct surface. To increase the heat transfer area, appendages may be intimately connected to the primary surface to provide an extended, secondary, or indirect surface. These extended surface elements are referred to as fins. Thus, heat is conducted through the fin and convected (and/or radiated) from the fin (through the surface area) to the surrounding fluid, or vice versa, depending on whether the fin is being cooled or heated.

As a result, the addition of fins to the primary surface reduces the thermal resistance on that side and thereby increases the total heat transfer from the surface for the same temperature difference. Fins may form flow passages for the individual fluids but do not separate the two (or more) fluids of the exchanger. These secondary surfaces or fins may also be introduced primarily for structural strength purposes or to provide thorough mixing of a highly viscous liquid.

2. Literature Review

This paper presents that Micro channels and Mini channels are found in many biological systems providing very high heat and mass transfer rates in organs such as the brain, lung, liver and kidney. Many high flux cooling applications are effectively utilizing their high heat transfer capabilities of these channels. Small channel diameters are at the heart of all biological systems. Fluid flow and mass transfer in the human body, for example, utilize the high heat and mass transfer coefficients associated with micro channels. The potential of micro channels in high heat flux removal application was first brought to our attention by the pioneering work of Tuckerman and Pease (1982). A broad historical perspective of micro channel and mini channel development was presented by Kandlikar and Grande (2003). [1]

Channel Classification Based on Channel Hydraulic Diameter:

Conventional Channels	D_h>3 mm
Mini channels:	3 mm ≥ D_h> 200 μm
Micro channels:	200 μm ≥ D_h> 10 μm
Transitional Channels:	10 μm ≥ D_h> 0.1 μm
Transitional Micro channels:	10 μm ≥ D_h> 1 μm
Transitional Nano channels:	1 μm ≥ D_h> 0.1 μm
Molecular Nano channels:	0.1 μm ≥ D_h

In This paper, PaisarnNaphon and Osod Khonseurperformed experiments to investigate the heat transfer characteristics and pressure drop in the micro-channel heat sinks under constant heat flux conditions. The experiments were performed for the Reynolds number and heat flux in the ranges of 200–1000 and 1.80–5.40 KW/m^2, respectively. The micro-channel heat sink with two different channel heights and two different channel widths are accomplished by wire electrical discharge machine. Higher heat transfer rate as air mass flow rate increases. However, increase of heat transfer rate is less than that of air mass flow rate. Therefore, outlet air temperature tends to decrease as air mass flow rate increases. Higher surface area and surface roughness result in increase heat transfer rate, therefore, the outlet air temperatures of channel with of w=0.2 mm are higher than those of w=0.3 mm.

The heat transfer rate depends on the cooling capacity rate of air. Therefore, the average heat sink temperature decreases as air Reynolds number increases. Due to higher surface area and surface roughness, the heat transfer rate from the heat sink surface to the cooling air increases. Therefore, the increase channel height results in lower heat sink temperatures. The heat transfer coefficient increases with increasing heat flux. Due to higher temperature difference between inlet air temperature and heat sink temperature, higher heat flux gives heat transfer coefficient higher than those lower ones. The heat transfer coefficients significant increase with increasing air Reynolds number. With the research and development of the miniaturized technologies, mini and micro-channel cooling systems have been widely used in the electronic devices [2]

In this paper Thanhtrung Dang et al reported that their study indicated that the heat transfer rate obtained from micro channel exchanger was higher than those obtained from the mini channel heat exchangers; however, the pressure drops obtained from the micro channel heat exchanger were also higher than those obtained from the mini channel heat exchangers. As a result, the micro channel heat exchanger should be selected for the systems where high heattransfer rates are needed. In addition, at the same average velocity of water in the channels used in this study, the effectiveness obtained from the micro channel heat exchanger was 1.2–1.53 times of that obtained from the mini channel heat exchanger. Micro channel and mini channel heat exchangers have been used in various fields of engineering and scientific applications. Heat transfer rates in these micro channels and mini channels are higher than those in conventional channels; as a result, for a given heat transfer capacity, mini channel heat exchangers are more compact and lighter in weight. The experimental system consists of three major components: the test section (the micro channel or mini channel heat exchanger), syringe system, and overall testing loop, as shown in Figure 2.2. One micro channel and two mini channel heat exchangers were designed and tested in this study. The three heat exchangers have the same total cross-sectional area of 1 mm^2 for all channels involved. That implies that the average velocity in the channels is the same. These heat exchangers can be used to cool electronic devices or for other cooling applications. The heat transfer process of these devices is carried out between two liquids which are hot water and cold water; the hot and cold fluids are flowing in the opposite directions. Figure 2.3 shows the dimensions of the test samples. The material for the heat exchanger is aluminium, used as a substrate with thermal conductivity of 237 W/mK, density of 2,700 kg/m^3, and specific heat at constant pressure of 904 J/kg K. The thickness of these substrates is 2 mm.[3]

