# Analysis of Effectiveness and Pressure Drop in Micro Cross-flow Heat Exchanger

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## Abstract

*Micro heat exchanger is an extremely high efficiency, cross flow, fluid-fluid, micro heat exchanger formed from high aspect ratio microstructures. Toconcurrently achieve the goals of high mass flow rate, low pressure drop, and high heat transfer rates, one embodiment of the micro heat exchanger comprises numerous parallel, but relatively short microchannels. The performance of these heat exchangersis superior to the performance of previously available heat exchangers, as measured by the heat exchange rate per unit volume or per unit mass. Typical gas channel lengths in the micro heat not exchangers are from a few hundred micrometers to about age. t 2000micrometers, with typical channel widths from around 50 in micrometers to a few hundred micrometers, although the dimensions in particular applications could be greater or smaller. The novel micro heat exchangers offer substantial advantages over conventional, larger heat exchangers in performance, weight, size, and cost.*

***Keywords:*** ***Micro Cross flow hea exchanger, effectiveness, pressure drop, Hea transfer rate***



Nomenclature

| | |
|---|---|
| a | plate thickness |
| Ab | mean area of heat sink |
| Ac | free flow area of one side |
| At | heat exchanger total heat transfer area on one side |
| Af | surface area of heat sink |
| b | spacing between plates |
| c | micro channe ls width |
| cp | specific heat at constant pressure |
| Cr | capacity-rate ratio |
| d | fin thickness |
| $D_h$ | hydraulic diameter |
| f | friction factor |
| G | mass velocity |
| gc | gravitational constant |
| h | convention heat transfer coefficient |
| k | thermal conductivity |
| ε | exchanger effectiveness |
| ṁ | mass flow rate |
| m | fin efficiency parameter |
| N | total number of channels on one side |
| NuT | constant wall temperature Nusselt number |
| NTU | number of transfer units |
| P | pressure |
| T | temperature |
| Re | Reynolds number |
| U | overall heat transfer coefficient |
| X,Y,Z | principal dimensions of heat exchanger |

## 1. Introduction

l A heat exchanger is a thermal device that transports energy by heat transfer between moving fluids at different temperatures. Heat exchangers are widely used in many different applications and industries worldwide, varying from space, energy, heating, ventilation and air conditioning, and transportation. A radiator for cooling a car or truck engine, and a condenser for an air conditioner are typicalheat exchangers in the automobile industry

A common definition for cross-flow heat exchanger is where both hot and cold fluid travel perpendicular to each other. With this configuration, many variations are possible, depending on construction constraints. Some of the variations can be each of the hot and cold fluids mixed, only one of the fluids mixed, and both fluids unmixed

Micro-heat exchangers have many advantages over their larger counterparts, particularly when used to handle clean fluid streams, either single- or two-phase. Probably the most exciting feature of such heat exchangers is their ability to operate with close approach temperatures, leading to high effectiveness. This can be particularly beneficial when the exchangers are used in power-producing or power-consuming systems, where the improved heat exchanger effectiveness can be immediately realised in higher power outputs or reduced power consumption.

The use of microchannels in a cross-flow micro-heat exchanger decreases the thermal diffusion lengths substantially, allowing substantially greater heat transfer per unit volume or per unit mass than has been achieved with prior heat exchangers. The novel cross-flow micro-heat exchanger has performance characteristics that are superior to state-of-the-art innovative car radiator designs, as measured on a per-unit-volume or per-unit-mass basis, using pressure drops for both the air and the coolant that are comparable to those for reported innovative car radiator designs..

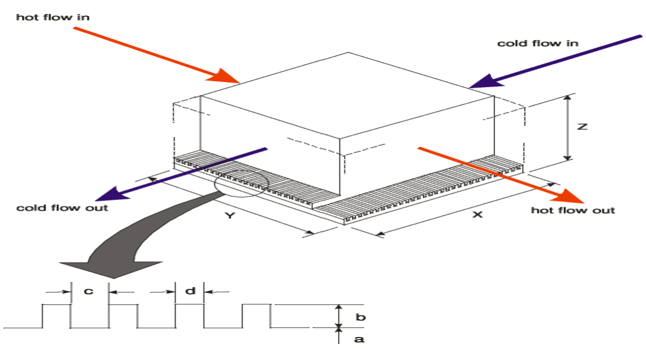


Figure : 1 Plate-type cross-flow micro heat exchanger.

