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A Study on the Responses Effect of the Flow Field and Temperature on Hybrid Micro-Channel Heat Sink (H-MCHS)

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ABSTRACT

Research on the microchannel and its flow and heat transfer properties has received much attention. This study employed Autodesk Inventor software to build the model, and the Computational Fluid Dynamics software (Ansys Fluent 14) was used for numerical simulation. Taguchi analysis methods, ANOVA, and Minitab statistics testing were used. The results obtained for single response analysis for temperature, pressure, and velocity values are reasonable. With the optimal model for temperature difference (ΔT) being W2H1S2 and the temperature difference across the model (ΔT_{all}), the pressure difference across the model (ΔP_{all}), maximum velocity in the channel (V_{max}), and maximum outlet velocity (V_{outmax}) are W3H1S3, W1H1S3, W3H2S1, and W1H1S2, respectively.

The analysis results for multi-response between the two values of velocity and pressure also achieved reasonable results with precisely defined parameters with response optimization for V_{max} and ΔP_{all}, V_{outmax} and ΔP_{all} the optimal model achieved is W(0.8mm), H(0.3mm), S(2.91), W(0.4mm), H (0.3mm), S(1.67), respectively. Analysis for V_{outmax} , V_{max}, V_{outmax}, V_{max}, and ΔP_{all}, the results are W(0.65mm), H(0.3mm), S(1), and W(0.4mm), H(0.3mm), S(1).

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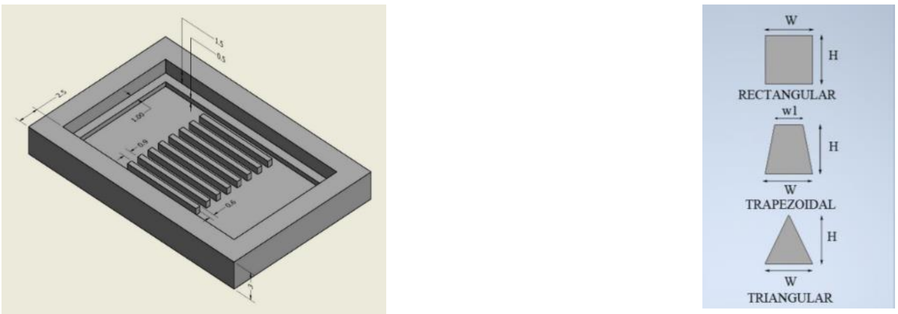
1. Introduction

