COOLING AUGMENTATION USING MICROCHANNELS WITH ROTATABLE SEPARATING PLATES

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A DL-microchannel cooling device with rotatable separating plate is disclosed. The separating plate is supported via anti-leaking flexible seals. The only allowable motion for that plate is the rotational motion about a pivot rod. The rod is taken to be aligned along the microchannel center line normal to its sides boundaries. The device can be configured as a flexible microheat exchanger and a heated DL-flexible microchannel device. The theory of linear elasticity applied to flexible seals supporting the separating plate is used to relate the moment of the pressure forces on that plate to its rotational angle. The energy equations for both fluids flows are solved numerically and analytically under special conditions. As such, the effectiveness of the flexible microheat exchanger and other performance indicators for flexible microheat exchanger and heated DL-flexible microchannel devices are calculated. The advantages of the proposed device in cooling attributes over the performance of the DL-rigid microchannel device is examined.

Publication Classification
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Figure 1B
Figure 2
Figure 3

\[ A_x=0.915, A_z=2.03, A_r=1.01, Pr_c=8.25, Pr_f=3.65, Re_c=7.26, Re_f=15 \]

\[ Ka = 30.5 \times 10^6 \]
Figure 4

\[ K_\alpha = 30.5 \times 10^6 \]

using Eqs. (54, 55)

\[ A_0 = 0.915, A_1 = 2.03, A_2 = 1.01, 1/A_3 = 40, Pr_1 = 8.25, Pr_2 = 3.65 \]
Figure 5

\[ Ka = 3.05 \times 10^6 \]

\[ A_i = 0.915, A = 2.03, A_e = 1.01, 1/A_e = 40, Pr_e = 8.25, Pr_i = 3.65 \]

- \( Re_s = 15 \)
- \( Re_s = 25 \)
Figure 6
Figure 8
Figure 9
Figure 10

\[ K_d = 30.5 \times 10^3 \]

- \( Re_d = 11 \)
- \( Re_d = 7.25 \)

\[ A_0 = 0.915, \ A_c = \frac{3}{2}, \ A_s = 2.03, \ A = 1.01, \ Pr_c = 8.25, \ Pr_s = 3.65, \ Re_w = 15 \]
Figure 11

$Ku = 30.5 \times 10^6$

$1 - \theta(x, y = 0)$

$Nu_x$

$Re = 21$

$Re = 10$

$Re = 13$

$Re = 21$

$A_r = 0.915, A_r = 5, A_r = 2.03, A_r = 1.01, 1/A_r = 40, Pr_r = 8.25, Re_r = 15, Pr_r = 3.65$
COOLING AUGMENTATION USING MICROCHANNELS WITH ROTATABLE SEPARATING PLATES

CROSS-REFERENCE TO PROVISIONAL APPLICATION


TECHNICAL FIELD

Embodiments are generally related to microchannel cooling devices. Embodiments also relate to MEMS (Microelectromechanical systems) and nano-scale devices and nanofabrication techniques. Embodiments also relate to cooling augmentation techniques that utilize double layered (DL) microchannels separated by rotatable plates.

BACKGROUND OF THE INVENTION


As the expansion in the flow passage volume may result in slight reduction in the convection heat transfer coefficient, see Khaled A.R. A and Vafai K, Analysis of flexible microchannel heat sinks, International Journal of Heat and Mass Transfer, 48, 1739-1746, 2005, a new configuration of DL-flexible microchannels device must be considered.

BRIEF SUMMARY

The following summary is provided to facilitate an understanding of some of the innovative features unique to the disclosed embodiments and is not intended to be a full description. A full appreciation of the various aspects of the embodiments disclosed herein can be gained by taking the entire specification, claims, drawings, and abstract as a whole.

It is therefore one aspect of the disclosed embodiments to provide for aDL-microchannel cooling device with rotatable separating plate.
[0012] It is another aspect of the disclosed embodiments to provide a flexible microheat exchanger and a heated DL-flexible microchannels device.

[0013] It is still another aspect of the disclosed embodiments to provide for a configuration in which the moment of the pressure forces on the separating plate is related to its rotational angle by a theorem of linear elasticity applied to its flexible supports.

[0014] It is still another aspect of the disclosed embodiments to provide for the use of energy equations of flowing fluids, which can be solved numerically utilizing an iterative finite-difference method.

[0015] It is a further aspect of the disclosed embodiments to provide for comparisons with obtained closed-form solutions that can be performed under fully developed conditions.

[0016] It is a further aspect of the disclosed embodiments to provide for a technique in which the effectiveness and the heat transfer rate per unit pumping power for the flexible microheat exchanger are always greater than that of the rigid one.

[0017] It is an additional aspect of the disclosed embodiments to provide for heated DL-flexible microchannels devices that provide more cooling effects per unit pumping power than rigid ones at low Reynolds numbers below specific values, and at stiffness number and aspect ratio above certain values. Note that these specific values can vary with the magnitude of the heating load.

[0018] It is another aspect of the disclosed embodiments to provide DL-microchannels with rotatable separating plates that can be utilized in electronic applications.

[0019] The aforementioned aspects and other objectives and advantages can now be achieved as described herein. An apparatus is disclosed, which may include a first substrate and a second substrate, the first substrate having a face in contact with at least one hot medium and having an other face in contact with a first heat exchanginating fluid; the second substrate having a face in contact with a cold medium and having the other face in contact with a second heat exchanging fluid; the faces of the first and second substrates in contact with the first heat exchanging fluid and the second heat exchanging fluid are opposing each other; at least one flexible seal attached to the first substrate and to the second substrate to form at least one closed enclosure; a pivoted rod aligned along the centre line between the first and second substrates; and a separating plate mounted about a pivot axis of the pivoted rod such that the at least one closed enclosure is divided to form an upper microchannel and a lower microchannel.

[0020] In another embodiment, the separating plate can be supported via the at least one flexible seal. In other embodiments, the first substrate can comprise at least two confined openings. In an additional embodiment, the second substrate can comprise at least two confined openings. In yet another embodiment, the hot and cold media are replaceable with insulated media. In still other embodiments, the first and second heat exchanging fluids can possess at least one of the following: different temperatures, different phases or both different temperatures and different phases. In another embodiment, the second heat exchanging fluid can flow in the upper microchannel and the first heat exchanging fluid can flow in the lower microchannel. In the still other embodiments, the separating plate can rotate about the pivot axis. In another embodiment, the first substrate, the second substrate and the separating plate can be configured from ultra-high thermally conductive materials. In another embodiment, the first heat exchanging fluid and the second heat exchanging fluid can be allowed to flow either in a counter-direction, a parallel-direction, a cross-direction or skew-directions within the lower and upper microchannels.

