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Comparative analysis of single phase microchannel for heat flow Experimental and using CFD

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Abstract

The emergence of close-packed energy-intensive elements of systems for many subject purposes necessitated their effective cooling in order to stabilize the temperature regime, providing the specified performance features. The solution to this difficult is based on the use of several methods of intensification heat transfer, but porous media have found the greatest application due to increase value of the heat transfer coefficient. The role of this method of intensification increases significantly when high-intensity heat fluxes are removed from compact heat-stressed surfaces, for example in electronic miniature devices in which electromagnetic energy dissipates into heat. The physical model of the currently recognized porous medium, which are commonly described as thick random sphere packaging, intertwined emptiness and completely refrigerated. The porosity of such layers is 0.2-0.4, and the application of factor intensification in the form of a rise in local speed inside the matrix results in considerable hydraulic losses in the pumped heat-sensitive atmosphere of liquid. Instead of high-pressure losses due to high porosity, thus retaining values of the local heat transfer coefficients, the usage of micro-channel heat exchange elements with a normal porous structure. The emergence of the possibility of growing homogeneous in structure and the geometry of silicon whiskers on a substrate has opened up new prospects in the use of microchannel elements for solving heat removal of high-intensity flows with compact surfaces. However, questions related to verification there are no hydrothermal characteristics of such media in the scientific literature, which does not allow you to go to the stage of creating specific heat exchange elements based on these environments.

The purpose of the study is to establish the regularities of convective heat transfer in microchannel media with a regular matrix structure from of silicon whiskers based on theoretical and CFD simulation and substantiation of intensification methods heat transfer during heat removal from compact surfaces.

Keywords: *microchannel, thermal management, I. C. electronic, CFD analysis, hydrothermal.*

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I. INTRODUCTION

1.1 Microelectronic devices management (Thermal)

The rise in heat dissipation and reduction in overall by microelectronic devices, thermal management becomes important to electronic product, semiconductor industries have been benefited the several decades following growth by the Moore‟s law. More than one billion transistors are used in today's high-performance Integrated Circuits (ICs). The size of incorporated circuits (ICs) has contracted drastically in late a long time because of expanded interest for higher preparing rates and bundle densities. High pass on temperatures because of these variables have hurt circuit effectiveness and dependability.

1.1.1 Need for cooling of integrated circuits

It is seen that throughout ongoing numerous years the amount of semiconductors that could be fixed on a silicon kick the basin has risen drastically. This example came to be known as the Moore‟s law, is intel originator and proposed name after [Moore G.E. (1965)] which portrays that the amount of semiconductors on a chip would twofold reliably. ITRS gauge that duplicating the semiconductors will notice Moor's law until 2014, after that the example will ease off with increasing of semiconductors after at customary spans**.**

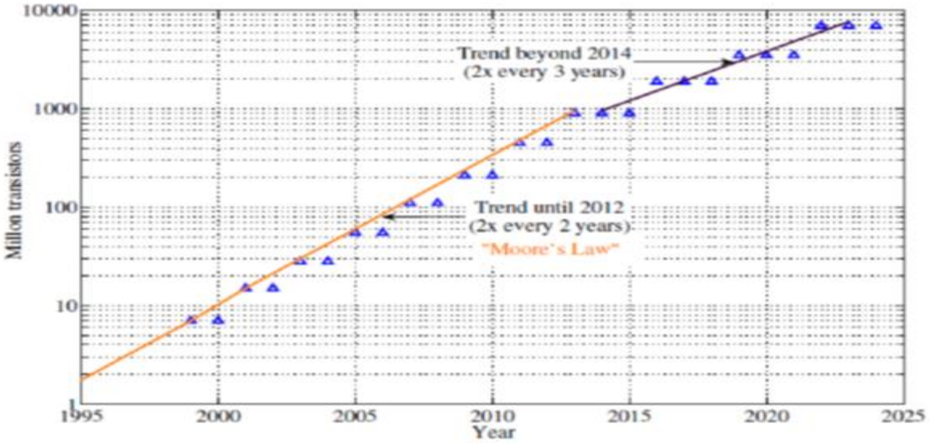

Figure1.1: Semiconductor Technology Road Map [Image source: ITRS update 2010]

1.1.2 Cooling of I. C as challenges

Most of the time semiconductor devices are subordinate temperature disillusionment segments Fig. 1.2 accelerates every development by chip crossing temperature. As per IRTS for gathering of individuals on the way of advancements, the crossing point semiconductor's temperature contraptions ought to be had at 85°C or lower to ensure the drawn out steady nature of devices. Table 1.1 records the all-encompassing characteristics for the best crossing point temperature, encompassing temperature, and use of power (heat dispersal) in the near term and expanded take for cost execution and unrivaled marketing variety.

1.2 Solutions as electronic cooling

1.2.1 Spreading heat and conduction

Taking everything together cooling applications, the glow from devices as heat sources ought to at first appear by methods for warm conductive surfaces which introduced to after cold fluid. It will in general allow to coolant. As example, as shown in Fig. 1.3, it ought to be driven from the chip through the top to the glow sink before it will in general be delivered to the including air. It can be shown, warm interface materials (TIMs) may be used to empower this cycle. All things considered a glow spreader as a level plate with high warm conductivity may be put between the chip and the top. Warmth dispersal is an incredibly amazing means to decrease the prerequisite for present day high-heat movement cooling decisions. It is generally seen that the warm benefit of decreasing the glow change by extending the district, increase the cost in light of consolidation of additional layer in the method of warmth stream.

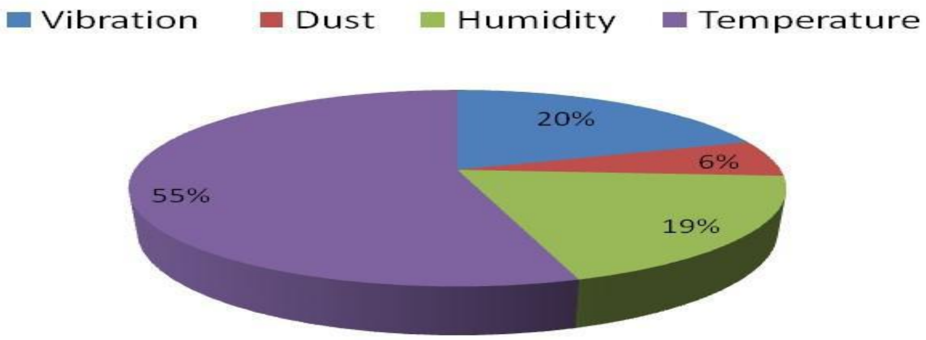

Figure1.2: Failure reasons of electronic devices [source data: Electronic Failure Analysis Handbook, Publisher: McGraw-Hill]

Table 1.1: ITRS short and lengthy define duration for 2003 to 2016

	Term							
Year of production	200 3	200 4	200 5	200 6	2 007	2 010	2 013	2016
Max. Junction Temperature (°C)								
Cost Performance	85	85	85	85	85	85	85	85
High Performance	85	85	85	85	85	85	85	85

