Microchannel Heat Sink with nanofluids

The Summary of the PhD thesis

University Politehnica Timişoara

ing. Laza Ioan

PhD supervisor:

Prof. dr.ing. Dorin LELEA

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The miniaturization of electronic or medical devices became a very important issue in the last few decades. Decreasing the characteristic length has an impact on thermal and hydrodynamic phenomena like viscous heating, temperature dependent thermophysical properties or axial conduction through the channel walls. Design of such micro-devices is influenced by these phenomena.

The applications of thermal micro-systems might be find in micro-electronics, Micro-Electro–Mechanical–Systems, Micro–Thermal–Machines, Micro Bio-Reactors, Lab–On–Chip or space applications.

In the case of micro-electronic devices or fuel cells, the heat flux might reach the values over 10^6 W/m^2. Accordingly to predictions of International Technology Roadmap for Semiconductors (ITRS 2011) until 2026 the heat flux of the IT devices will exceed 800 W/cm^2 (fig.1.1) [1]. For the proper operation of the microsystems, the temperature has to be controled. The micro-thermal systems used for cooling of the electronic devices imply the combined convection – conduction phenomena.

Micro-thermal devices consist of the series of microchannels with a very large ratio between the length and diameter. Consequently the Nusselt number might be considered constant as the fluid flow and heat transfer is in the fully developed region. It means that as the diameter decreases the heat transfer coefficient increases (eq. 1). In Fig. 2 the relation between the heat transfer coefficient and channel diameter is presented:

$$h = \mathrm{Nu}\frac{\lambda}{D} \tag{1}$$

It is observed that for water, hydraulic diameter of 100 μm and constant heat flux boundary condition q = const (Nu = 4.36), the heat transfer coefficient has the approximate value of $h \cong$ 30000 W/m^2 K.

Besides, the large pressure drops might be a very serious disadvantage of these systems. The ratio between the pressure drop and channel length increases with decreasing of diameter with power of 2 ($1/D^2$):

$$\frac{\Delta p}{L} = \frac{fRe \cdot u_m \cdot \mu}{2 \cdot D^2}$$

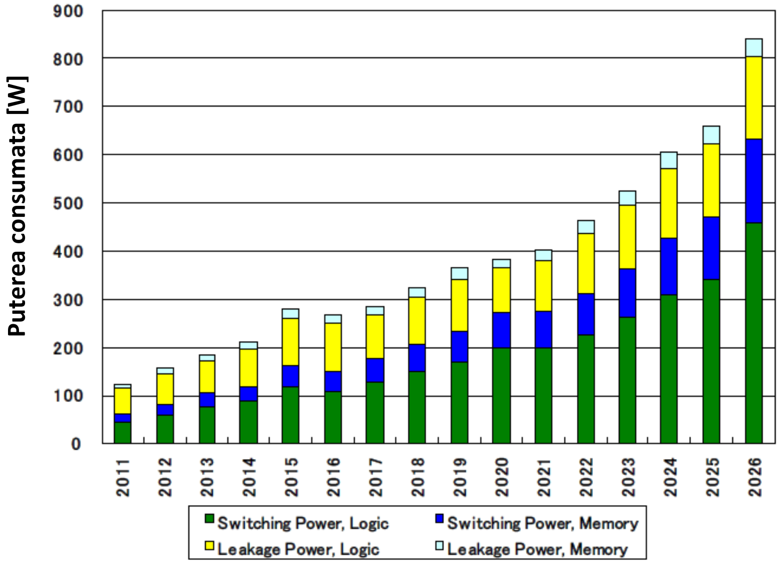

Figure 1.1 The heat consumption of IT devices (ITRS 2011)

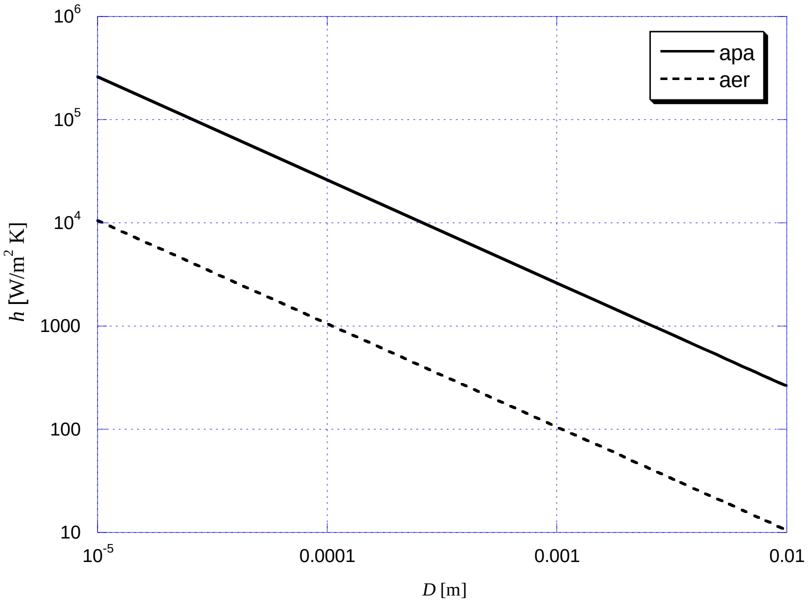

Figure 1.2 The heat transfer coefficient relation versus microtube diameter

The nanofluids were first defined and realized by Choi [2] as the mixture of nanoparticles and base fluid. The advantage of using them as the cooling medium is related to increasing fluid thermal conductivity. The comparative values of the thermal conductivity with the base fluid are presented in the table 1.1. Besides, the nanofluid specific heat is lower than that of the basic fluid. Moreover the nanofluid viscosity is higher that the base fluid viscosity. For nanofluids with volume concentrations up to $\phi = 7$ %, the viscosity increasing is approximately 20 – 40 % compared to the bas fluid. Consequently the higher fluid viscosity results in higher pumping power.