## 2 Pressure drop & Effectivness calculation formula

The hydraulic diameter of the channel can be expressed as

$$D_h = \frac{4*bc}{2(b+c)}$$

The constant wall temperature Nusselt number can be written as

$$Nu_t = \frac{hD_h}{k_f}$$

the heat transfer coefficient can be find as following

$$h_1 = \frac{kf_1 NuT}{D_h}$$

$$h_2 = \frac{kf_2 NuT}{D_h}$$

Pressure drops of the hot and cold flow sides are

$$DP_1 = \frac{f_1 G_1^2 Y}{D_h (2gc)\rho 1}$$

$$DP_2 = \frac{f_2 G_2^2 Y}{D_h (2gc)\rho_2}$$

where

$$f_1 = 96[1-1:3553(c/b)+1:9467(c/b)^2-1:7012(c/b)^3+0.9564(c/b)^4-0:2537(c/b)^5]/Re_1$$

$$f_2 = 96[1-1:3553(c/b)+1:9467(c/b)^2-1:7012(c/b)^3+0.9564(c/b)^4-0:2537(c/b)^5]/Re_2$$

The mass velocity is

$$G_1 = m_1 /Ac_1$$

$$G_2 = m_2 /Ac_2$$

The effectiveness of the heat exchanger is

$$\varepsilon = 1- \exp[(1/Cr)\,(NTU)^{0.22} \{\exp - Cr(NTU)^{0.7}-1\}]$$

$$Cr = C\ min /C\ max$$

$$m_1 = \sqrt{\frac{h_1 * 2(d_1 + y)}{k_s * d_1 y}}$$

$$m_2 = \sqrt{\frac{h_2 * 2(d_2 + y)}{k_s * d_2 y}}$$

$$d_1 = \frac{X - [N_1/(Z/2a+2b)]*c}{N_1/(Z/2a+2b)+1}$$

$$d_2 = \frac{X - [N_2/(Z/2a+2b)]*c}{N_2/(Z/2a+2b)+1}$$

the fin efficiency is

$$\eta_{f2} = \frac{\tanh(m_1 * b/2)}{m_1 * b/2}$$

$$\eta_{f2} = \frac{\tanh(m_2 * b/2)}{m_2 * b/2}$$

The total heat transfer area of the hot and the cold flow side is

$$A_{t1} = N_1 A_{f1} + A_{b1}$$

$$A_{t2} = N_2 A_{f2} + A_{b2}$$

where the surface area of heat sink is

$$A_{f1} = (b/2)*2*y$$

$$A_{f2} = (b/2)*2*y$$

The mean area of heat sink is

$$A_{b1} = N_1 cY$$

$$A_{b2} = N_2 cY$$

The overall thermal conductance (AtU) is

$$A_t U = \frac{1}{1/(\alpha_1 XYZh_1\eta_{01}) + 1/(\alpha_2 XYZh_2\eta_{02})}$$

$$NTU = \frac{A_t U}{C_{min}}$$

Therefore the overall efficiency of fin array is

$$\eta_{01} = 1 - \frac{N_1 A_{f1}}{A_{t1}}(1 - \eta_{f1})$$

$$\eta_{02} = 1 - \frac{N_2 A_{f2}}{A_{t2}}(1 - \eta_{f2})$$

The first portion of the procedure involves determining the two ratios. The first ratio is the total heat transfer area on one side of the exchanger to the total volume of the exchanger a. The second ratio is the total heat transfer area on one side of the exchanger to the volume between the plates on that side b, expressed as

$$\alpha_1 = \frac{b\beta_1}{2a + 2b}$$

$$\alpha_2 = \frac{b\beta_2}{2a + 2b}$$

and

$$\beta_1 = \frac{N_1 * [(2b + 2c)] * Y}{XYZ * \frac{b}{2b + 2a}}$$

$$\beta_2 = \frac{N_2 * [(2b + 2c)] * Y}{XYZ * \frac{b}{2b + 2a}}$$

## 2.1 Same effectiveness, different average temperature

| ε | Thi $^0$(C) | Tho (C) | Tci (C) | Tco $^0$(C) | ṁ Si (kg/s) | ṁ Cu (kg/s) | Ta $^0$(C) |
|---|---|---|---|---|---|---|---|
| 0.3 | 40 | 30 | 10 | 20 | 0.03 | 0.063 | 25 |
| 0.3 | 50 | 40 | 20 | 30 | 0.01 | 0.062 | 35 |
| 0.3 | 60 | 50 | 30 | 40 | 0.07 | 0.069 | 45 |
| 0.3 | 70 | 60 | 40 | 50 | 0.06 | 0.071 | 55 |
| 0.3 | 80 | 70 | 50 | 60 | 0.07 | 0.072 | 65 |