Ambient Temperature (°C								
Cost Performance	45	45	45	45	45	45	45	45
High Performance	45	45	45	45	45	45	45	45
Power (W)								
Cost Performance	81	85	92	98	104	120	138	158
High Performance	150	160	170	180	190	218	251	288
Required Thermal Resistance(°C/W)								
Cost Performance	0.49	0.47	0.43	0.41	0.38	0.33	0.29	0.25
High Performance	0.27	0.25	0.24	0.22	0.21	0.18	0.16	0.14

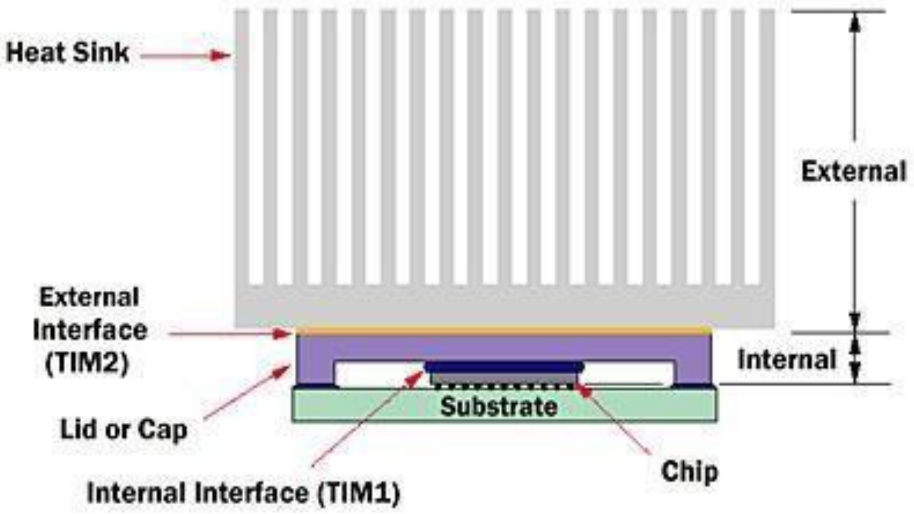

Figure1.3: heat sink with thermal conduction as chip package

1.2.2 Air cooling

It is by and large recognized that conventional air-cooling strategies are going to arrive at their cutoff for high-power applications. With standard fans a most extreme warmth move factor about 1500 W/m^{2}K can be reached with a satisfactory commotion level, which is around 1 W/cm^2 for a $\Delta T = 60K$ temperature contrast. Utilizing "large scale fly" impingement, hypothetically we may arrive at 900W/m2 K, however with unsatisfactory commotion levels. Non-standard fan/particular warmth sink mixes for CPU cooling are required to have a limit of about q = 50W/cm2.

1.2.2.1 Air cooling with new strategies:

Piezo fans

Fans of piezoelectric are generally low power, low-commotion, strong state contraptions that offer reasonable warm organization responses for a variety of adaptable electronic applications, incorporating PCs telephones In these fans piezoceramic patches are reinforced onto dainty, low-recurrence adaptable sharp edges driven at reverberation recurrence, consequently making an air stream coordinated at the hardware segments.

1.2.2.2 Synthetic jet cooling

A methodology utilizing intermittent miniature planes called "engineered jets" is as yet in the underlying phases of study. On account of the pulsating thought of the stream, the planes make more grounded entrainment than customary steady planes with a comparative Reynolds number, and more inconceivable mixing between as far as possible layers and stream.

1.2.3 Nano lightning

Another methodology for expanding the warmth move coefficient, known as "nanolightning," is likewise concentrated now-a-days. Nanolightning depends on "small size particle driven wind stream" utilizing extremely solid fields of electronic are made by nanotubes. As demonstrated in Figure 1.4, the ionized air particles are moved by another electric field, subsequently initiating optional wind stream. Cooling a warmth motion level of 40 W/cm2 has been accounted for. Innovation is being popularized through a new business (Thorrn).

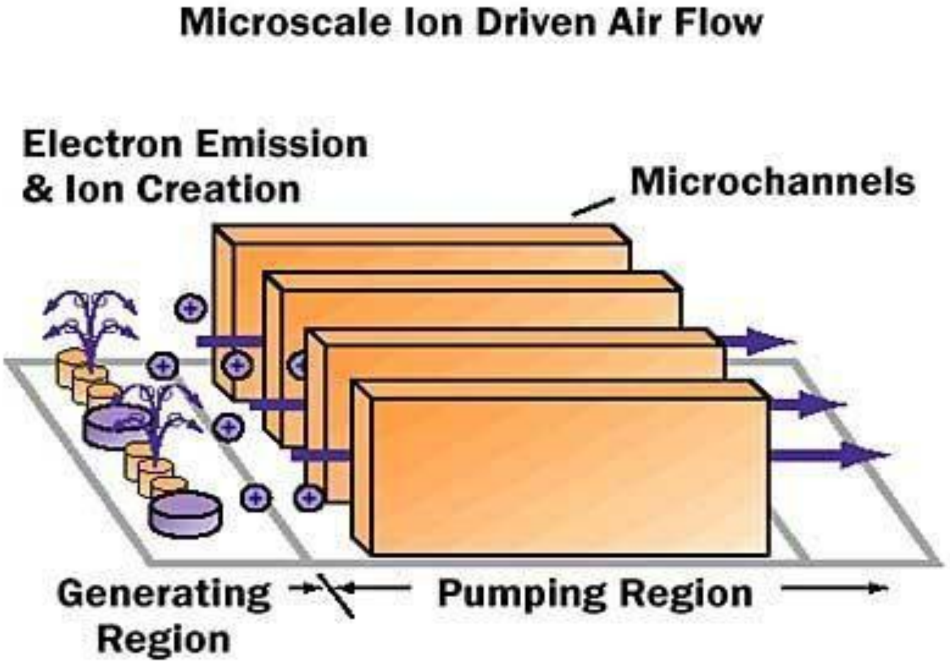

Figure1.4: Nano-lightning sketch [Lasance and Simons (2005)]

1.3 Liquid cooling needs

The proceeding with push towards all the more thickly pressed central processor will before long require more prominent warm dissemination than that can be given by straightforward constrained air cooling. It is for the most part seen that makers of electronic gadgets normally determine the pace of warmth dispersal and the greatest admissible segment temperature for solid activity. These two boundaries assist the specialist with deciding the cooling strategies that could be proper for the gadget viable.

1.4 Cooling of liquids

It is seen that fluids ordinarily have a lot higher warm conductivities than gases, and accordingly a lot higher warmth move coefficients related with them. Consequently, fluid cooling is undeniably more powerful than gas cooling. In any case, fluid cooling accompanies its own dangers and likely issues, like spillage, consumption, additional weight, and buildup. The pioneer water cooled warm administration item was presented by IBM in 1964.

1.4.1 Heat pipes

A glow pipe is a glow move device that combines the principles of both warm conductivity and stage progress to gainfully manage the trading of warmth between two in number interfaces. The glow pipe has an essential arrangement with a shut, cleared cylinder molded vessel with the internal dividers fixed with slim development or wick that is inundated with a working fluid.