The micro heatsink is an optimized cooling method for microelectronic components by Tuckerman and Pease [1], electronic devices such as laptops, computers, and devices with large capacities. Micro channel's outstanding heat dissipation performance has been proven in terms of maximum temperature, cooling rate, and heat resistance. Temperature profiles along the Microchannel are extracted, and even small temperature disturbances can be detected in the heat source's formation temperature peak shifts with increasing flow rate. One of the liquid cooling techniques for electronics is to attach a heatsink Microchannel to or fabricate the channel directly on the inactive side of the chip. Stacked Micro channel integrates multiple layers to form one block. Compared to single microphone channels, stacked microphone channels provide larger flows. The isothermal process can be achieved by reverse flow arrangement in adjacent Microchannels. Pfaler et al. [2] Dedicated manifolds help distribute coolant evenly to the Microchannel. The stacked channel was fabricated using silicon micro-engineering techniques. Thermal performance is characterized through experimental measurements and numerical simulation. The effects of cooling water flow, interlayer flow rate distribution, and heterogeneous heating were studied. The wall temperature parameter is measured by installing 9 resistance thermometers on the back of the stacked structure. The overall cooling efficiency reached (0.09 $^{o}C/W.cm^{2}$) as shown in the experiments. It has also been determined that in the tested flow rate range, the flow arrangement provides better temperature uniformity, and parallel flow performs best in reducing the peak temperature. The heat transfer effects for the stacked channels at different flow conditions are studied through numerical simulations. Based on the results, some general design guidelines for stacked Micro channel heatsinks are provided. Megahed et al. [3] researched flow visualization on 45 straight Micro channels (D_h = 727) connected via three 500 µm wide crosslinks. Choi et al. [4] performed 2-phase flow experiments of water and nitrogen gas over the surface velocities of liquids (0.06 - 1.0 m/s) and gases (0.06 - 72 m/s) over five different types of rectangular channels (D_h = 141, 143, 304, 322 and 490). Qu and Mudawar et al. [5] performed experimental research and used numerical methods to predict the pressure drop for single-phase flow in a rectangular channel heatsink using an aqueous fluid. Ergu et al. [6] performed experiments in the range of Reynolds coefficients from 100 - 845 using a water-based fluid in a rectangular channel. Cornwell et al. [7] conducted experiments with R113 flowing inside rectangular channels of size (W, H) (1200, 900). Szczukiewicz et al. [8] concluded through their visual observations on 67 rectangular evaporators (100, 100) and inlets that there was no more flow instability or backflow and significantly improved flow uniformity through the Microchannel. Sobierska et al. [9] performed experiments using water in a rectangular Microchannel (W, H) (2000, 860mm) and observed bubbly flow, flug flow, and annular flow. Megahed et al. [10] performed flow visualization research on 45 straight Micro channels (D_h = 727) connected via three 500 µm wide crosslinks. Zhang et al. [11] performed experiments on upward-facing tubes with inner diameters of 531 and 1042 µm using nitrogen as the fluid. Wang et al. [12] performed flow visualization research in parallel channels with three different types of input/output geometry. Since the hydraulic diameter of the Microchannel is very small, it is expected that the pressure drop of the single-phase line per unit length of the channel will be much higher than that of conventional channels under the same operating conditions. The boiling in the channel even promotes a pressure drop compared to normal-size channels. Although associated with large pressure drops, Microchannel radiators have attracted much attention due to their strong control over heat transfer characteristics. High pressure has a big effect on power consumption. Therefore, the study of channel pressure drop is equally important as other related aspects. The pressure drop in the channel mainly depends on the properties of the fluid (density, viscosity, and surface tension), flow (mass flow rate, flow rate, or Reynolds coefficient), effective heat (wall temperature), dryness, and channel geometry proportional to frame, hydraulic ratio, and cross-section). Many researchers have researched the influence of these parameters on the pressure drop characteristics of the Microchannel. Ling et al. [13] conducted pressure drop analysis on round tubes with diameters of 13 and 20 µm and lengths ranging from 40 to 100 mm under pressure-driven force conditions. The heat transfer coefficient is the most important parameter that governs the usefulness of the heatsink in the Microchannel. The channel boiling heat transfer coefficient is very high due to the combined effect of the tiny hydraulic diameter and the evaporator temperature. Various researchers have carried out experimental research in single-phase as well as two-phase heat transfer in Microchannel. However, the focus of the study of two-phase heat transfer. Choi et al. [14,15] performed 2-phase flow experiments of water and nitrogen gas over the surface velocities of liquids (0.06 - 1.0 m/s) and gases (0.06 - 72 m/s) over five different types of rectangular channels (D_h = 141, 143, 304, 322 and 490). Peng et al. [16] investigated the effect of force convection on single-phase heat transfer characteristics using a rectangular (W, H) channel (700, 600). Wang et al. [17] also performed a single-phase forced convection study using six heatsinks with channel sizes (W, H, N) (800, 700, 4), (600, 700, 4), (400, 700, 4), (400, 700, 6), (200, 700, 4) and (200, 700, 6) using water fluids. Qi et al. [18] performed single-phase heat transfer analysis experiments on microchannels using nitrogenous fluids. Yun et al. [19] performed experiments to investigate the effects of flow rate, heat flow density, and saturation pressure on the heat transfer characteristics. Lee et al. [20] Fluid flow and heat transfer characteristics of low temperature two-phase micro-channel heat sinks subcooled boiling pressure drop and heat transfer. Wang et al. [21] experimentally analyzed the effect of rectangular channel inclination with D_h = 825. Much of the Microchannel research work over the past two decades has been directed towards a better understanding the mechanism involved in heat transfer. Current comparative heat transfer research shows that there is still much effort to establish a general heat transfer correlation for the Microchannel. Limited test range, differences in operating conditions, and channel geometry may affect results. Future research will certainly focus more on finding techniques to improve heat transfer by choosing among conventional proven methods. Instability is also called the breakdown of the flow in the Microchannel. It can cause several problems such as vibration, system control problems, overheating, and in extreme cases it can even cause surface burn. Channel-related instability is due to flow reversals, changes in pressure, surface temperature, flow distribution, and Ledinegg instability.