DESCRIPTION OF THE DRAWINGS

[0021] The accompanying figures, in which like reference numerals refer to identical or functionally-similar elements throughout the separate views and which are incorporated in and form a part of the specification, further illustrate the present invention and, together with the detailed description of the invention, serve to explain the principles of the disclosed embodiments.

[0022] FIG. 1A illustrates a three dimensional view of the double layered microchannels device with rotatable separating plate, in accordance with the disclosed embodiments;

[0023] FIG. 1B illustrates a side view of the device depicted in FIG. 1A and its coordinate system, in accordance with the disclosed embodiments;

[0024] FIG. 2 illustrates the effects of the elastic parameter E, on A, and CF, in accordance with the disclosed embodiments;

[0025] FIG. 3 illustrates the effects of X, and A, on Nu, and Nu, for the flexible microheat exchanger, in accordance with the disclosed embodiments;

[0026] FIG. 4 illustrates the effects of Re, on ε for the flexible microheat exchanger, in accordance with the disclosed embodiments;

[0027] FIG. 5 illustrates the effects of Re, on γ, for the flexible microheat exchanger, in accordance with the disclosed embodiments;

[0028] FIG. 6 illustrates the effects of π, on ε and γ, for the flexible microheat exchanger, in accordance with the disclosed embodiments;

[0029] FIG. 7 illustrates the effects of 1/A, on γ, for the flexible microheat exchanger, in accordance with the disclosed embodiments;

[0030] FIG. 8 illustrates the effects of Re, on A, and γ, for the heated DL-flexible microchannel, in accordance with the disclosed embodiments;

[0031] FIG. 9 illustrates the effects of Ka on γ, for the heated DL-flexible microchannel, in accordance with the disclosed embodiments;

[0032] FIG. 10 illustrates the effects of Re, on λ, and γ, for the heated DL-flexible microchannel, in accordance with the disclosed embodiments; and

[0033] FIG. 11 illustrates the effects of Re, and x on Nu, and heated source temperature the heated DL-flexible microchannel, in accordance with the disclosed embodiments.

DETAILED DESCRIPTION

[0034] The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate at least one embodiment and are not intended to limit the scope thereof.

[0035] The embodiments now will be described more fully hereinafter with reference to the accompanying drawings, in which illustrative embodiments of the invention are shown. The embodiments disclosed herein can be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are
provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

The following Table 1 provides the various symbols and meanings used in this section:

### TABLE 1

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_d )</td>
<td>maximum relative displacement of the separating plate, ( d/H_c )</td>
</tr>
<tr>
<td>( A_{th} )</td>
<td>cold to hot fluids thermal conductivities ratio, ( k_c/k_h )</td>
</tr>
<tr>
<td>( a_{th} )</td>
<td>cold to hot fluids density ratio, ( \rho_c/\rho_h )</td>
</tr>
<tr>
<td>( C_h, C_c )</td>
<td>cold and hot fluids thermal capacities per unit width [Wm(^{-1}) K(^{-1})]</td>
</tr>
<tr>
<td>( d )</td>
<td>maximum displacement of the separating plate [m]</td>
</tr>
<tr>
<td>( E_0 )</td>
<td>dimensionless elastic parameter defined in Equation 11</td>
</tr>
<tr>
<td>( H )</td>
<td>microchannel height [m]</td>
</tr>
<tr>
<td>( H_h, H_c )</td>
<td>microchannel dimensionless height, defined in Equation 1</td>
</tr>
<tr>
<td>( h )</td>
<td>half main microchannel height [m]</td>
</tr>
<tr>
<td>( h_c )</td>
<td>convection heat transfer coefficient [W m(^{-2}) K(^{-1})]</td>
</tr>
<tr>
<td>( K )</td>
<td>stiffness of the supporting seals per unit separating plate width [N]</td>
</tr>
<tr>
<td>( K_a )</td>
<td>stiffness number defined in Equation 30</td>
</tr>
<tr>
<td>( k )</td>
<td>thermal conductivity [W m(^{-1}) K(^{-1})]</td>
</tr>
<tr>
<td>( L )</td>
<td>microchannel length [m]</td>
</tr>
<tr>
<td>( Na )</td>
<td>local Nusselt number defined Equations 47, 48 and 62</td>
</tr>
<tr>
<td>( P )</td>
<td>total ideal pumping power requirement [Wm(^{-1})]</td>
</tr>
<tr>
<td>( \rho )</td>
<td>mean pressure [N m(^{-2})]</td>
</tr>
<tr>
<td>( \phi )</td>
<td>heat transfer rate per unit width [W m(^{-1})]</td>
</tr>
<tr>
<td>( \Pr )</td>
<td>Prandtl number, ( \mu c_p/\kappa )</td>
</tr>
<tr>
<td>( Re )</td>
<td>Reynolds number, ( \rho_{ref} U c_p/\mu )</td>
</tr>
<tr>
<td>( T )</td>
<td>temperature field [K]</td>
</tr>
<tr>
<td>( T_{\text{mean}} )</td>
<td>mean bulk temperature [K]</td>
</tr>
<tr>
<td>( U )</td>
<td>local overall heat transfer coefficient [W m(^{-2}) K(^{-1})]</td>
</tr>
<tr>
<td>( U_{\text{c}} )</td>
<td>equivalent overall heat transfer coefficient [W m(^{-2}) K(^{-1})]</td>
</tr>
<tr>
<td>( u )</td>
<td>velocity field [m s(^{-1})]</td>
</tr>
<tr>
<td>( \xi )</td>
<td>axial micro-passage coordinate [m]</td>
</tr>
<tr>
<td>( \chi )</td>
<td>dimensionless axial micro-passage coordinate defined in Equations 19, 20</td>
</tr>
<tr>
<td>( \chi_{\text{trans}} )</td>
<td>transverse micro-passage coordinate [m]</td>
</tr>
<tr>
<td>( x_{\text{trans}} )</td>
<td>dimensionless transverse coordinates defined in Equations 18(a, b)</td>
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### TABLE 1-continued

<table>
<thead>
<tr>
<th>Subscripts</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>1</td>
<td>inlet</td>
</tr>
<tr>
<td>2</td>
<td>exit</td>
</tr>
<tr>
<td>c</td>
<td>cold fluid</td>
</tr>
<tr>
<td>( \theta )</td>
<td>thermally fully developed</td>
</tr>
<tr>
<td>h</td>
<td>hot fluid</td>
</tr>
<tr>
<td>m</td>
<td>mean value</td>
</tr>
</tbody>
</table>