Figure 1.5 shows a commonplace warmth pipe which has fixed and vacuum-siphoned vessels part of the way loaded up with fluid. At the point when warmth is applied aside of the line the fluid starts to disintegrate. The pressing factor inclination makes the fume stream towards the cooler areas, where it gathers and is shipped back by the wick structure, accordingly shutting the circle. Warmth pipes are considered as alow cost answer for cooling issue as they have best and have incredible potential when force levels and volume prerequisites increments.

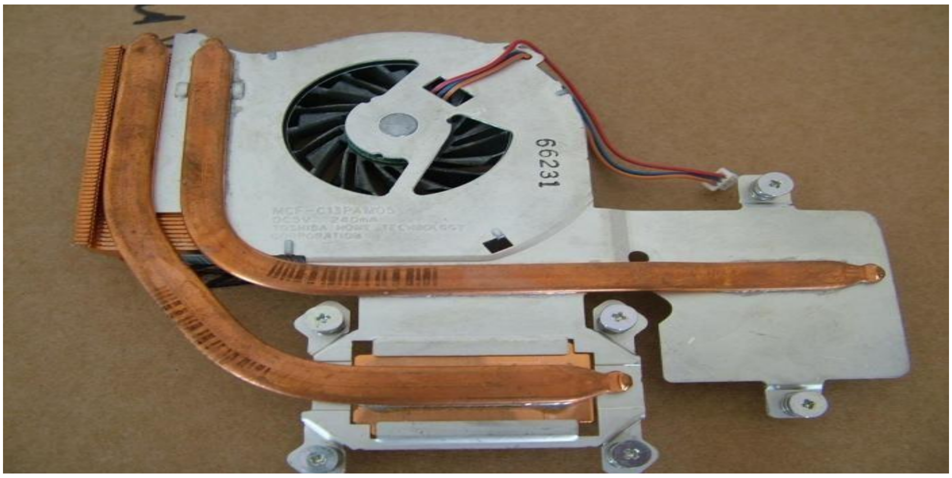

Figure1.5: Heat Pipe (Actual photograph)

1.4.2 Cold plates

Kandlikar and Hayner (2009) described substrate fluid flow channels configurations into four major parts:

- Cold plate (Formed tube type)
- Cold plate (Deep drilled)
- Cold plate (Machined Channel)
- Fin-fold pocket type Cold Plates

1.4.3 Immersion cooling

Actually the term „immersion cooling" infers that the gadget is dove totally into a liquid. In drenching cooling, bubbling warmth move happens on the grounds that the temperature of the material to be cooled is generally higher than the bubbling temperature of the fluid coolant. Direct fluid submersion cooling gives higher warmth move, as there is no divider isolating the warmth source from the coolant, the warmth can be taken out straightforwardly from the chip.

1.4.4 Indirect liquid cooling

Aberrant fluid cooling of electronic gadgets is considered as one, in which the fluid isn't in contact with the microelectronic chips, nor the substrate whereupon the chips are mounted. The test of this framework is to plan a decent warm conduction way from the microelectronic warmth source to the fluid cooled cold-plate appended to the module. The significant benefit of this aberrant fluid cooling is that, as there is no immediate contact with the electronic gadget, even water can be utilized as the coolant.

1.4.5 Single phase and two phase liquid cooling

Because of the higher coefficient of warmth movement, fluid coolant in comparison to conventional air cooling may be used. Heat move and liquid stream can be read for electrical cooling depending on the time of the coolant (single and two phases). The cooling of single-stage fluids includes dielectro and non-dielectric fluids. The major disadvantage of a fluid cooling in a single stage is that it demands large speeds or moderate water-driven widths, resulting in a greater decrease in the pressing factor.

1.5 Heat sink

Heat sink is a product, framework or atmosphere that uses warm touch to ingest and disseminate heat from another (either immediate or brilliant). The warmth sink is seen to move nuclear energy from a higher temperature to a lower liquid temperature form. Air is usually the liquid source, but water, coolant, oil and other fluids may also be used. Warm sinks are used in integrated circuits and force care for semiconductors by increasing warm mass and warmth dispersion to reduce their temperature (fundamentally by conduction and convection however less significantly by radiation). Aluminum blends and copper are the most commonly accepted heat sink components. Electronic devices are now and again used in warm administration of precious stone and other composite materials.

1.6 Cooling of integrated circuits using microchannel heat sink (MCHS)

It is seen that various cooling answers for warm administration of microelectronic gadgets have been created which incorporate expanded surface (balances), exceptionally equal air and fluid impingement frameworks, secluded inner conduction improvement, roundabout and direct fluid cooling with water and dielectric coolants. It is seen in incorporated circuits as the size decreases, expulsion of warmth turns into a more confounded since something very similar (or better) preparing power is stuffed into a more modest bundle. It is important to eliminate this warmth as successfully as could really be expected, ideally utilizing some cooling liquids.

For laminar, completely created single stage stream at steady Nusselt number these little channel size (Dh) in microchannel heat sink gives high warmth move coefficient. hDh 1 Nuconstant h (1.1) k Dh

1.1 Mathematical model of microchannel heat exchange an part based on a matrix of whisker monocrystals of silicon

The emergence of technology for directed growth of filamentous single crystals on a silicon substrate allows you to create a new type porous media with a regular structure [162]. The difference between such porous media from classical is in the absence of local conjugation (touch) crystals, i.e. the porous medium is a bundle of "quasi-cylinders"[163]. Based on the technology described in a layout was developed and created the basic version of a heat-removing element made of whisker monocrystals silicon grown on a silicon substrate (Figure 3.1).

II. RESULT AND DISCUSSION

2.1 Numerical modeling of hydrodynamics and heat transfer in microchannel's

Below are the results and analysis of numerical calculations [172-175] for determination of the required characteristics of a microchannel heat exchanger on based on a matrix of silicon whiskers developed in the course of performing the thesis to confirm the correctness and the adequacy of the proposed mathematical model.

An important step in building a mathematical model for research the characteristics of the coolant flow is the choice of the system of equations for calculation. The quality and accuracy of the results obtained depends on this. ANSYS Fluent these systems of equations are represented in turbulence models [124, 125,176-178].

The computational experiment was carried out for model representations a heat exchange element with a matrix of whisker silicon monocrystals, depicted in Model constants used in the ANSYS package are presented. The geometric dimensions of the model were 2 × 20 mm. Rest the geometrical dimensions and the arrangement of the spikes remained unchanged (Figure 1.6).

