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The Heat Transfer Enhancement Analysis and Experimental Investigation of Non-Uniform Cross-Section Channel SEMOS Heat Pipe

Shang Fu-Min[1], Liu Jian-Hong[1] and Liu Deng-Ying[2]
[1]*Changchun Institute of Technology, Changchun 130012, Jilin,*
[2]*Institute of Engineering Thermo physics, Chinese Academy of Sciences, Beijing 100080,*
China

1. Introduction

Along with the development of modern high-technology, the heat generation of many equipments that were heated in unit area becomes more and more, usually it is over 100W/cm^2, even 10^3~10^{4}W/cm^2, such as super power integrate circuit, high temperature battery for electricity generation, nuclear reactor, high power mini-machinery, mini-sized steam turbine, superconductive electricity generation and distribution devices and airship. Due to the trend of high rate heat generation, a new cooling technology is needed to solve the problem between design flexibility, needed space and heat-dissipating performance.

A new period of heat pipe began with Pulsation Heat Pipe, invented by Japanese Doctor H. Akachi in 1994, later is called Self-Exciting Mode Oscillating-Flow Heat Pipe[1, 2] (SEMOS Heat Pipe). Although it is just known less than sixteen years, the SEMOS Heat Pipe is drawing worldwide attention because of its immeasurable application potency. A lot of research about the SEMOS Heat Pipe is doing in Japan, U.S.A, Germany, Russia, Ukraine and China[3-5].

Notwithstanding all the research done is to understand the working principles of SEMOS Heat Pipe because it is still at its initial stage, this new high effective heat transfer device is catching attention on heat transfer due to phase transition all over the world. Thus the contradiction between cooling device downsizing and heat generation increasing is still the major technical problem to improve and bring the heat-dissipating performance to a higher lever for all of the researchers along with the development of new high-technology.

2. Heat transfer characteristics of SEMOS Heat Pipe

According to the working principles of SEMOS Heat Pipe, there are two basic methods to improve the heat transfer performance, one is to enhance the thermal conduction between the interface of the pipe and the working gas-liquid medium in the pipe, the other method is to increase the surge frequency and circulating power. Actually the thermal conduction of the SEMOS Heat Pipe between the pipe surface and the working liquid in the pipe is the non-steady phase transition heat transfer between the biphasic fluid and the interface of pipe. The first method to enhance the thermal conductive performance is to improve the liquid evaporation, the clotted phases transforming frequency, and intensity of phase transforming. Another method is to increase the heat transfer rate between the working liquid and the working surface. What needed to do to enhance the surge frequency and the reliable circulating power is to increase the difference in temperatures between the hot and cold liquid via enhancing the pulsing process inside the pipe. Obviously the two enhancing methods discussed above could supplement each other.

On the principle of field coordination heat transfer enhancement[6, 7], which was put forward by Guo Zengyuan academician, the heat transfer rate increases as field coordination coefficient between velocity vector field and temperature grads field increases. Although the convection heat transfer theory of single phase has been demonstrated, there still exists the problem about the heat transfer during the phases transforming between two phases, especially in a limited heat-dissipating space. Thus it needs further study on that if the coordination theory could be used universally.

This experiment to enhance the heat transfer rate of SEMOS Heat Pipe is to validate the application of field cooperation theory on the heat transfer field with phases transforming. The SEMOS Heat Pipe with non-uniform cross-section is used for this experiment so as to improve surging frequency and circulating power.