### 1. PROBLEM FORMULATION

1.1. Modeling of the Maximum Relative Displacement of the Moving Plate

FIG. 1A illustrates a three dimensional view of the double layered microchannels device 100 with rotatable separating plate 125. A wide microchannel of height 2\( H_c \) which is much smaller than its length is divided into two identical microchannels 150 and 155 by a highly conductive and inflexible separating plate 125 mounted about a pivot axis. The pivot axis is taken to be a rod 130 aligned along the normal centerline axis of the device 100 as seen in FIG. 1A. Accordingly, the allowable motion of the separating plate 125 is the rotational motion about that pivot axis. The inlet and outlet ports 105, 115, 120 and 110 of the passages of the device 100 can be drilled on the upper and lower plates 140 and 145. Two fluids at different temperatures are allowed to flow in counter-direction inside the lower and upper microchannels 150 and 155. The hot fluid which is at temperature \( T_{h_c} \) enters the lower microchannel 155 and flows towards the left direction along the \( x_{h} \)-axis as shown in FIG. 1B. However, the cold fluid which is at temperature \( T_{h_c} \) (\( T_{h_c} < T_{h_c} \)) is allowed to flow in the upper microchannel 150 to the right direction along the \( x_{c} \)-axis as shown in FIG. 1B. See A.-R. A. Khaled, “Analysis of heat transfer inside flexible thin-film channels with nonuniform height distributions, Journal of Heat Transfer—Transactions of the ASME 129 (2007) pp. 401-404. The heights of the microchannels 150 and 155 denoted by \( H_{h,c} \) (\( H_{h} \) and \( H_{c} \)) vary with the axial coordinates according to the following relationships:

\[
H_{h,c}(x_{h,c}) = H_{h,c}(x_{h,c}) = 1 + A_d(1 - 2A_d x_{h,c}) \quad \text{Eqs. 1, 2}
\]

The subscript “h” stands for the hot fluid while the subscript “c” stands for the cold fluid. The parameters \( A_d, A_c \) and the dimensionless variable \( x \) are the maximum relative displacement of separating plate, the aspect ratio and the dimensionless axial coordinate, respectively. They are given by

\[
A_d = \frac{d}{H_c}; \quad \text{Eqs. 3(a-d)}
\]

\[
A_c = \frac{H_c}{L};
\]

\[
x_{h,c} = \frac{x_{h,c}}{L}.
\]

where \( d \) is the maximum displacement of the separating plate.
The width of the microchannel is taken to be much larger than its height in order to have enough pressure forces to cause rotation of the separating plate. As such, the two-dimensional flow model is adopted. See, Khaled A R A and Vafai K, Analysis of flexible microchannel heat sinks, International Journal of Heat and Mass Transfer, 48, 1739-1746, 2005. Therefore, the steady state Reynolds equations for the microchannels are given by

$$\frac{d}{dx_e}\left(\frac{H_e u_{e}}{dx_e}\right) = 0$$  \hspace{1cm} \text{Eqs. 4, 5}$$

where $p_e$ and $p_s$ are the mean pressures inside the lower and upper microchannels, respectively. The solution to Equations 4 and 5 can be arranged in the following forms:

$$\frac{p_{e2}(x_e) - p_{e1}(x_e)}{p_{e2}(x_e) - p_{e1}(x_e)} = 1 - \left(\frac{1 + A_e}{H(x_e)}\right)^2$$  \hspace{1cm} \text{Eqs. 6, 7}$$

where $p_{e1}$ and $p_{e2}$ are the inlet and exit pressures of the hot fluid, respectively. Moreover, $p_{e2}$ and $p_{s}$ are the inlet and exit pressures of cold fluid, respectively.

Now, let the motion of the separating plate be restrained by the stiffness effect of the elastic seals supporting it. As such, the net moment of pressure forces applied on that plate about the pivot axis per unit width, $\Sigma M_{e_1}^s$, is equal to

$$\Sigma M_{e_1}^s = K \tan^{-1}(2d/L)$$  \hspace{1cm} \text{Eq. 8}$$

where $K$ is the stiffness of the supporting seals per unit separating plate width. When $A_e < 0.05$ as for microchannels applications, the rotational angle which is equal to $\tan^{-1}(2d/L)$ can be approximated by the value $(2d/L)$. $\Sigma M_{e_1}^s$ is equal to the following expression when $A_e < 0.05$:

$$\Sigma M_{e_1}^s = \int_0^L p_e \left(\frac{L}{2} - x_e\right) dx_e - \int_0^L p_s \left(\frac{L}{2} - x_e\right) dx_e$$  \hspace{1cm} \text{Eq. 9}$$

Substitution Equation 9 into Equation 8 and solving Equation 8 yields the following relationship:

$$\left(1 - \frac{1 + A_e}{1 + A_e}\right)^2 \frac{A_e^2}{1 + A_e} = E_0$$  \hspace{1cm} \text{Eq. 10}$$

where $E_0$ is the dimensionless elastic parameter which is equal to

$$E_0 = \frac{(p_e - p_s) + (p_s - p_e)}{4KA_e L/2}$$  \hspace{1cm} \text{Eq. 11}$$

The inverse of Equation 11 is difficult to be obtained analytically. However, with the aid of one of the advanced statistical softwares, $A_e$ is correlated to $E_0$ by the following functional form:

$$A_e = a_1 + a_2 F_{a_1} + a_3 F_{a_2} + a_4 F_{a_3} + a_5 F_{a_4}$$  \hspace{1cm} \text{Eq. 12}$$

where $F_{a_i}$ is equal to $\tan^{-1}(2d/L)$ can be approximated by the value $(2d/L)$. $XM_{e_1}^s$ is equal to the following expression when $A_e < 0.05$:

$$X_{M_{e_1}^s} = \frac{\theta_{e_1}}{\sqrt{\rho_1 C_p}} \frac{\partial T_{e_1}}{\partial x_e} = \frac{\theta_{e_1}}{\sqrt{\rho_1 C_p}} \frac{\partial T_{e_1}}{\partial x_e}$$  \hspace{1cm} \text{Eq. 13(a-i)}$$