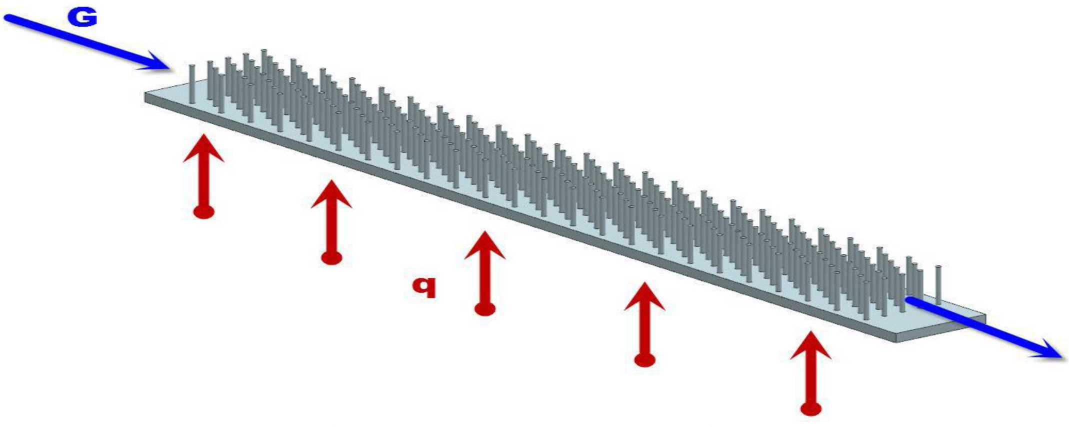

Figure 1.6: Plot of the substrate with thorns (coolant flow area not shown)

Arrows from left to right show the inlet and outlet of the cooler, from below the inlet heat flow. Computational domain with generated discrete partitioning shown in the figure consisted of 1.7.

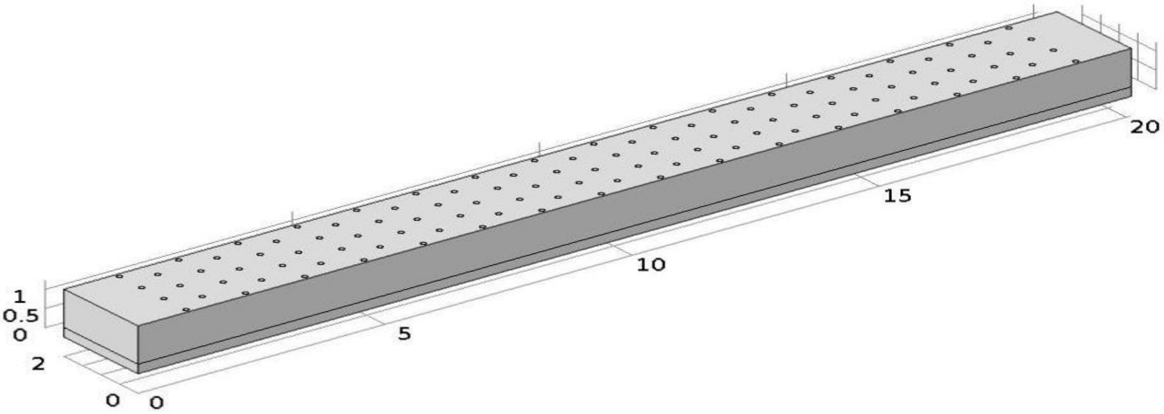

Figure 1.7: 3D model of the computational domain: 1- thorns; 2 - the core of the flow Cooler

The calculations varied the structure of the matrix with different center-to-center spike spacing 200x200, 400x400 and 600x600 microns. When analyzing the presented software image for the ANSYS package the following assumptions were used [124, 125, 183]:

- the coolant was a Newtonian fluid;
- the flow of the coolant was considered stationary and three-dimensional;
- the thermophysical properties of the flow were calculated at an average process temperature;
- initial hydrodynamic section at the inlet of the heat exchange element was absent;
- there was no heat flow through the heat exchanger body.

Flow rate range, inlet temperature and heat input were the same for all substrate designs. Initial data for the calculation:

- coolant consumption: 0.0006 kg / s, 0.0008 kg / s, 0.0010 kg / s, 0.0030 kg / s, 0.0050 kg / s, 0.0080 kg / s, 0.0100 kg / s;
- specific heat flux 100 W / cm^2
- specific heat flux 100 W / cm^2
- coefficient of thermal conductivity of silicon 130 W / (m · K);
- coefficient of thermal conductivity of water 0.6 W / (m · K);
- temperature of the cooler at the inlet 20 ° C.

Generated mesh for computational domains with the following parameters:
200x200 microns - mesh type: tetragonal; cell sizes: min 3.793176 · 10 –17 m, max 2.098848 · 10 –11 m; number of cells - 17,736,744 pcs;
400x400 microns - mesh type: tetragonal; cell sizes: min 4.980473 10 m, max 3.267845 · 10 –11 m; number of cells - 16,999,847 pcs;
600x600 microns - mesh type: tetragonal; cell sizes min 3.569304 10 m, max 3.999074 · 10 –11 m; number of cells - 16534874 pcs.

The grid is shown in Figures 2.3, 2.4.

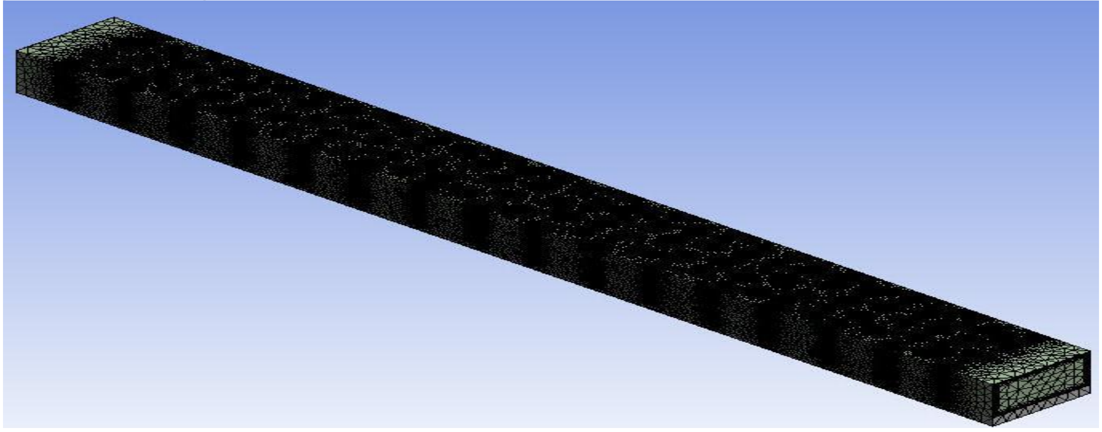

Figure 2.3: Generated mesh for the computational domain model

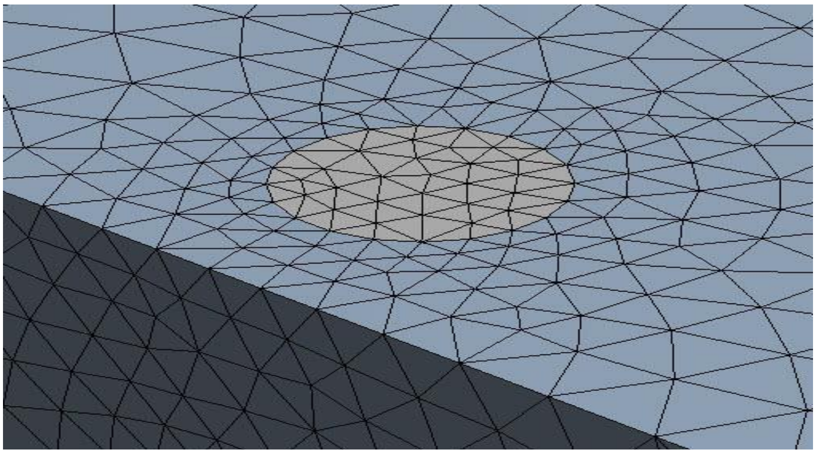

Figure 2.4: Enlarged image of the area of mesh thickening around the spike (heat sink element)