In this work, X. L. Xie el al reported that with the rapid development of the information technology (IT) industry, the heat flux in integrated circuit (IC) chips cooled by air has almost reached its limit of about 100 W/cm2. The micro channel flow geometry offers large surface area of heat transfer and a high convective heat transfer coefficient. However, it has been hard to implement because of its very high pressure head required to pump the coolant fluid though the channels. A normal channel could not give high heat flux although the pressure drop is very small. A mini channel can be used in heat sink with a quite high heat flux and a mild pressure loss. A mini channel heat sink with bottom size of 20 mm x 20 mm is analysed numerically for the single-phase laminar flow of water as coolant through small hydraulic diameters and a constant heat flux boundary condition is assumed. The effects of channel dimensions, channel wall thickness, bottom thickness and inlet velocity on the pressure drop, thermal resistance and the maximum allowable heat flux are presented. The results indicate that a narrow and deep channel with thin bottom thickness and relatively thin channel wall thickness results in improved heat transfer performance with a relatively high but acceptable pressure drop. A nearly-optimized configuration of heat sink is found which can cool a chip with heat flux of 256 W/cm2 at the pumping power of 0.205 W. They concluded that heat transfer, a narrow and deep channel is better than that of a wide and shallow channel, in spite of the high pressure drop penalty. A nearly-optimized configuration is obtained for the heat sink with bottom size of 20 mm x 20 mm. For this heat sink the maximum heat flux reaches about 256W/cm2 under the constraint of temperature difference 50 K with inlet velocity of 1.5 m/s, the corresponding thermal resistance is 0.0488 K/W and pumping power is 0.205 W. Even at lower inlet velocity of 0.1 m/s, the thermal performance is also quite good with thermal resistance of 0.091 K/W, pumping power of 5.3 $x10^{-4}$ W and the maximum heat flux of 137 W/cm^2. The orthogonal analysis has verified the nearly-optimized configuration to be the best one in the research ranges of parameters [4]

In his work, Shung et alreported that the analytical results show that the average temperature of the hot and cold side flow significantly affects the heat transfer rate and the pressure drop at the same effectiveness. Different effectiveness has a great influence upon the heat transfer rateand pressure drop. When the micro heat exchanger material is changed from silicon to copper, the thermal conductivity changes from 148 to 400 W/m K. The heat exchanger efficiency is also similar. Therefore, the (110) orientation silicon based micro heat exchanger made using the MEMS fabrication process is feasible and efficient. Furthermore, the dimensions effect has a great influence upon the relationship between the heat transfer rate and pressure drop. Under the same effectiveness, the heat transfer rate increases with rising working fluid temperature in the hot and the cold flow side. The pressure drop decreases because of the temperature influence, especially on the cold flow side. And the higher average temperature situation has the larger heat transfer rate. Under the different effectiveness, the heat transfer rate and pressure drop decrease with the increase in effectiveness. Contrasting the increasing magnitude of the pressure drop, the cold flow side is larger than the hot flow side. At this time, the better heat transfer rate is in the low effectiveness situation. Although the thermal conductivity of the copper k = 400 W/m K exceeds the silicon k = 148 W/m k by two times, the influence is very small for a micro heat exchanger. This is because the fin thickness between the hot and the cold flow channels is very thin, and the thermal resistance of the fin is very small. Therefore, it reduces the influence of the material thermal resistance in the micro heat exchanger. With the dimensions enlarged two times and the outer dimensions enlarged two times, there are advantages and disadvantages in the pressure drop and the heat transfer rate. The designer can choose the appropriate plan by their requirement [5]

In this work, M. Thirumarimurugan, T.Kannadasan and E.Ramasamyhave investigated heat transfer study on a solvent and solution by using Shell and Tube Heat Exchanger. In which Steam is taken as the hot fluid and Water and acetic acid-Water miscible solution taken as cold fluid. A series of runs were made between steam and water, steam and Acetic acid solution. Experimental results such as exchanger effectiveness, overall heat transfer coefficients were calculated. [6]

In this work Muhammad MahmoodAslamBhutta, Nasir Hayat, Muhammad Hassan Bashir, AhmerRaisKhan,KanwarNaveed Ahmad, SarfarazKhani,focused on the applications of Computational (Fluid Dynamics (CFD) in the field of heat exchangers. It has been found that CFD employed for the fluid flow mal-distribution, fouling, pressure drop and thermal analysis in the design and optimization phase. Different turbulence models such as standard, realizable and RNG, k – ε, RSM, and SST k - ε with velocity-pressure coupling schemes suchas SIMPLE, SIMPLEC, PISO and etc. have been adopted to carry out the simulations. Conventional methods used for the design and development of Heat Exchangers are expensive. CFD provides cost effective alternative, speedy solution and eliminate the need of prototype, it is limited to Plate, Shell and Tube, Vertical Mantle, Compact and Printed Circuit Board Exchangers but also flexible enough to predict the fluid flow behavior to complete heat exchanger design and optimization involving a wide range of turbulence models and Integrating schemes the k - ε turbulence model is most widely employed design and optimization .The simulations results ranging from 2% to 10% with the experimental studies. In some exceptional cases, it varies to 36%. [7]