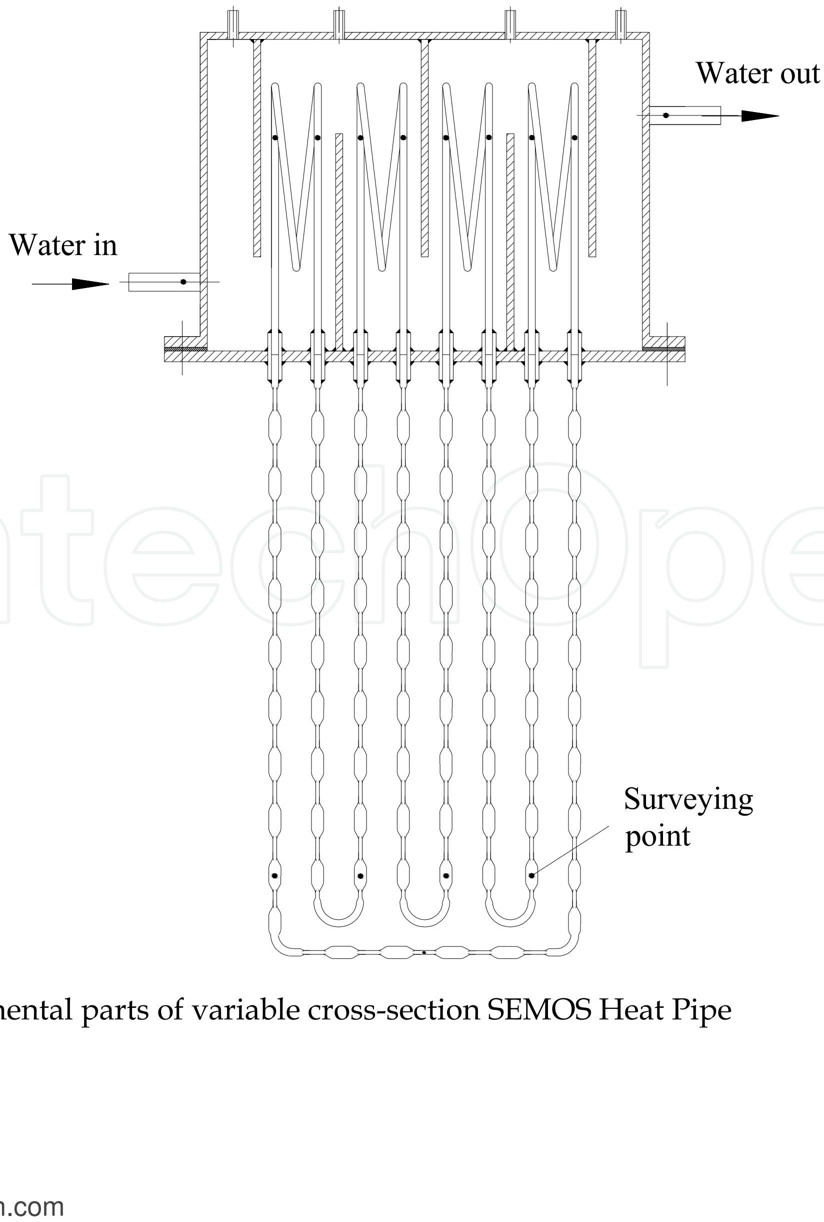
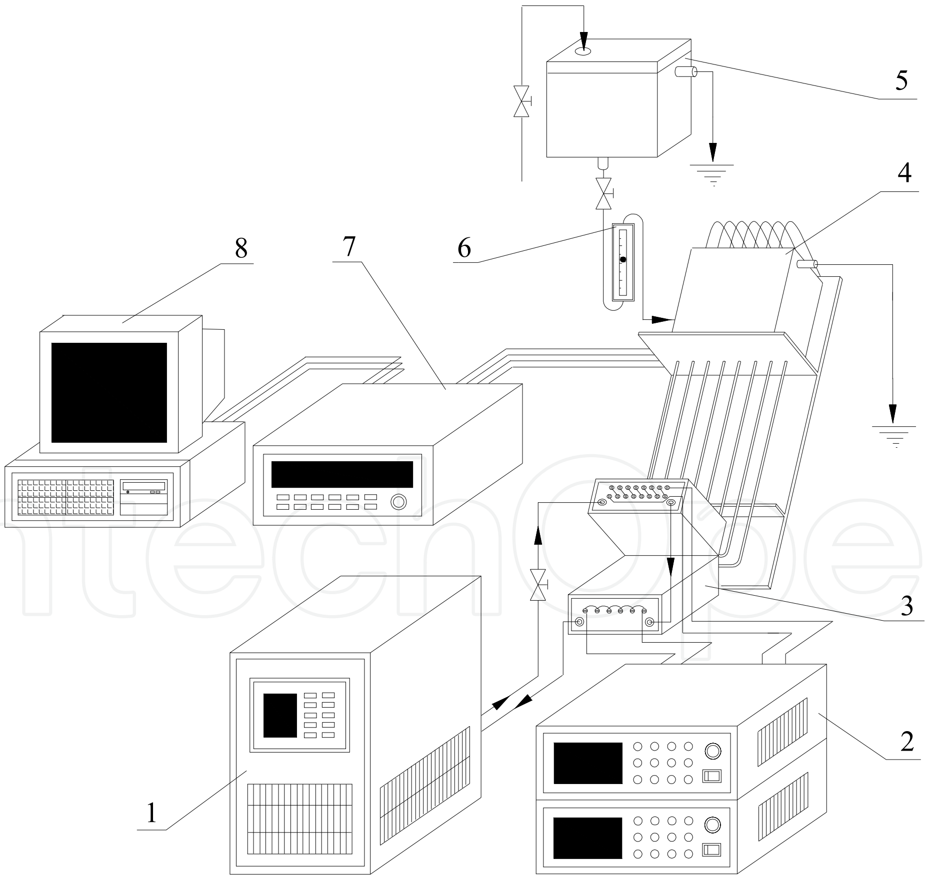