1.2. Modeling of Flow and Heat Transfer Inside the Two Microchannels

Let both fluids be Newtonian fluids having constant average properties. The momentum and energy equations inside each microchannel are given by Khaled A R A and Vafai K, Analysis of flexible microchannel heat sinks, International Journal of Heat and Mass Transfer, 48, 1739-1746, 2005:

$$0 = \frac{d p_{e1}}{dx_e} + u_1 \frac{\partial u_1}{\partial x_e}$$  \hspace{1cm} \text{Eqs. 14, 15}$$

$$\rho_1 C_p u_1 \frac{\partial T_{e_1}}{\partial x_e} = \frac{\partial q_{e_1}}{\partial x_e}$$  \hspace{1cm} \text{Eqs. 16, 17}$$

where $\mu$, $u$, $T$, $\rho$, $c$, and $k$ are the dynamic viscosity of the fluid, velocity field, temperature field, fluid density, fluid specific heat and the fluid thermal conductivity, respectively. Define the following dimensionless variables:

$$\tilde{\gamma}_e = \frac{\gamma_{e_1}}{H(x_e)}$$  \hspace{1cm} \text{Eqs. 18(a-d)}$$

$$\theta_e = \frac{T_{e_1}(x_e)}{\theta_{e_1}}$$  \hspace{1cm} \text{Eqs. 19, 20}$$

The dimensionless velocity fields $\tilde{u}_{e_1}(\tilde{x}_e)$ are obtained by solving Equation 14 and 15. They are equal to

$$\tilde{u}_{e_1}(\tilde{x}_e) = \frac{u_{e_1}(\tilde{x}_e)}{u_{e_1}(\tilde{x}_e)}$$  \hspace{1cm} \text{Eq. 19, 20}$$

The mean velocities $u_{e_1}(\tilde{x}_e)$ and $u_{e_1}(\tilde{x}_e)$ are related to pressure gradients inside the microchannels according to the following relationships:

$$u_{e_1}(\tilde{x}_e) = \frac{u_{e_1}(\tilde{x}_e)}{u_{e_1}(\tilde{x}_e)}$$  \hspace{1cm} \text{Eq. 21, 22}$$

where $u_{e_1}$ and $u_{e_1}$ are the mean velocities of the hot and cold fluids when $d=0$, respectively.
The quantities $u_{mom}$ and $u_{moc}$, and the mean velocities correction factor $CF$ are given by

$$u_{mom,c} = \frac{1}{12\mu_{k}} \frac{\Delta p_{h} / L}{\mu_{c} L}$$

Eqs. 23, 24

$$CF = \frac{A_{a}(1 + A_{d})^{2}}{(1 - A_{d})^{2}} - 1$$

Eqs. 25

where $\Delta p_{h} = P_{h} - P_{c}$ and $\Delta p_{c} = P_{c} - P_{e}$.

Imposing the variables given by Equations 3(c, d) and 18 on Equations 16 and 17 results in the following dimensionless equations:

$$Re_{hy}Pr_{hy}(CF)\mu_{hy}H_{hy} \frac{\partial \theta_{hy}}{\partial \xi_{hy}} = \frac{\partial^{2} \theta_{hy}}{\partial \eta_{hy}^{2}}$$

Eqs. 26, 27

where $Re$ and $Pr$ are the Reynolds number and the Prandtl number, respectively.

The Reynolds numbers are defined based on the following expressions:

$$Re_{hy} = \frac{\rho_{hy}u_{mom,hy}H_{hy}}{\mu_{hy}}$$

Eqs. 28(a, b)

The dimensionless parameter $E_{ct}$ can be expressed in terms of the flow Reynolds numbers as follows:

$$E_{ct} = \frac{3}{A_{a}K_{a}} \left( \frac{A_{d}}{A_{a}} \right) Re_{hy} + Re_{cy}$$

Eq. 29

where $K_{a}$, $A_{p}$, and $A_{a}$ are the dimensionless stiffness number, cold to hot fluids densities ratio and cold to hot fluids dynamic viscosity ratio, respectively. Mathematically, they are equal to $K_{a} = \frac{K}{\rho_{h} / \rho_{c}}$.

$$A_{p} = \frac{\rho_{p}}{\rho_{h}}$$

$$A_{a} = \frac{\mu_{a}}{\mu_{h}}$$

Eqs. 30, 31, 32

1.3. The Ideal Total Pumping Power Requirement

The total ideal pumping power requirements, $P_{n}$, can be expressed in terms of the dimensionless parameters as follows:

$$P_{n} = \frac{P_{n}}{\rho_{h}^{2}(\rho_{c}^{2} H_{c}^{2})}$$

Eq. 33

-continued

$$= \frac{\Delta p_{h} \theta_{hy} / \rho_{h} + \Delta p_{c} \mu_{hy} / \rho_{c}}{\rho_{c}^{2}(\rho_{c}^{2} H_{c}^{2})}$$

$$= \frac{12}{A_{a}} \left( \frac{A_{d}}{A_{a}} \right) \left( \frac{A_{a}}{A_{d}} \right) \mu_{c} \mu_{hy} H_{hy} CF$$

where $\dot{m}_{h}$ and $\dot{m}_{c}$ are the mass flow rate of hot and cold fluids, respectively.

1.4.1 Case (A): Insulated Di-Microchannels with Rotatable Separating Plate (Flexible Microheat Exchanger)

The boundary conditions for this case are given by

$$\theta_{h}(\xi_{h} = 0, \eta_{h}) = 0; \theta_{c}(\xi_{c} = 0, \eta_{c}) = 0$$

Eqs. 34(a, b)

$$\theta_{h}(\xi_{h} = 1 / A_{h} - \xi_{h}, \eta_{c} = 1) = 1 - \theta_{h}(\xi_{h}, \eta_{c} = 1)$$

Eq. 34(c)

$$\frac{\partial \theta_{h}}{\partial \eta_{h}} \bigg|_{\eta_{h}=1} = 0$$

Eq. 34(d)

$$\frac{\partial \theta_{h}}{\partial \eta_{h}} \bigg|_{\eta_{h}=a} = \frac{\partial \theta_{c}}{\partial \eta_{c}} \bigg|_{\eta_{c}=0} = 0$$

Eqs. 34(e, f)

where $A_{h} = \frac{\eta_{h}}{\eta_{h}}$. For this case, the effectiveness of the hot and cold fluids flows $\epsilon_{h}$ and $\epsilon_{c}$ can be defined as follows:

$$\epsilon_{h} = \frac{q'}{\theta_{h}(\xi_{h})_{T_{h}} - T_{c}}$$

Eq. 35, 36

$$\epsilon_{c} = \frac{q'}{\theta_{c}(\xi_{c})_{T_{c}} - T_{h}}$$

where $q'$ is the rate of heat transfer between the two fluids per unit width. Recall that $q'$ is given by

$$q' = (\rho_{h}c_{p})_{h}u_{h}H_{h}(T_{b,h} - T_{c}) - (\rho_{c}c_{p})_{c}u_{c}H_{c}(T_{b,c} - T_{c})$$

Eqs. 37, 38

where $T_{b,h}$ and $T_{b,c}$ are the mean bulk temperature at the exit of the hot and cold fluids, respectively. The mean bulk temperatures are given by:

$$T_{b,h,c} = \int_{0}^{\xi_{h,c}} \frac{u_{h,c}}{u_{h,c}} - u_{h,c}T_{c} d\eta_{h,c}$$