According to the results of the computational experiment, the fields of distributions of pressures, velocities and temperatures in the coolant are obtained and in the matrix (the results are given for0.003 *G* = kg / s). Dependencies defined Nusselt numbers (*Nu)* versus Reynolds number (*Re*) , temperature drop at the inlet and exit from the matrix, *t* Δ °C, average flow rate= υ m / s, pressure drop, *p* Δ kPa from the coolant flow rate, *G* kg / s for matrices with different center-to-center spike spacing: 200x200 microns (Figure 2.6-2.9), 400x400 microns(Figure 2.10–2.21) and 600x600 µm (Figure 2.23–2.33). Figures 214, 2.26the temperature dependences in the coolant flow and in the matrix frame are shown whiskers of silicon monocrystals from various flow rates, *G* kg / s, as well as temperature distribution along the height of the pins (Figure 2.15, 2.27) for matrices400x400 and 600x600 microns, respectively. The geometry of the spike dislocation is shown

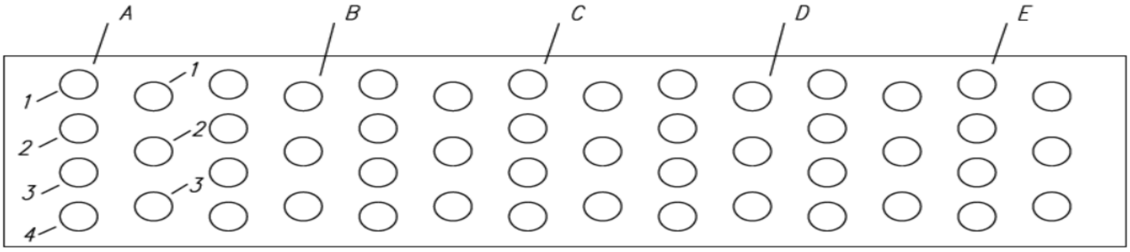

Figure 2.5: Scheme of arrangement of thorns

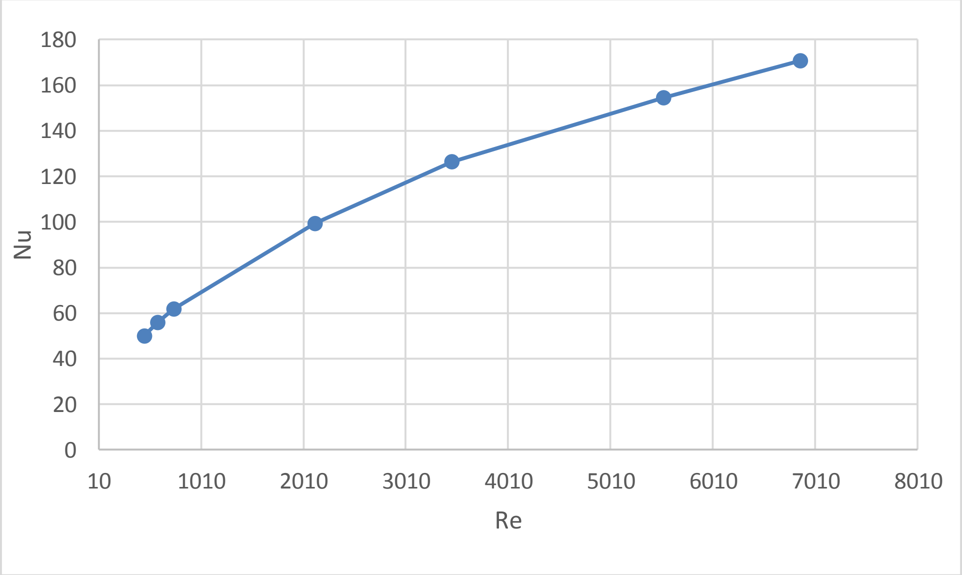

Figure 2.6: Dependence of the *Nu* number on the *Re* number (400x400 µm)

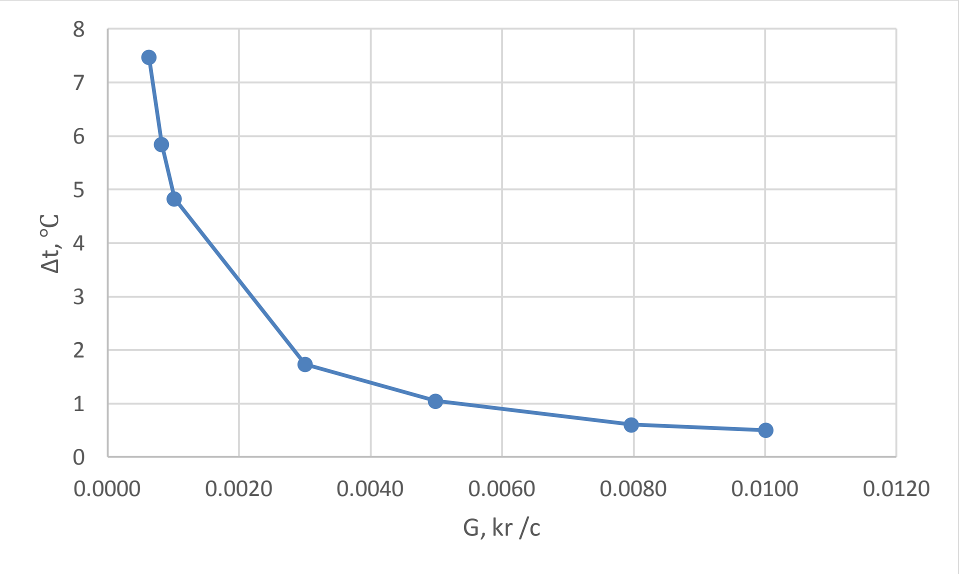

Figure 2.7: Dependence of the temperature difference at the inlet and outlet from the sample from the flow rate of the cooler (400x400 microns)