Fig. 1. Experimental parts of variable cross-section SEMOS Heat Pipe

3. Experiment set up and method

The object for this experiment is SEMOS Heat Pipes with closed loop, one is a SEMOS Heat Pipe with a uniform cross-section of 3mm inner diameter, the other heat pipe based on the uniform one with elliptic non-uniform cross-section is consisted of vertically intervened heating section and insulating section of the pipes. As shown in figure 1 the material of the heat pipe is brass, the working fluid in the pipe is distilled water with high purity, the amount of working is φ=42%, the obliquity of the heat pipe is θ=55^0, the pressure in the heat pipe is p=1.8×10^{-3}Pa.

Figure 2 shows the experiment set up for the thermal performance measurement consisting of the main test apparatus, a laser supply and its cooler and its power supply system, a data acquisition system combined with personal computer to show the data collected. As shown in figure 2, the laser supply is consisted of eight passages Quantum Well Laser Diode Arrays, the maximum output power of every single channel is 50W, the heating electrical current range is 5~40A, the wave length of the laser is 94nm. The heat input comes from continual laser heating while every single could work individually or together as heater, and 20 K-type thermocouples were mounted on the surface at diameter of 1mm totaling 20 in number. Accordingly, the data acquisition frequency is 1/s based on the 20 data collecting channels and the data acquisition precision is at ms.



1—Unit of refrigeration cycle, 2—Power supply, 3—Laser supply, 4—Experimental table of SEMOS Heat Pipe, 5—Water tank, 6—Flow meter, 7—Data acquisition system, 8—Personal computer

Fig. 2. Experimental system of SEMOS Heat Pipe heat transfer enhancement

4. Experiment result and discussions

4.1 Compare and contrast heat pipes uniform with non-uniform cross-section

Judging from the experiments above mentioned to the heat pipes with uniform cross-section and non-uniform cross-section, figure 3 shows the transfer efficiency under different heating power (heat electrical current *I*). The transfer efficiency is given by the following equation.

$$P_o = Gc_p\left(T_2 - T_1\right) \tag{1}$$

Where, G denotes the amount of the cooling water, kg/s; c_p is the specific heat of water under constant pressure, J/(kg·K). T_2 and T_1 denote the output and input temperature of cooling water, K.

As can be seen from the figure, the transfer rate of the heat pipe with non-uniform cross-section is lower than that of the heat pipe with uniform cross-section when the heating electrical current is relatively low, while the rate of heat pipe with non-uniform cross-section would exceed that of the heat pipe with uniform cross-section as the heating electrical current of laser supply increases. It is suggested from the trend of the graph of transfer rate P_o~I that the more heat input the more of the difference of transfer rate between the heat pipe with non-uniform cross-section and the heat pipe with uniform cross-section becomes. The transfer rate of heat pipe with non-uniform cross-section is 13.6% higher than that of the heat pipe with uniform cross-section at the maximum heat input in this experiment, the heating electrical current of every channel is 23A that is about 25.5W.