Eqs. 39, 40

In dimensionless parameters, the parameters $\epsilon_{h}$ and $\epsilon_{c}$ are equal to

$$\epsilon_{h} = \theta_{h,c} \cdot \eta_{h,c} = \frac{1}{A_{h}}$$

Eqs. 41, 42

$$\int_{0}^{\xi_{h,c}} u_{h,c} \eta_{h,c} T_{h,c} d\eta_{h,c}$$

[0055] Accordingly, the effectiveness of the microheat exchanger, $\epsilon$, which is the maximum value of $\epsilon_{h}$ and $\epsilon_{c}$ [15] is expressed mathematically as
Now, define the first performance indicator, $\gamma_1$, as the ratio of the rate of heat transferred between the two fluids per its ideal total pumping power requirement to that of the rigid microheat exchanger (case with $E_{\text{ext}}=0$). Mathematically, it is equal to

$$\gamma_1 = \frac{\epsilon_1}{\epsilon_{\text{ext}}},$$

Eq. 44

The local hot and cold flows convection heat transfer coefficients $h_h$ and $h_c$, respectively, are defined as

$$h_{h,c}(T_{\text{hot,cm}}(y_{\text{h,c}}) - T_{\text{h,c}}(y_{\text{h,c}})) =$$

$$-k_{h,c}\left(\frac{\partial T_{h,c}}{\partial y_{\text{h,c}}} \right)_{y_{\text{h,c}}=y_{\text{h,c}}}$$

Eq. 45, 46

Thus, the local hot and cold flows Nusselt numbers $Nu_h$ and $Nu_c$, respectively, are equal to

$$Nu_{h,c} = \frac{h_{h,c}H_{h,c}}{k_{h,c}} =$$

$$\frac{1}{\theta_{h,c}(x_{h,c}) - \theta_h(y_{h,c})} \left| \frac{\partial \theta_{h,c}}{\partial y_{h,c}} \right|_{y_{h,c}=y_{h,c}}$$

Eq. 47, 48

1.4.1A Approximate Analytical Solution for Fully Developed Conditions:


The latter number is for the case of laminar flow between insulated plate and plate subject to constant heat flux. The heat transfer rate across a differential element within the flexible microheat exchanger containing both fluids is given by:

$$\delta q' = -C_h \delta T_{\text{cm}}$$

$$= -C_h \delta T_{\text{cm}}$$

$$= \left(\frac{T_{\text{cm}} - T_{\text{cm}}}{(1/h_h) + (1/h_c)}\right) \delta q$$

Eq. 50

$$\delta q' = \left(\frac{Nu_{h,c}}{H_{h,c}(A_h - 1) + 2} \right) \left(\frac{T_{\text{cm}} - T_{\text{cm}}}{H_h/k_h}\right) \delta q$$

Eq. 51

The differential of the mean bulk temperatures difference across any section can be obtained using Equations 49(a-c). It is equal to

$$d(T_{\text{cm}} - T_{\text{cm}}) = \left(\frac{1}{C_h} \frac{1}{C_c} \frac{Nu_{h,c}/H_h}{(A_h - 1) + 2} \right) d\gamma$$

\[ \text{Eq. 52} \]

The power $\Phi$ is given by

$$\Phi = \left(\frac{A_t}{P_{\text{cm}}} - \frac{1}{P_c} \right) \left(\frac{Nu_{h,c}}{2A_tA_t(A_t - 1)CP} \right)$$

Eq. 53

It can be shown using Equations 35 and 52 that $\epsilon_s$ is equal to

$$\epsilon_s = 1 - \left(\frac{A_t + \left[\frac{1 + A_t}{1 - A_t}\right]}{1 + A_t}\right) \left(\frac{1 + A_t \left[\frac{1 + A_t}{1 - A_t}\right]}{1 + A_t\left[\frac{1 + A_t}{1 - A_t}\right]}\right)^g$$

Eq. 54

Similarly, $\epsilon_c$ can be found to be equal to the following using Equations 36 and 52:

$$\epsilon_c = 1 - \left(\frac{A_t + \left[\frac{1 + A_t}{1 - A_t}\right]}{1 + A_t\left[\frac{1 + A_t}{1 - A_t}\right]}\right) \left(\frac{1 + A_t\left[\frac{1 + A_t}{1 - A_t}\right]}{1 + A_t\left[\frac{1 + A_t}{1 - A_t}\right]}\right)^g$$

Eq. 55


$$\epsilon = 1 - \exp(-NTU(1 - C^s))$$

Eq. 56

where $C_h = \frac{\rho_h c_v h_h H_h}$ and $C_c = \frac{\rho_c c_v h_c H_c}{}$. Note that $U$ is the overall heat transfer coefficient. In dimensionless parameters, Equation 49(c) can be expressed as

$$\frac{d(T_{\text{cm}} - T_{\text{cm}})}{d\gamma} = \left(\frac{1}{C_h} \frac{1}{C_c} \frac{Nu_{h,c}/H_h}{(A_h - 1) + 2} \right) d\gamma$$

\[ \text{Eq. 57} \]

Accordingly, NTU will be the equivalent number of transfer units. It is given by
where \( U_e \) is the equivalent overall heat transfer coefficient. Note that \( C^* = \frac{C_{\text{min}}}{C_{\text{max}}} \), where \( C_{\text{min}} \) and \( C_{\text{max}} \) are the minimum and maximum values of \( C \), and \( C^* \), respectively. By utilization of Equations 54 and 55, the following relationship can be obtained:

\[
\frac{U_e}{U_e^{\infty \rightarrow \infty}} = \frac{1}{2A_p(C^*)} \left( \frac{1 + A_p}{1 + A_p (1 + A_p)/(1 + A_p)} \right) \quad \text{Eq. 58}
\]

1.4.2 Case (B): DL-Microchannels with Rotatable Separating Plates Subject to Uniform Heat Flux, \( \dot{q}^* \), from Below

[0068] The boundary condition given by Equation 34(e) is changed for this case to the following:

\[
\frac{\partial h}{\partial y} |_{y=0} = A_p \cdot H_0 (x_h)
\]

where \( A_p \) is the dimensionless heat flux parameter. Mathematically, it is equal to the following:

\[
A_p = \frac{q^*_h H_0}{k_h (T_h - T_e)} \quad \text{Eq. 59}
\]

[0069] The local convection heat transfer coefficient for the heated plate side, \( h_{\text{hs}} \), is defined as

\[
h_{\text{hs}} = \frac{\partial h}{\partial y} |_{y=0} = A_p \cdot H_0 (x_h)
\]