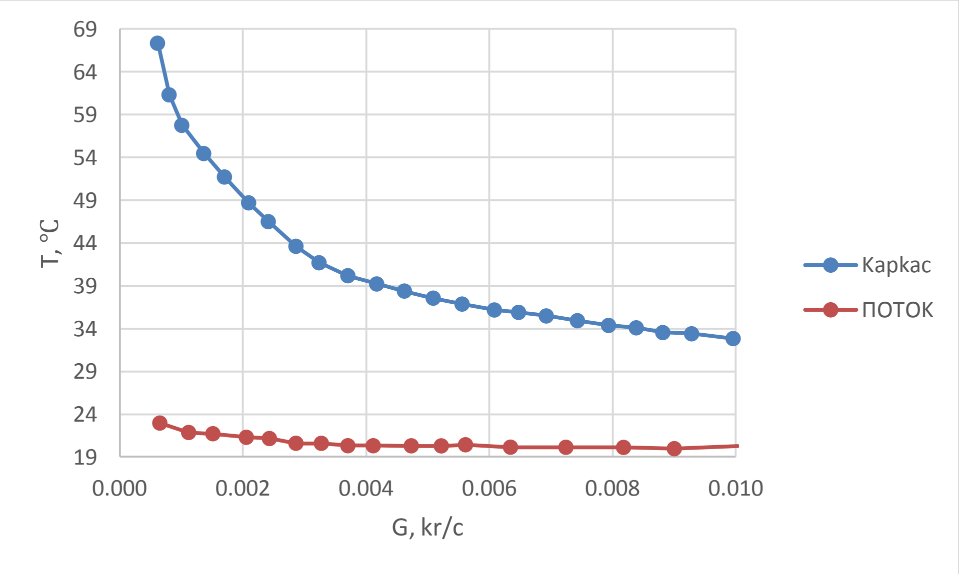

Figure 2.8: Dependence of the temperature of the flow and the matrix frame on the flow rate cooler (400x400) microns)

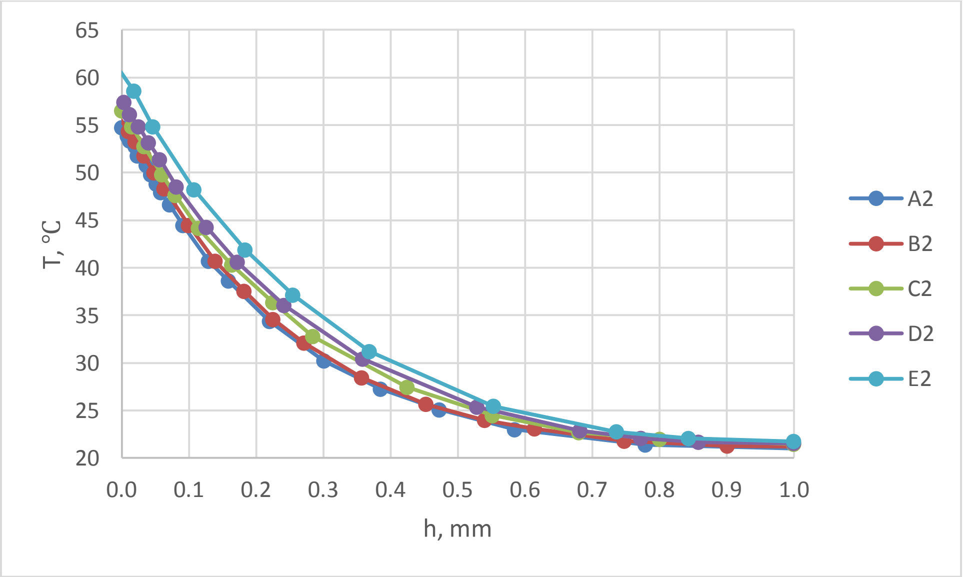

Figure 2.9: Dependence of temperature on the height of the spikes (400x400 microns)

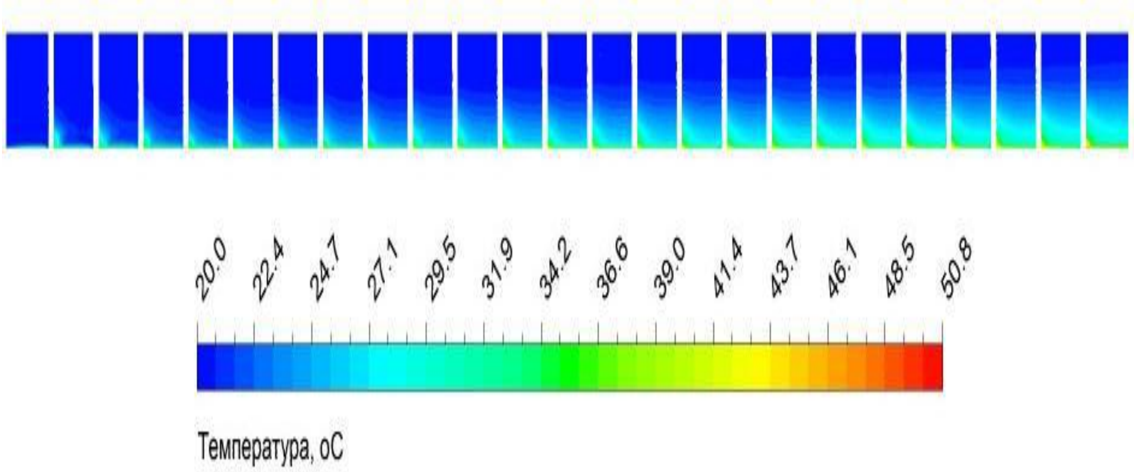

Figure 2.10: Temperature distribution in the flow (400x400 microns)

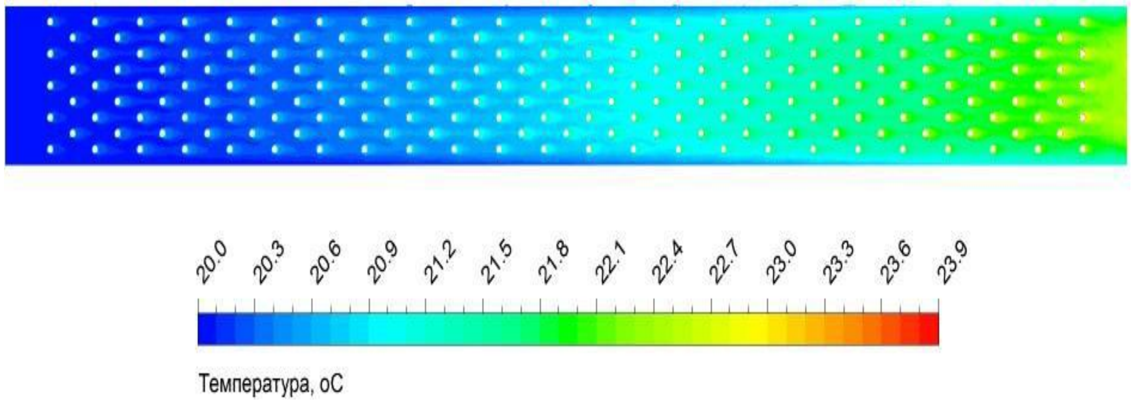

Figure 2.11: Temperature distribution in the flow (top view) (400x400 μm)