Bogojevic et al. [22] performed experiments on 40 parallel Microchannels (D_h = 194) using water fluids. Balasubramanian et al. [23] Experimental investigations of flow boiling heat transfer and pressure drop in straight and expanding microchannels. Kaun et al. [24] performed experiments with input limiters and observed that the flow became steady, and the problem of flow reversal was reduced due to the application of limiters. Wang et al. have also confirmed that the input limiter helps to reduce flow reversal instability. Nguyen Trong Hieu et al. [25] Studying heat transfer characteristics in a Microchannel evaporator using CO_2 by numerical simulation method. Research on the influence of flow diagrams on the evaporation process in Microchannel is done by numerical and experimental simulation methods. Research the influence of fluid flow on the cooling capacity of the square Micro channel evaporator research on heat transfer characteristics of condensation in Microchannel heat exchangers. Nguyen Huy Bich et al. [26] Research the influence of thermal boundary conditions on the movement of liquid droplets in the Microchannel. In this study, the finite element method is used to solve nonlinear equations with boundary conditions based on Comsol multi-physics 4.3a software. Dang et al. [27] have studied the hybrid profile microchannel for the first time. In this study, the profile of the channel side is mentioned, and the study considers their three different geometries to the flow factors and channel heat transfer, shown in Figure 1 below. However, the model used in this study only stops at simulating the substrate of the channel with the channel cap in theoretical conditions that have not been clarified and come closer to the experiment.



(a) *(b)*

Figure 1. *Paragraph setup for H-MCHS (a): the primary substrate (b) cross-section of the ribs*

Therefore, in this study, the simulation of the entire H-MCHS with the outer shell structures and the materials corresponding to the experiment are mentioned, so the complexity of the H-MCHS is increased significantly to serve for the following work to proceed to experimental research. In addition, in this study, responses such as channel temperature, channel pressure, and flow parameters are considered in more detail. For the temperature value, the highest and lowest temperature difference of the whole model is assessed, and the highest and lowest temperature values between the inlet and outlet of the fluid zone are also taken into account pressure difference to find out and evaluate the consumption of the pump equipment that will be used in the experiment and the required capacity. Finally, the velocity values that are of most interest include the inlet and outlet velocities, the velocities inside the channel, and the speed difference of the outlet area compared to the whole model.

2. Materials and Methods

In this study, due to the complexity of the H-MCHS, the H-MCHS building is done by Autodesk Inventor software, and then the H-MCHS is entered and simulated through Ansys Fluent numerical simulation software. To ensure that the input parameters are close to the actual conditions, Matlab software is used to run for the input random parameters. Taguchi and ANOVA tools are used in setting theoretical parameters and as tools for academic analysis. Minitab software is used as statistical software to verify the theoretical parts used in Taguchi and ANOVA to evaluate and verify the relationship between univariate responses and multi-responses.

2.1. H-MCHS building on Autodesk Inventor software

H-MCHS is done in Inventor by rendering parts one by one and then reassembling them into a unified whole with full physical parameters before being put into simulation. The whole H-MCHS is composed of the following 7 parts, 1 outer base used to cover the entire channel is made of Bakelite material, the material and role of this area in addition to the insulating function, the insulation of the channel is also

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a task, 2 main parts of the resistor as a heat source to be cooled is set up with iron material, 3 next is the main substrate area of the channel that plays a significant role in heat dissipation for the resistor, and the flow direction is made of aluminum, the 4 fluid zones with the material here are water, the 5 main covers of the channel to ensure the channel, as well as the flow direction, are made of aluminum. The top 6 areas are a sheet of plexiglass with the role of insulation between the structure of the H-MCHS, and finally, area 7 is the two ports leading inlet and outlet of the H-MCHS, shown in Figures 2 and 3.