The nanofluids might be the suitable solution also for the renewable energy systems. Solar colectors, concentrated photovoltaic solar cells or desalinization systems are few examples. Moreover, the fundamental research on nanofluid flow and heat transfer is the pre-condition for suitable design of mixing devices used for nanodrug delivery as the remedy of some complex issues like Parkinson disease.

Table 1.1 Thermophysical properties of nanoparticles and water

Property	Water	Al_2O_3	TiO_2
Particle diameter [nm]		40	20
Density [kg/m^3]	998	3000	3940
Specific heat [J/kg K]	4183	880	710
Thermal conductivity [W/m K]	0.6	42.35	8.4

The scope of this PhD research is to define the novel concept for micro-electronics cooling based on microchannel heat transfer and nanofluids with metallic nanoparticles. Moreover the optimization of the micro-thermal system will be performed. Besides, proper definition and critical analysis on the evaluation criteria will be done. The later will be analyzed considering the temperature dependent fluid properties or a nanoparticle thermal conductivity.

The optimization of the thermal device will be made considering the nanoparticle volume concentration or diameter and material thermal conductivity.

Considering that nanofluids are two phase medium, the proper mathematic model for nanofluid flow and heat transfer simulations is analyzed. Consequently, there are two models available:

- The single phase approach, where these two phases are considered as the homogenous medium while the nanoparticle influence is considered through the relations for nanofluid thermal properties.
- The two-phase approach with separate definition of each of the phases through the partial differential equations.

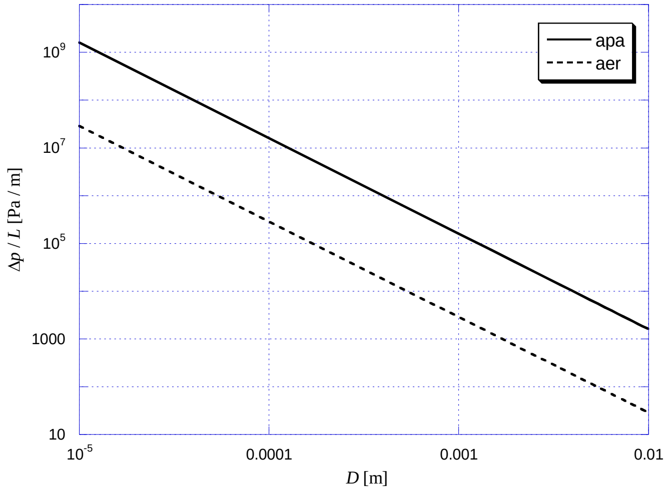

Figura 1.3 Variația căderii de presiune liniare în funcție de diametrul tubului

It has to be mentioned that the numerical simulations were validated with experimental results available in the literature. The maximum deviation was up to 8 % in the case of the Microchannel Heat Sink with tangential inlets, having diameter of 4 mm and nanofluids.

The obtained results presented in the chapter 5 reveal that conclusions regarding the performance evaluation are strongly dependent on evaluation criteria. In the case of the Reynolds number, higher viscosity of the nanofluids means higher fluid velocity. Consequently the question that arises in this case is if better performance is due to higher thermal conductivity or higher heat transfer coefficient obtained for higher velocity. So the performance evaluation based on the pumping power or flow rate is more realistic and closer to industrial applications.

If the surface temperature difference is considered as the constraint, the reduction is about $\Delta T = 0.7$ K for nanofluids with $d_p = 13$ nm and $\phi = 3\%$, only for lower mass flow rates. Moreover there is an optimum diameter that minimizes the substrate maximum temperature.

In chapter 6 the particle thermal conductivity influence on micro-heat sink performance is analyzed. The obtained numerical results have been presented as the relation between heat transfer coefficient or maximum temperature and Reynolds number or pumping power. The common conclusion is that thermal performance of the microchannel depends on nanoparticle thermal conductivity as well as particle volume concentration or particle diameter. For nanoparticle diameter $d_p = 13$ nm, the water has the highest heat transfer coefficient compared with Al_2O_3-water or TiO_2–water nanofluids. Besides, the heat transfer coefficient of Cu-water nanofluid has the higher values than those obtained for water. For larger nanoparticle diameters $d_p = 36$ nm, all the nanofluids considered in this research have higher values of the heat transfer coefficient compared with water. It has to be mentioned that the analysis was based on the fixed pumping power. Moreover the maximum temperature of the substrate is lower for Cu-water nanofluid.

References

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