[0070] Thus, the local Nusselt number for the heated plate side, \( N_{\text{Nu}} \), is equal to

\[
N_{\text{Nu}} = h_{\text{hs}} \cdot \frac{T_h - T_e}{k_h} = \frac{A_p \cdot H_0 (x_h)}{[\theta_0(y_h, y_h = 0) - \theta_{\text{h0}}(y_h)]}
\]

[0071] An important indicator for this case is the ratio of the difference between the maximum heated surface temperature and inlet cold fluid temperature to the difference between the inlet hot and inlet cold temperatures. It is denoted by \( \lambda_{\text{hs}} \). Mathematically, it is equal to:

\[
\lambda_{\text{hs}} = \frac{T_h - T_e}{T_h - T_e} = 1 - \theta_0(y_h, y_h = 0)_{\infty \rightarrow \infty}
\]

[0072] Define the second performance indicator, \( \gamma_2 \), as the ratio of \( \lambda_{\text{hs}} \) value for the present heated DL-flexible microchannel to that for the conventional rigid one (case with \( K_a \rightarrow \infty \)) when both operated under the same ideal pumping power. Mathematically, it is given by

\[
\gamma_2 = \left( \frac{\lambda_{\text{hs}}}{\lambda_{\text{hs}}^{\infty \rightarrow \infty}} \right)_{\infty \rightarrow \infty}
\]

[0073] The relation between the hot flow Reynolds number for the present case, \( Re_h \), and that for the conventional rigid one, \( Re_h \), that satisfies the constraint of Equation 64 is given by

\[
Re_h = \sqrt{\frac{1}{CF} - \left( \frac{A_p}{A_p} \right)^2 \frac{Re_h^2}{Re_h^{\infty \rightarrow \infty}}}
\]

when both microchannels have the same the same cold flow Reynolds number. Equation 65 can be solved using iterations, as \( C_F \) acts as a function of both \( Re_h \) and \( Re_h \).

2. NUMERICAL METHODOLOGY

[0074] Equations 26 and 27 are coupled through their boundary conditions given by Equations 34(c, d) and must be solved numerically using an iterative method. The accurate implicit-finite-difference method given by Blottner, F. G., 1970, “Finite-Difference Methods of Solution of the Boundary-Layer Equations”, AIAA Journal, 8, pp. 193-205, is appropriate to be used for the present problem. These equations were discretized using three-points central difference quotients for the first and second derivative terms with respect to \( y_h \) and \( y_c \) directions. For the first derivative with respect to \( y_h \) and \( y_c \), two points backward differencing quotients was used. The finite difference equations of Equations 26 and 27 along with their boundary conditions for the flexible microheat exchanger case are given by

\[
R_{\text{hs}} = \frac{Pr_{\text{hs}} C_F (H_{\text{hs}}) (\theta_h)_{i,j} - \theta_h)_{i,j+1} - \theta_h)_{i,j-1}}{\Delta x_h} \quad \text{Eq. 66, 67}
\]

\[
\theta_h)_{i,j+1} = \theta_h)_{i,j-1} = 0; \quad \text{Eq. 68(a-f)}
\]

\[
(\theta_h)_{i,j} = 1 - (\theta_h)_{i,j-M+1,j-N} - (\theta_h)_{i,j-M+1,i-j-1}
\]

where \( (i, j) \) and \( (ii, jj) \) are the location of the discretized points in the numerical grids of the lower and upper microchannels, respectively. \( \Delta x_h \) and \( \Delta x_c \) are the distances between the two consecutive \( i \) and \( ii \) vertical lines in the numerical grid, respectively. However, \( \Delta y_h \) and \( \Delta y_c \) are the distances between the two consecutive \( j \) and \( jj \) horizontal lines in the numerical grid, respectively.

[0075] The resulting \( N-1 \times (N+1) \) tridiagonal systems of algebraic equations obtained by Equations 66 and 67 at a given \( i \) and \( ii \)-sections, respectively, were solved using the
Thomas algorithm as in Blottner, F. G. (1970). The solution was based on the initial estimate of the temperature at the separating plate, \( T_{i,n} \). The same procedure was repeated for the consecutive \( i \) and \( ii \) values until they reached the value \( M (M = 2001) \) at which \( T_{i,n} - T_{i,n} \). Then, the temperatures at the separating plate are corrected using Equation 68(d). After that, the tri-diagonal systems given by Equations 64 and 65 were resolved again. Then, the previous procedure was repeated until the maximum change in \( \theta_{i,j} \) is less than between the current and previous iteration is lower than 10^-3. The results of the numerical method were compared with the analytical solutions derived in this work as can be shown in FIG. 4. Excellent agreements between both solutions are shown in this figure.

In the discussed results, both hot and cold fluids are taken to be liquid water. The maximum cold flow Reynolds number was taken to be \( Re_{c} = 33 \). This corresponds to cold flow mean velocity of \( u_{m} = 0.11 \) m/s when the average height of the microchannel is \( H_{c} = 300 \) μm. The maximum stiffness number was taken to be \( K = 120 \times 10^6 \). This corresponds to supporting seals stiffness per unit separating plate width equal to \( K = 0.12 \) N.

3. RESULTS AND DISCUSSION

3.1. Effect of \( E_{o} \) on Maximum Relative Displacement and CF-Correction Factor

The variations of the maximum displacement of the separating plate \( (A_{d}) \) and the mean velocity correction factor (CF) with the dimensionless elastic parameter, \( E_{o} \), are shown in FIG. 2. The elastic parameter increases as the stiffness of the separating plate decreases. This effect increases the separating plate rotation causing an increase in \( A_{d} \). As \( A_{d} \) increases, both upper and lower microchannels approach the close flows passages condition under same pressure drops. Thus, the CF-mean velocity correction factor decreases as \( E_{o} \) increases. This effect is clearly seen in FIG. 2.

3.2. Results and Discussion of the Flexible Microheat Exchanger Case

3.2.1 Nusselt Numbers Distributions and Analytical Solution Assumption Validity

Effects of the dimensionless axial distance \( (x) \) and the aspect ratio \( (A_{d}) \) on hot and cold flows local Nusselt numbers \( (Nu_{h}, Nu_{c}) \), respectively, are illustrated in FIG. 3. This figure is generated for the case when both fluids have the same thermal capacitance \( (Re_{c}Pr_{h}=A_{h}Re_{c}Pr_{h}) \). For long microchannels as when \( 1/A_{d} = 60 \), both \( Nu_{h} \) and \( Nu_{c} \) converge to a constant value for most of \( x_{c} \)-values. This value is very close to \( Nu_{ad} = 2.605 \). This corresponds to the case of fully developed channel flow between insulated plate and plate subject to constant heat flux. Thermal entry region effect is clearly seen in FIG. 3 for the case with \( 1/A_{d} = 10 \), short flexible microheat exchangers. For this case, both \( Nu_{h} \) and \( Nu_{c} \) are noticed to decrease as distances from the inlet sections increase as shown in FIG. 3.