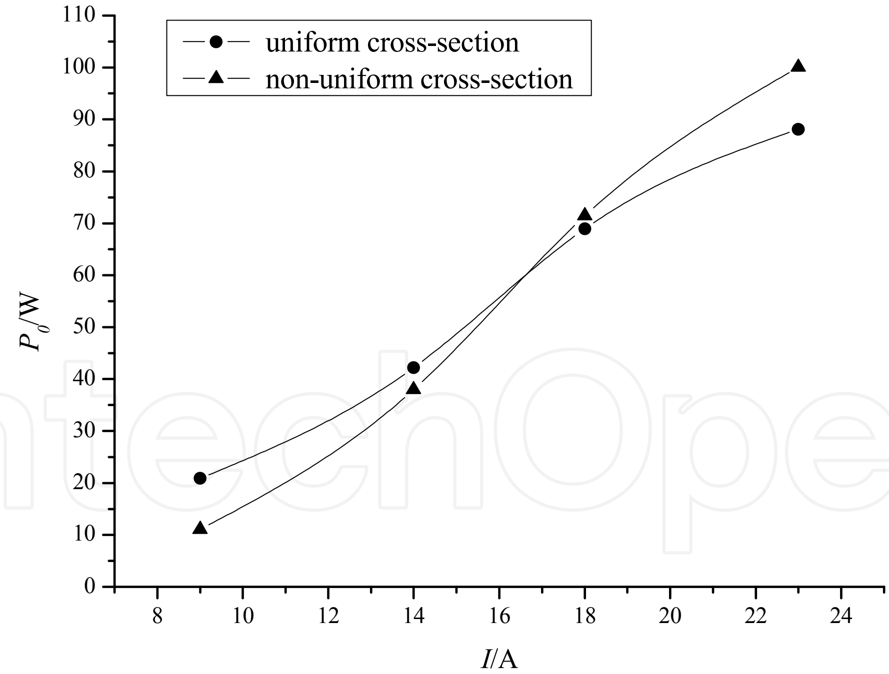


Fig. 3. Compare transferred power uniform with non-uniform cross-section heat pipes

4.2 Compare uniform and non-uniform cross-section with pure conductor equivalent thermal conductivity

Figure 4 shows the relationship between heat input and equivalent weight heat transfer coefficient under three different conditions, SEMOS Heat Pipes with non-uniform cross-section and uniform cross-section and the heat pipe without working fluid that means pure conductor. According to the different output and the difference in temperature of corresponding hot and cold end of the heat pipe, the equation of heat transfer coefficient is shown as below, while

$$\lambda_d = \frac{P_o l}{\left(\overline{T_h} - \overline{T_c}\right)F} \tag{2}$$

Where, P_o denotes transfer rate, W. l is the distance between the hot and cold end, m. $\overline{T_h}$ and $\overline{T_c}$ Mean temperature of hot end and cold end, K. F Total heat transfer area, m², total circulate cross section area for heat transfer, total cross section area for pure conductor.