Table 1 : Temperature parameters and flow rate of the same effectiveness

| ε | Thi $^0$(C) | Tho $^0$(C) | Tci $^0$(C) | Tco $^0$(C) | ṁ Si (kg/s) | ṁ Cu (kg/s) |
|---|---|---|---|---|---|---|
| 0.167 | 80 | 70 | 20 | 30 | 0.1746 | 0.1803 |
| 0.333 | 80 | 60 | 20 | 40 | 0.0679 | 0.0701 |
| 0.500 | 80 | 50 | 20 | 50 | 0.0323 | 0.0334 |
| 0.667 | 80 | 40 | 20 | 60 | 0.0139 | 0.0144 |
| 0.833 | 80 | 30 | 20 | 70 | 0.0026 | 0.0027 |

Table 2 : Temperature parameters and flow rate of the difference effectiveness

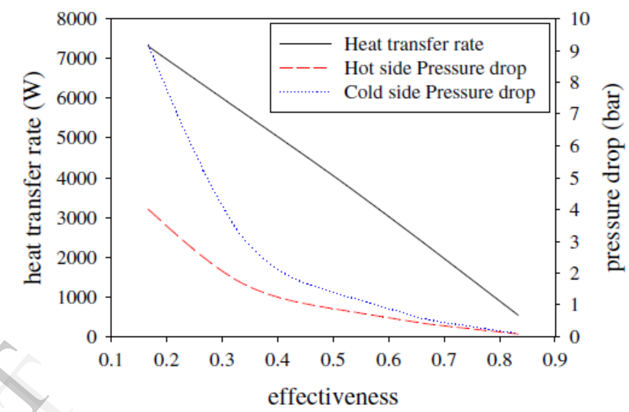




Figure : 2.1 Relationship of the pressure drop and the heat transfer rate in the difference effectiveness (b = $10^5/3$).

The inflow temperatures of the hot and cold side were fixed, and the outflow temperatures were changed, the temperature settings show in Table 2. The effectiveness range was adjusted between 0.167 and 0.833. The influence of the different effectiveness is illustrated in the Figs. 2 and 3. From Fig. 2, the effectiveness of the heat exchanger was increased, the working fluid flow rate will reduce in order to increase the heat exchange time. The flow rate will reduce from 0.1764 to 0.0026 kg/s. It will cause the heat transfer rate reduce because of the reducing of the flow rate. The variation of the pressure drop is violent when the effectiveness is below 0.4, and gradual when the effectiveness is above 0.4. From Figs. 2 and 3, under the same heat transfer rate and effectiveness, enlarging dimension will cause pressure drop to reduce substantially. Overall, the heat transfer rate does not rise very much. When the effectiveness is below 0.4, enlarging dimension has a good suitable range, because the variation in the pressure drop is small.

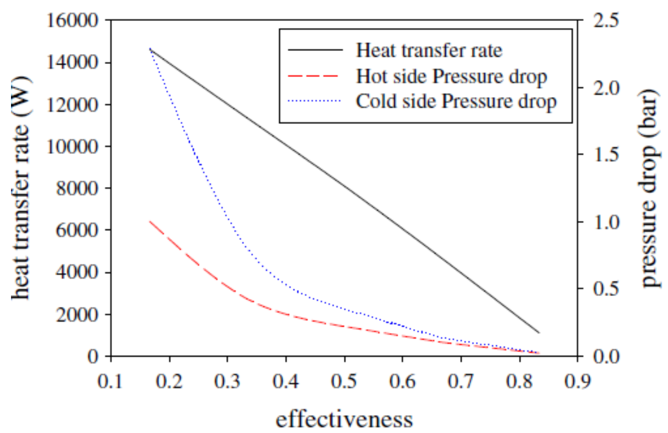


Figure : 2..3 Relationship of the pressure drop and the heat transfer rate in the difference effectiveness, X, Y, Z, a, b, c, d enlarge the double times (b = $10^5/6$).