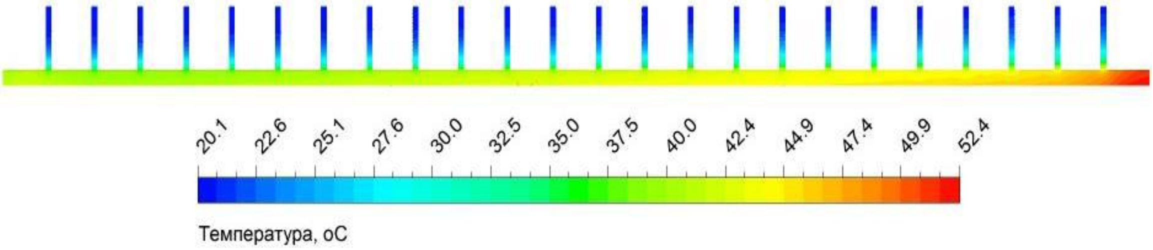

Figure 2.12: Temperature distribution in the matrix (400x400 microns)

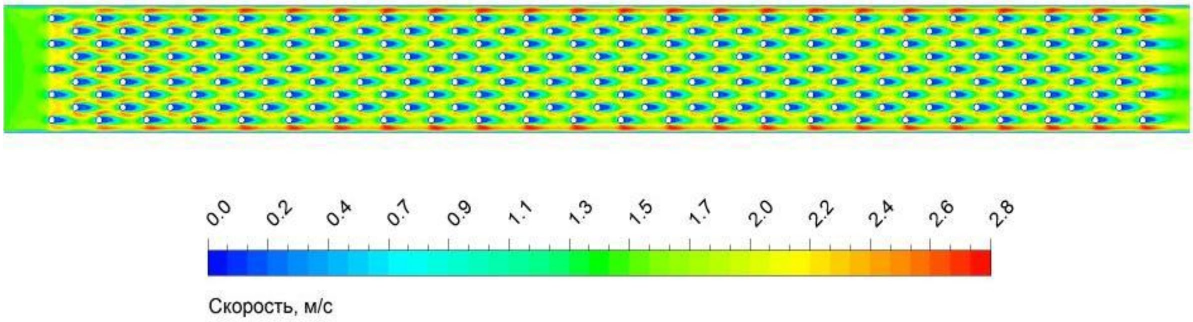

Figure 2.13: Velocity distribution in the flow (400x400 microns)

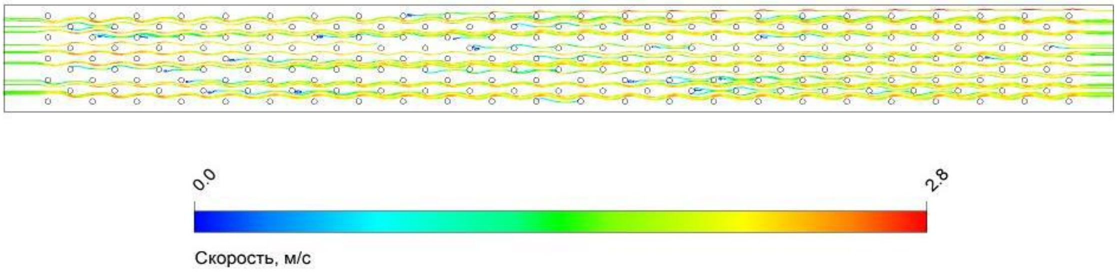

Figure 2.14: Distribution of streamlines (400x400 microns)

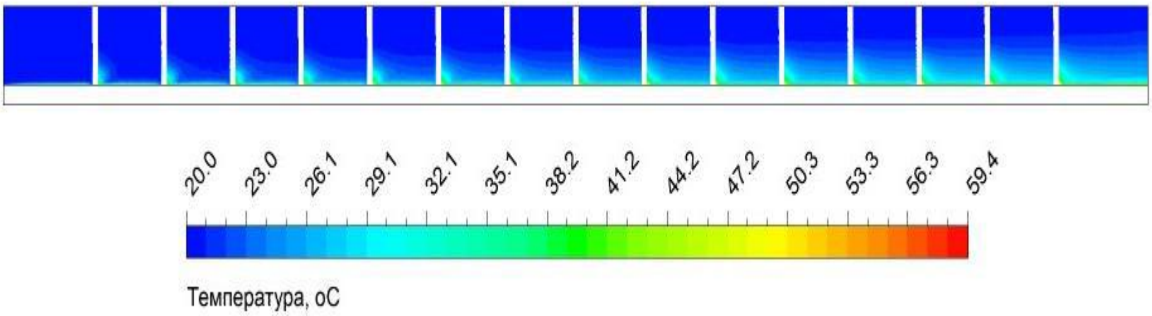

Figure 2.15: Temperature distribution in the flow (600x600 μm)

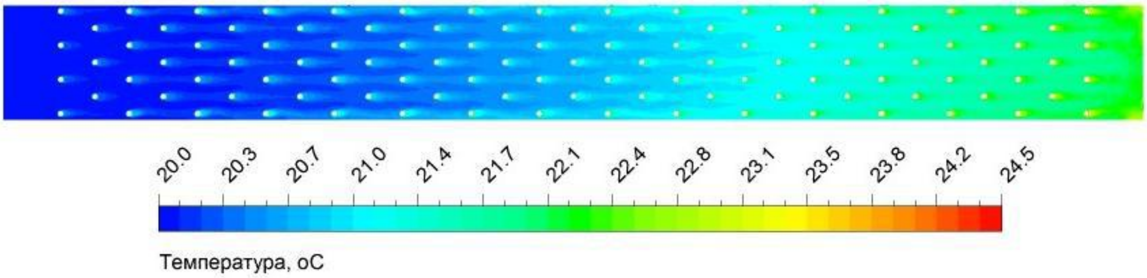

Figure 2.16: Temperature distribution in the flow (top view) (600x600 μm)

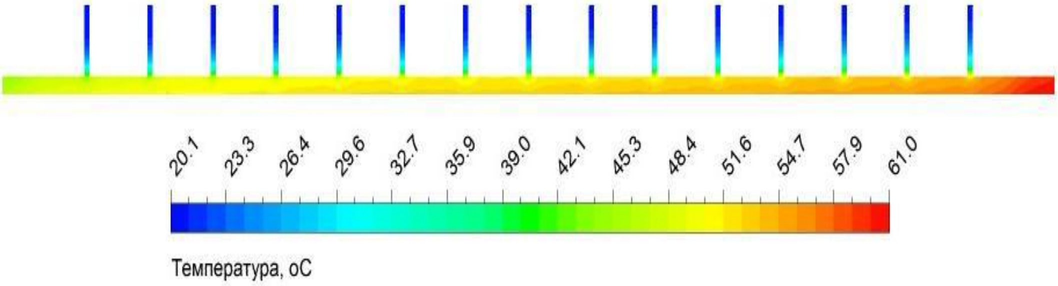

Figure 2.17: Temperature distribution in the matrix (600x600 microns)