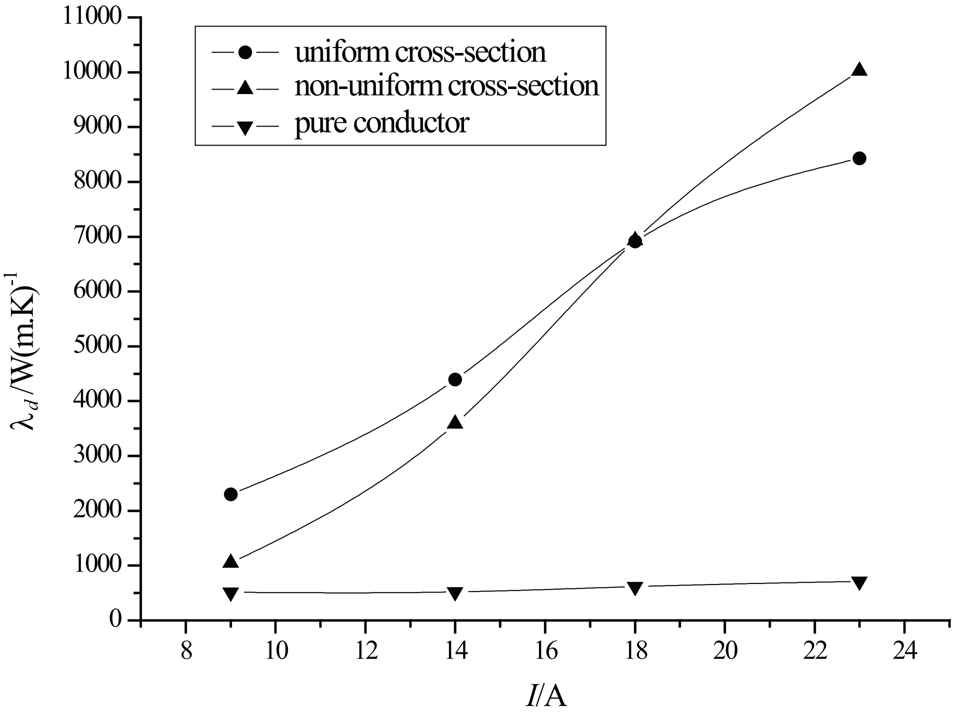


Fig. 4. Compare equivalent thermal conductivity in varying cases

It can be seen from the figure that the equivalent weight heat transfer coefficients under all the three conditions increase as the heat input increases, while the coefficient of the non-uniform heat pipe increased the most and that of the pure conductor heat pipe the lest. When the heat input is low, the heat transfer coefficient of uniform cross-section heat pipe is higher than that of the non-uniform one. As the heat input increases, the heat transfer coefficient of the non-uniform cross-section heat pipe becomes higher that that of the uniform one and the difference between them becomes bigger and bigger, so it is suggested that under certain condition the heat transfer rate could be improved by changing the form of the cross-section of the SEMOS Heat Pipe. The figure also shows that the function on heat transferring of heat pipes especially SEMOS Heat Pipes is better than the function on heat conducting of brass pipe. Under that heat input range, the equivalent weight heat transfer coefficient of heat pipe is as 4~15 times as that of the pure conductor one, and this difference becomes bigger as the heat input increases. At maximum heat input (23A for every single channel) in this experiment, the equivalent weight heat transfer rate of non-uniform cross-section heat pipe is 19% higher than that of uniform cross-section one, 14 times higher than that of the pure conductor one.

4.3 Heat transfer performance of the heat pipe with non-uniform cross-section

Theoretically, there are two reasons to answer that why non-uniform heat pipe consisted of the heating section and insulating section could improve heat transfer rate. One is that the portrait eddy formed for the Non-uniform Cross-Section of cross and adds parts of the velocity on the pipe surface vertically, that means the temperature grads field and velocity vector field co-operate together, then the heat transfer rate could be improved. Meanwhile the resistance on the working fluid increases because of the non-uniformity of the cross-section, certain amount of the heat input is needed for the SEMOS Heat Pipe with non-uniform cross-section to improve heat transfer performance in word and deed. Because the advantage of the SEMOS Heat Pipe with non-uniform cross-section on improving heat transferring could be demonstrated easily when the portrait eddy becomes stronger and circulating power becomes declining, the SEMOS Heat Pipe with non-uniform cross-section is more suitable for the high density working fluid.

On the other side, as shown in figure 5 it could be found by monitoring the temperature of the cold and hot end surface that the hot end surface temperature surging amplitude of the non-uniform heat pipe is lower than that of the uniform one, while the surging frequency is higher. In SEMOS Heat Pipe with non-uniform cross-section the circulating power increases because of the alternation of liquid evaporation and gas clot. The accelerated motion inside the pipe because of unsteady expanding and contracting process along with the vertical velocity on the interface could finally improve the heat transfer performance.