## 2.2 Different effectiveness, average temperature $50^0$C

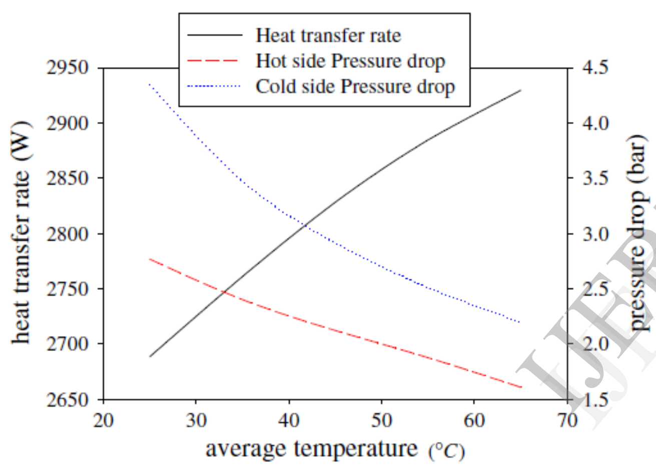


Figure : 2 4 Relationship of the pressure drop and the heat transfer rate in the different average temperature and the effectiveness is 0.333 (b = $10^5/3$).

Fig : 2.4 utilize table 1 to indicate the relationship between the pressure drop, heat transfer rate and the different average temperature of the hot and cold side in silicon based micro heat exchanger, and the effectiveness is 0.333. The average temperature is the average value of the entrance and exit fluid temperature of the hot and cold side. From Fig. 4, under the same level of the effectiveness, the major influence of the heat transfer rate on the working fluid is the fluid average temperature. And the heat transfer rate has the trend increasing with the rising of the average temperature. Conversely, the pressure drop decreases. The heat transfer rate increases because of the increase in the working fluid flow rate. Although the increase of the working fluid flow rate and whole temperature allows the working fluid density to decrease, the inside pressure drop of the micro channels then increases. However, the rising temperature causes the fluid viscosity to decrease and the pressure drop of the heat exchanger then reduces. Under the same flow rate of the hot and cold side channels, the cold side pressure drop is larger than hot side.

## 2.3 Different heat exchanger materials

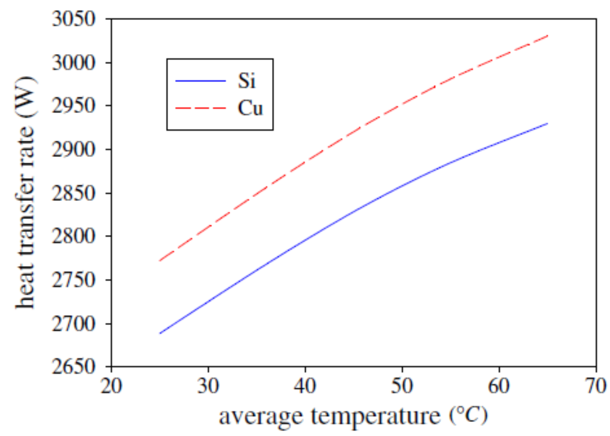


Figure : 2. 5 The heat transfer rate of Si and Cu in the different average temperature and the effectiveness is 0.333.

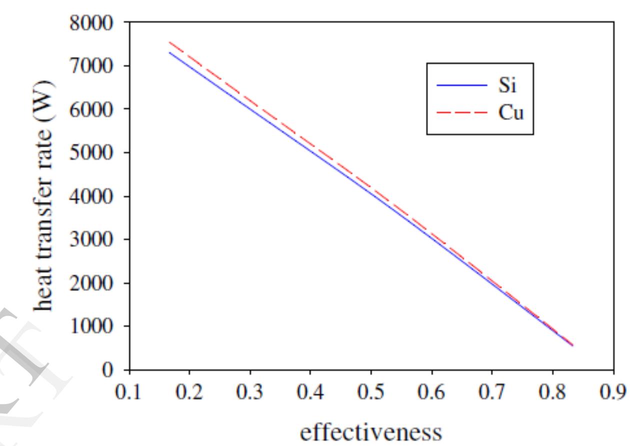


Figure :2.6 The heat transfer rate of Si and Cu in the different effectiveness.

From Figures. 2.5 and 2. 6, it can be discovered that copper micro heat exchanger material produces a larger flow rate than aluminium at the same and the different effectiveness. Copper produces a larger heat transfer rate. The difference in the heat transfer rate is very small. Therefore, the (11 0) orientation silicon based micro heat exchanger made by the MEMS fabrication process is feasible in efficiency.

## 3. Conclusion

This study used the fundamental heat transfer and fluid flow equations to establish a theoretical model for a micro heat exchanger in this paper. And it utilized Ref. [4], the (11 0) orientation silicon based micro heat exchanger made using the MEMS fabrication process. The design dimensions and temperature parameters were substituted into the theoretical model to verify the design. This study examined the interactive effect between the effectiveness of the heat exchanger and pressure drop of the micro channels.Key findings from this study are as follows:

(1) 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.
(2) 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.
(3) 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.

(4) 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.

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