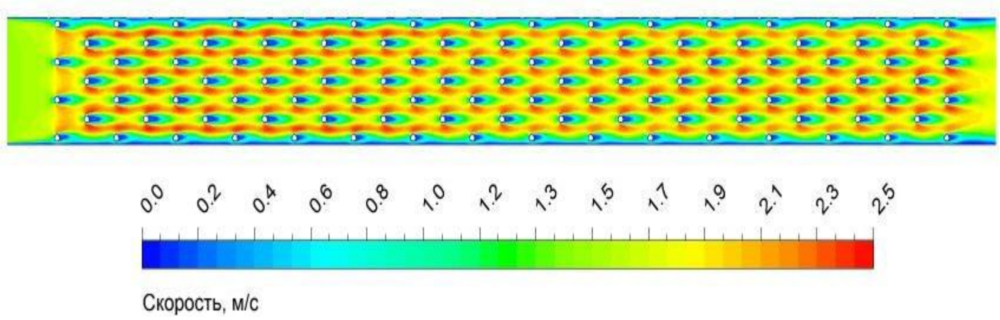

Figure 2.18: Velocity distribution in the flow (600x600 µm)

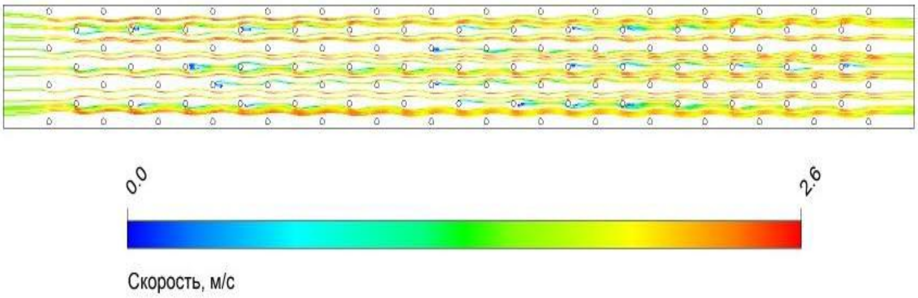

Figure 2.19: Distribution of streamlines (600x600 µm)

Below are the data on the influence of the geometry of the matrix onhydrothermal characteristics of the heat exchange element (Figures 5.34–5.36)

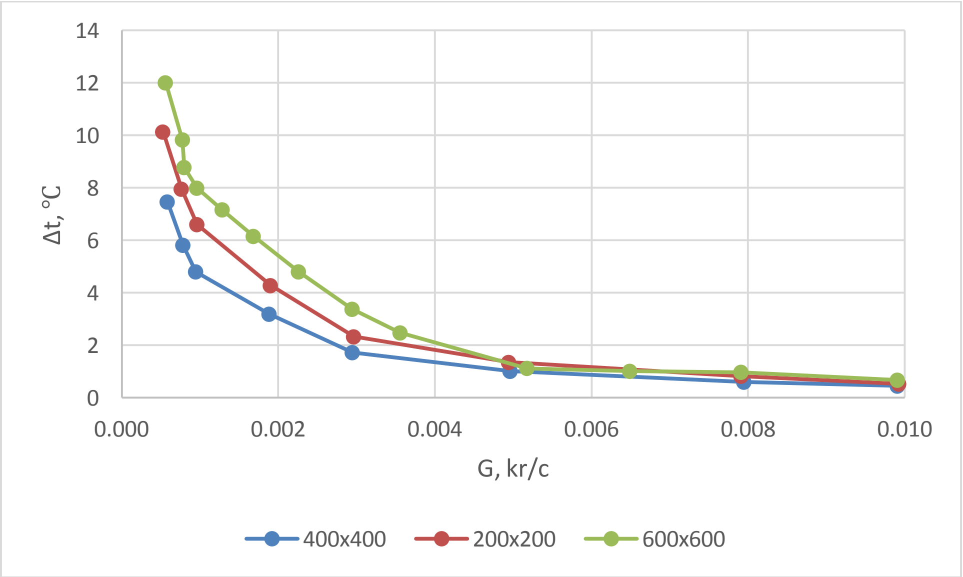

Figure 2.20: Comparative graph of the dependence of the temperature drop oninlet and outlet from the matrix from the coolant flow

The processing of the results of computational experiments is presented incriterial form for the applied spectrum of the structure of the matrices used:

substrate with a center-to-center distance of spikes 200x200 microns

$$du = 12{,}035 \cdot Re^{0{,}3876}$$
$$\Delta p = 154{,}295 \cdot G^{1{,}4888}$$

substrate with a center-to-center distance of spikes 400x400 microns

$$Nu = 3{,}173 \cdot Re^{0{,}4515}$$
$$\Delta p = 24{,}841 \cdot G^{1{,}5422}$$

substrate with a center-to-center distance of pins 600x600 microns

$$Nu = 1{,}9698 \cdot Re^{0{,}4833}$$
$$\Delta p = 28{,}645 \cdot G^{1{,}6057}$$

From the analysis of the results of the computational experiment, it follows symmetry of the coolant flow. At a flow rate of 0.0006 kg / s, 0.0008 kg / s, 0.0010 kg / s, 0.0030 kg / s, the flow is laminar. When spending more 0.0030 kg / s, a pronounced transient flow regime from laminar to turbulent with local occurrence of separated flows after thorns, which indicates the emergence of stagnant zones, the size of which reaches the distance between the pins only at high consumables
characteristics. It is shown that the temperature of the framework of the matrix of thread like monocrystals of silicon differ from the temperature of the cooler. It indicates the correctness of the application of the two-temperature approach at building a mathematical model.
From the data obtained, it follows that with an increase in the coolant flow rate, there is an increase in heat removal, because heating of the coolant occurs only at the bottom of it. Reducing the pitch of the cleats is also not conducive to increasing the efficiency of cooling, and also significantly increases pressure loss of the coolant through a matrix of silicon whiskers.

Found the rational height of the spike 0.6 ≈ mm and center distance between the spikes 600x600 microns, which allow maximum cooling substrate with an insignificant increase in the pressure loss for pumping coolant.

The developed mathematical model makes it possible to assess localization by the temperature field of the coolant, the critical isotherm, and draw a conclusion about possible phase transition, taking into account the obtained on the given isotherm absolute pressure.

III. CONCLUSION

1. A mathematical model of a microchannel heat exchanger has been developed. based on a matrix of whisker silicon monocrystals. The model is based on hydrodynamic approximation of the coolant flow in the ideal displacement and made it possible to obtain a detailed picture of stationary temperature fields of the matrix and coolant, as well as to determineheterogeneitytemperaturefieldsrefrigeratedsurfacesfromidentification of the Nusselt number in the axial direction of motioncoolant.
2. A numerical experiment using the ANSYS packet made it possible to explain local coolant flow hydrodynamic structures and shown that the impact on the coolant mixture during its flow through a heat exchange element is not important because of the frequency of the stalked arrangement of spikes in the ranges 0.2x0.2, 0.4x0.4 and 0.6x0.6 mm. The perfect movement model has been confirmed by a normal matrix of silicone whisker monocrystal in the description of heat transfer in a heat exchange element.
3. The results of the analytical and numerical solution show a significant temperature difference between the frame and the cooler, as well as significant nonlinearity of temperature distribution along the height of the thorns.It is shown that when modeling microchannel heat exchange elements with matrix of whisker single crystals of silicon, it is necessary to take into account the data facts to exclude local overheating.

4 It is shown that the model can be considered as a toolkit for selection of design parameters of the designed heat exchange systems and identification of rational modes of their functioning.

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