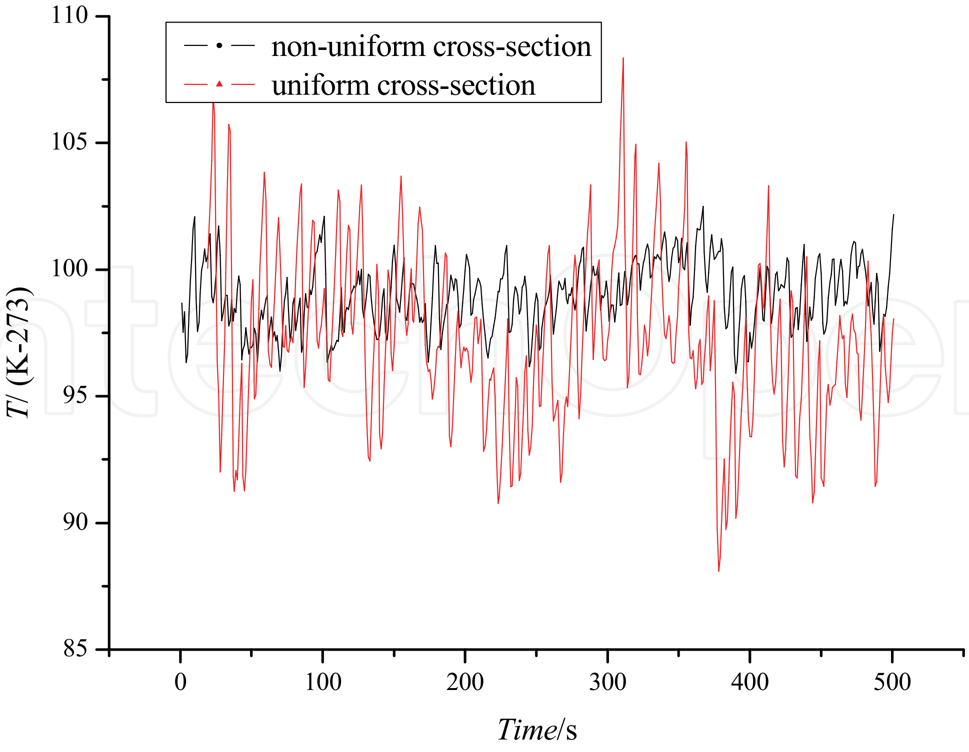


Fig. 5. Compare wave with hot end surface temperature

5. Conclusions

1. The precondition to improve heat transfer performance with non-uniform SEMOS Heat Pipe is that heat input must be high enough to overcome the resistance brought by the non-uniform cross-section.
2. The heat transfer rate of SEMOS Heat Pipes with non-uniform cross-section and uniform cross-section is much higher than that of the pure conductor under same experimental condition. The SEMOS Heat Pipe with non-uniform cross-section is more suitable for high density heat current because it especially shows its advantage when the heat input is high.
3. The surging frequency of SEMOS heat pipe with non-uniform cross-section becomes higher than that of the SEMOS Heat Pipe with uniform cross-section as the heat input increase.
4. It is confirmed in this experiment that field coordination heat transfer enhancement theory suit for heat transfer due to phase transition of the SEMOS Heat Pipe, which is an exemplification that this law could be used in the heat transfer domain of heterogeneous fluid. Which is the base of the future research and development for new SEMOS Heat Pipe.

6. Acknowledgement

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7. Nomenclature

P	heating power, W
G	rate of mass flow, $\text{kg}\cdot\text{s}^{-1}$
T	temperature, K
$\bar{T}$	mean temperature, K
I	heating electrical current, A
F	Total heat transfer area, m^2
c	specific heat at constant pressure, $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$
l	distance between the hot and cold end, m
λ	heat transfer coefficient, $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$

Subscripts

p	pressure
o	out
d	equivalent
h	hot end
c	cold end

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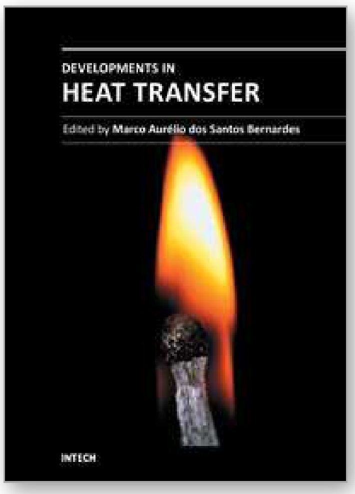

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This book comprises heat transfer fundamental concepts and modes (specifically conduction, convection and radiation), bioheat, entransy theory development, micro heat transfer, high temperature applications, turbulent shear flows, mass transfer, heat pipes, design optimization, medical therapies, fiber-optics, heat transfer in surfactant solutions, landmine detection, heat exchangers, radiant floor, packed bed thermal storage systems, inverse space marching method, heat transfer in short slot ducts, freezing an drying mechanisms, variable property effects in heat transfer, heat transfer in electronics and process industries, fission-track thermochronology, combustion, heat transfer in liquid metal flows, human comfort in underground mining, heat transfer on electrical discharge machining and mixing convection. The experimental and theoretical investigations, assessment and enhancement techniques illustrated here aspire to be useful for many researchers, scientists, engineers and graduate students.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821