3.2.2 Variation of Effectiveness and First Performance Indicator with \( Re_{c} \)

The variation of the flexible microheat exchanger effectiveness \( (e) \) with the cold fluid Reynolds number \( (Re_{c}) \) is shown in FIG. 4. The increase in \( Re_{c} \) causes an increase in the cold-flow thermal capacitance \( (C_{c}) \). As \( Re_{c} \) approaches \( Re_{c} = 7.256 \) (when \( Re_{c} = 15 \)) or \( Re_{c} = 12.0881 \) (when \( Re_{c} = 25 \)), the value of \( C_{c} \) approaches \( C_{c} \). This results in \( e_{c} = e_{c} \) and produces the minimum effectiveness \( (e = e_{min}) \) as shown in FIG. 4. If \( Re_{c} < 7.256 \) (when \( Re_{c} = 15 \)) or if \( Re_{c} > 12.0881 \) (when \( Re_{c} = 25 \)), the temperature difference for the cold fluid is larger than that for the hot fluid thus, \( e = e_{c} > e_{min} \). However, \( e = e_{c} < e_{min} \) if \( Re_{c} > 7.256 \) (when \( Re_{c} = 15 \)) or if \( Re_{c} > 12.0881 \) (when \( Re_{c} = 25 \)). Therefore, \( e \) decreases as \( Re_{c} \) increases until it reaches \( e = e_{min} \), after which it starts to increase as \( Re_{c} \) increases as depicted from FIG. 5. For rigid microheat exchangers \( (K \rightarrow \infty) \), the effectiveness is smaller than that for the flexible microheat exchangers as shown in FIG. 4. It is noticed from FIG. 5 that the first performance indicator \( (\gamma_{1}) \) is always larger than one indicating that the proposed flexible microheat exchanger transfer more heat than the rigid one under constant pumping power. As such, the superiority of flexible microheat exchangers over rigid ones is implied.

3.2.3 Variation of Effectiveness and the First Performance Indicator with \( KA \)

The increase in the dimensionless stiffness number \( (Ka) \) is accomplished by an increase in the supporting seals stiffness per unit width of the separating plate \( (K) \). As \( Ka \) decreases, the separating plate supporting seals softness increases. As such, the separating plate maximum relative displacement \( (A_{d}) \) increases as \( Ka \) decreases. As a consequence, velocities near the separating plate in regions very close to the fluids exits increase. Also, expansions of the microchannels near the inlet regions increase, which allow the thermal boundary layers to further, develop down stream applications. Thus, convection heat transfer coefficients are expected to increase as \( Ka \) decreases. As such, \( e \) increases as \( Ka \) decreases as can be seen in FIG. 6. Similarly, it is noticed from this figure that \( \gamma_{1} \) is always larger than one and it increases as \( Ka \) decreases. Again, this proves the superiority of flexible microheat exchangers over rigid ones.

3.2.4 Variation of the First Performance Indicator with Aspect Ratio

The increase in the microchannel length causes a decrease in the aspect ratio. As such, the moment of the pressure forces across the separating plate increases. Thus, the maximum relative displacement \( A_{d} \) increases which augments the first performance indicator as shown in FIG. 7.

3.3. Results and Discussion of Heated D1-Flexible Microchannels Device

FIG. 8 illustrates that the second performance indicator \( (\gamma_{2}) \) is smaller than one at small cold flow Reynolds numbers. This is expected because large pressure drops which induce large Reynolds numbers and further produce large moments of forces that can cause closing of flows passages. This effect increases \( \gamma_{2} \) significantly above one. On the other hand, it is noticed from FIG. 9 that the second performance indicator is smaller than one for large stiffness numbers. Similar effects can be concluded for the role of the aspect ratio on the second performance indicator as shown in FIG. 10. It is seen from FIGS. 8, 9 and 10 that \( \gamma_{2} \) has local minimum near the switch points. At these points, the increase in \( Re_{c} \) or the decrease in both \( Ka \) and \( A_{d} \) values cause the values of \( \gamma_{2} \) to be larger than one. Therefore, the superiority of the heated microchannels with rotatable separating plates can be implied for moderate aspect ratios and moderate Reynolds and stiffness numbers. Typical heated plate temperature and Nusselt number distributions are shown in FIG. 11 for different cold flow Reynolds numbers.
3.4. Feasibility of the Microchannels with Rotatable Separating Plates Devices

[0083] The inlet and outlet ports 105, 115, 120 and 110 of the passages of the proposed device 100 can be drilled on the upper and lower plates 140 and 145 as shown in FIG. 1A. For this configuration, changes in inlet and exit heights with operating conditions have no influence on inlet and exit ports dimensions. Moreover, the expected leakage of fluid flow between the passages of the proposed device can be controlled by having well sealed separating plates using carefully designed soft seals. The manufacturing of such kinds of seals, which should exhibit high softness, high strength and high anti-leaking sealant attributes, is most probably possible especially after the rapid development of nanotechnology fabrication methods. Finally, having multiple micro-passage systems within each layer can eliminate the possibility of having deflected separating plate other than that due to its rotation. See, Lee, D. Y., and Vafai, K., 1999, “Comparative Analysis of Jet Impingement and Microchannel Cooling for High Heat Flux Applications” International Journal of Heat and Mass Transfer, 42, pp. 1555-1568. For this case, each micro-passage is isolated against the other one by using sides anti-leaking soft seals that provide an additional support to the separating plate.

4. CONCLUSIONS

[0084] The problem of heat transfer inside DL-microchannels devices with rotatable separating plates was considered. Two different devices having different boundary conditions are analyzed. These are the flexible microheat exchanger and the heated DL-flexible microchannels device. The rotational angle of the separating plate is related to the moment of pressure forces on it by the theorem of linear elasticity applied on its flexible supports. Appropriate forms of the coupled energy equations for both fluid flows were solved using an iterative implicit-finite-difference method. The numerical results of flexible microheat exchanger were validated against obtained closed-form solutions based on fully developed thermal conditions.