In this paper Sharad Kumar *et al.*presents the effect of arc shaped geometry on heat transfer co-efficient, friction factor and performance enhancement were investigated covering the range of roughness parameter (from 0.0299 to 0.0426) and working parameter (Re from 6000 to 18000).Different turbulent models have been used for the analysis and their results were compared. Re normalization group (RNG) κ- ε model based results have been found in good agreement and accordingly this model was used to predict heat transfer and friction factor in the duct [8]

In this paper,Kadirbilen*et al.*Experimentally investigated the surface heat transfer and friction characteristics of a fully developed turbulent air flow in different grooved tubes. Tests were performed for Reynolds number range of 10000 to 38000 and for different geometric grooved shape (circular, trapezoidal and rectangular) tubes [9]

3. Selection of design Parameters for heat exchanger

3.1 Overall Heat-transfer coeffiecient

While dealing with the problems of fluid to fluid heat transfer across a metal boundary, it is usual to adopt an overall heat transfer coefficient U which gives the heat transfer transmitted per unit area per unit time per degree temperature difference between the bulk fluids on each side of the metal.

3.2 Specific Heat

Specific heat is defined as Heat required to increase or to decrease one degree of temperature of one kg of mass of fluid.

3.3 Heat exchanger effectiveness

It is defined as the ratio of actual heat transfer to the maximum possible heat transfer.

Heat exchanger design method

A heat exchanger can be designed by the LMTD (logarithmic mean temperature difference) when inlet and outlet condition are specified. However, when the problem is to determine the inlet or exit temperatures for a particular heat exchanger, the analysis is performed more easily, by using a method based on effectiveness of the heat exchanger (concept first proposed by Nusselt) and number of transfer unit (NTU).

Number of transfer units (NTU) method

The effectiveness ε is a function of several variables and as such it is inconvenient to combine them in a graphical or tabular form. However, by compiling, a non-dimensional grouping, ε can be expressed as a function of three non-dimensional parameters. This method is known as NTU method. This method/facilitates the comparison between the various types of heat exchanger which may be used for a particular application.

Conclusion

It has been concluded after reviewing the various research papers and books that shell and tube type Heat exchanger is not suitable for cooling purpose of microprocessor and silicon chips for consideration of shape, size, weight and cost. To accomplish this cooling purpose, newly design of mini channel or micro channel compact heat exchanger can be designed. This compact heat exchanger will be useful to reduce size and cost. After deigning and modelling of compact heat exchanger CFD simulation would be carried out, Thus for that CFD simulation, K-ε turbulence model would be preferable. The error between CFD results and experimental reading should not be more 36%.

REFERENCES

[1] Kandlikar S.G. and Mark E. Steinke "Examples of micro channels mass transfer processes in Biological system", first international conference on micro channels and mini channels April 24 -25 , 2003 Rochester , new york USA

[2] PaisamNaphon and osod Khonseur" study on the convective Heat transfer and pressure drop In the micro channel heat sink", International communication in Heat and mass transfer

[3] Thanhtrung Dang and Juhn – Tong Teng " The effects of configurations on the performance of Micro channel counter flow Heat exchanger – An experimental study"

[4] X.L.Xie.el.at. "Numerical study of laminar heat transfer and pressure drop characteristics in A water – cooled mini channel heat sink ", science direct applied thermal engineering 29(2009)

[5] Shung Wen Kang et. Al , " Analysis of effectiveness and pressure drop in micro cross flow heat Exchanger " , science direct applied thermal engineering27(2007)

[6] CFD Analysis of shell and tube heat exchanger – A review , International journal of engineering Science and innovative technology , volume 2 , issue 2, March 2013

.

[7] Muhammad Mahmood ,AslamBhutta , " Numerical Analysis if fin tube plate heat exchanger By using CFD Technique " ARPN journal of engineering and Applied Science Volume 6 , No7 July 2011 , ISSN 1819 – 6608

[8] KabirBilenet. al. ,sharad Kumar et.al. "CFD analysis of Heat transfer and friction factor characteristics of a Turbulent flow for Internally grooved tubes ", National Institute of Technology ,Tiruchirapalli - 620

[9] Mark A Pierson, Srinath V Ekkad, Robert Hendricks, "Development of a Mini Channel Compact Primary Heat Exchanger for a molten salt reactor" , April 28, 2011, Blackburg VA