[0085] It has been found that flexible microheat exchangers have a higher effectiveness than rigid microheat exchangers. Moreover, flexible microheat exchangers can transfer more heat than rigid exchangers operating under the same pumping power. Moreover, the heated DL-flexible microchannels device can provide more cooling effects per unit pumping power than rigid devices at flow Reynolds numbers below specific values. In addition, the cooling attributes for DL-flexible microchannels device where found to be better than those for the heated DL-rigid microchannels device at stiffness numbers and aspect ratios above certain values. In accordance with the disclosed embodiments, specific values have been found to vary with the heating load magnitude. Finally, DL-microchannels devices with rotatable separating plates can be utilized in electronic cooling applications, particularly those involving nanofabrication technologies.

[0086] Based on the foregoing, it can be appreciated that a number of embodiments, preferred and alternative, can be implemented. For example, in one embodiment, an apparatus may include a first substrate and a second substrate, the first substrate having a face in contact with at least one hot medium and having an other face in contact with a first heat exchanging fluid; the second substrate having a face in contact with a cold medium and having the other face in contact with a second heat exchanging fluid; the faces of the first and second substrates in contact with the first heat exchanging fluid and the second heat exchanging fluid are opposing each other; at least one flexible seal attached to the first substrate and to the second substrate to form at least one closed enclosure; a pivoted rod aligned along the centre line between the first and second substrates; and a separating plate mounted about a pivoted axis of the pivoted rod such that at least one closed enclosure is divided to form an upper microchannel and a lower microchannel.

[0087] In another embodiment, the separating plate can be supported via the at least one flexible seal. In other embodiments, the first substrate can comprise at least two confined openings. In an additional embodiment, the second substrate can comprise at least two confined openings. In yet another embodiment, the hot and cold media are replaceable with insulated media. In still other embodiments, the first and second heat exchanging fluids can possess at least one of the following: different temperatures, different phases or both different temperatures and different phases. In another embodiment, the second heat exchanging fluid can flow in the upper microchannel and the first heat exchanging fluid can flow in the lower microchannel. In the still other embodiments, the separating plate can rotate about the pivoted axis. In another embodiment, the first substrate, the second substrate and the separating plate can be configured from ultra high thermally conductive materials. In another embodiment, the first heat exchanging fluid and the second heat exchanging fluid can be allowed to flow either in a counter-direction, a parallel-direction, a cross-direction or skew-directions within the lower and upper microchannels. Note that in general, the moment of pressure forces on the separating plate is related to its rotational angle by a theorem of linear elasticity applied to the at least one flexible seal.

[0088] It will be appreciated that variations of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

What is claimed is:

1. An apparatus comprising:
   a first substrate and a second substrate, said first substrate having a face in contact with at least one hot medium and having another face in contact with a first heat exchanging fluid;
   said second substrate having a face in contact with a cold medium and having said other face in contact with a second heat exchanging fluid;
   said faces of said first and second substrates in contact with said first heat exchanging fluid and said second heat exchanging fluid are opposing each other;
   at least one flexible seal attached to said first substrate and to said second substrate to form at least one closed enclosure;
   a pivoted rod aligned along said centre line between said first and second substrates; and
   a separating plate mounted about a pivoted axis of said pivoted rod such that at least one closed enclosure is divided to form an upper microchannel and a lower microchannel.

2. The apparatus of claim 1 wherein said separating plate is supported via said at least one flexible seal.
3. The apparatus of claim 1 wherein said first substrate comprises at least two confined openings.

4. The apparatus of claim 1 wherein said second substrate comprises at least two confined openings.

5. The apparatus of claim 1 wherein said hot and cold media are replaceable with insulated media.

6. The apparatus of claim 1 wherein said first and second heat exchanging fluids possess at least one of the following: different temperatures, different phases or both different temperatures and different phases.

7. The apparatus of claim 1 wherein said second heat exchanging fluid flows in said upper microchannel and said first heat exchanging fluid flows in said lower microchannel.

8. The apparatus of claim 1 wherein said separating plate rotates about said pivoted axis.

9. The apparatus of claim 1 wherein said first substrate, said second substrate and said separating plate are configured from ultrahigh thermally conductive materials.

10. The apparatus of claim 1 wherein said first heat exchanging fluid and said second heat exchanging fluid are allowed to flow either in a counter-direction, a parallel-direction, a cross-direction or skew-directions within said lower and upper microchannels.

11. The apparatus of claim 1 wherein said moment of the pressure forces on said separating plate is related to its rotational angle by a theorem of linear elasticity applied to said at least one flexible seal.

12. An apparatus comprising:
   a first substrate and a second substrate, said first substrate having a face in contact with at least one hot medium and having another face in contact with a first heat exchanging fluid;
   said second substrate having a face in contact with a cold medium and having another face in contact with a second heat exchanging fluid;
   said faces of said first and second substrates in contact with said first heat exchanging fluid and said second heat exchanging fluid are opposing each other;
   at least one flexible seal attached to said first substrate and to said second substrate to form at least one closed enclosure;
   a pivoted rod aligned along said centre line between said first and second substrates; and
   a separating plate mounted about a pivoted axis of said pivoted rod such that said at least one closed enclosure is divided to form an upper microchannel and a lower microchannel, wherein said separating plate is supported via said at least one flexible seal.

13. The apparatus of claim 12 wherein said first substrate comprises at least two confined openings.

14. The apparatus of claim 12 wherein said second substrate comprises at least two confined openings.

15. The apparatus of claim 12 wherein said hot and cold media are replaceable with insulated media.

16. The apparatus of claim 12 wherein said first and second heat exchanging fluids possess at least one of the following: different temperatures, different phases or both different temperatures and different phases.

17. The apparatus of claim 12 wherein said second heat exchanging fluid flows in said upper microchannel and said first heat exchanging fluid flows in said lower microchannel.

18. The apparatus of claim 12 wherein said separating plate rotates about said pivoted axis.

19. The apparatus of claim 12 wherein said first substrate, said second substrate and said separating plate are configured from ultrahigh thermally conductive materials.

20. An apparatus comprising:
   a first substrate and a second substrate, said first substrate having a face in contact with at least one hot medium and having another face in contact with a first heat exchanging fluid;
   said second substrate having a face in contact with a cold medium and having another face in contact with a second heat exchanging fluid;
   said faces of said first and second substrates in contact with said first heat exchanging fluid and said second heat exchanging fluid are opposing each other;
   at least one flexible seal attached to said first substrate and to said second substrate to form at least one closed enclosure;
   a pivoted rod aligned along said centre line between said first and second substrates; and
   a separating plate mounted about a pivoted axis of said pivoted rod such that said at least one closed enclosure is divided to form an upper microchannel and a lower microchannel, wherein said first heat exchanging fluid and said second heat exchanging fluid are allowed to flow either in a counter-direction, a parallel-direction, a cross-direction or skew-directions within said lower and upper microchannels.