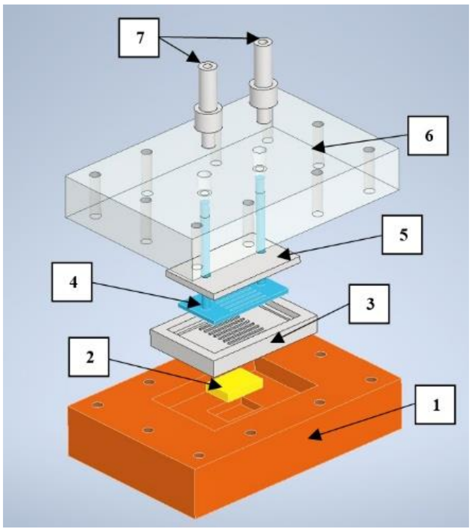

Figure 2. *Reassembling of H-MCHS*

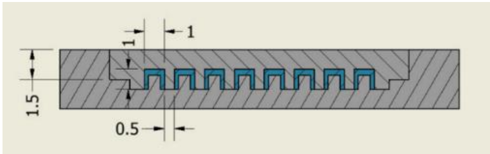

Figure 3. *Dimensions of the H-MCHS*

Constructing The model includes the following components: the main channel section depicted by the figure below is the joint between two aluminum materials, this part is divided into small channels with different cross-sectional profiles, this time, the gaps are filled with water and conduct water through the heat exchanger, with the smallest slot size being 100 microns. The complete H-MCHS is fixed after being secured with screws, the size of the H-MCHS is 60mmx30mmx22mm when excluding the height of the 2 ports and the excess of the screws.

2.2. Set up the H-MCHS according to the Taguchi and ANOVA method

Based on previous studies [27] that were established according to parameters such as changes in channel shape, flow direction, disturbance factors, and channel cross-section, in this study, the factors in actual parameter collection and modeling, there were three factors were selected with three levels for each element as shown in table 1 below.

Table 1. *Parameters and values levels*

Parameters Factors	Levels		
	1	2	3
P1: W Channel width(mm)	0.4	0.6	0.8
P2: H Channel height(mm)	0.3	0.5	0.7
P3: S Ribs cross-section	Rec	Trape	Tri

To set up an orthogonal matrix table based on the selected elements and their levels, the orthogonal matrix table L9 is suitable in terms of cost and time balance to increase efficiency in conducting research. Factors and levels, after being assigned and included in Table L9, serve the numerical simulation step described in Table 2. To perform the analysis of simulation results, the theory of Taguchi is used to calculate the SN index of the responses divided into 3 cases, normal is better, as large as possible, and as small as possible depending on for different purposes. ANOVA was used to verify the Taguchi analysis results. The Minitab software is used to verify both Taguchi and ANOVA and to analyze and determine the multi-response model.

Table 2. *H-MCHS build according to Taguchi Orthogonal Arrays*

No.	P1: W Channel width (mm)	P2: H Channel height (mm)	P3: S (Ribs cross-section)
1	0.4	0.3	Rec
2	0.4	0.5	Trape
3	0.4	0.7	Tri
4	0.6	0.3	Trape
5	0.6	0.5	Tri
6	0.6	0.7	Rec
7	0.8	0.3	Tri
8	0.8	0.5	Rec
9	0.8	0.7	Trape

2.3. Simulation with Ansys Fluent

The Ansys Fluent is a thermodynamic and flow simulation software in the engineering field. It allows users to simulate and analyze problems related to fluid flow and thermodynamic sensors. Critical features of Ansys Fluent include Flow Simulation, Thermodynamic analysis, Surface Feature Calculation, and Simulation of 2-phase flow. In this study, the selected ambient temperature was 300 K, heat flux 2.10 6 W/m 2, and inlet velocity 1.5 m/s. For these parameters to be objective and close to experimental conditions, the random distribution function in Matlab is used to set up a table of random values with 3 repetitions. Ansys Meshing is applied in meshing and proceeds through many trials with different mesh types and the number of elements to find the optimal mesh type and best fit the survey H-MCHS. Select three best-quality meshes with other mesh elements to save simulation time and computer resources to compare mesh convergence results. Two parameters, skewness and orthogonal, are considered and evaluated, meshing scheme with skewness max 0.94 and orthogonal min 0.30 with about 2.8 million elements shown in Figure 4. Two-equation turbulence models allow the determination of a turbulent length and time scale by solving two separate transport equations. The standard $k-\varepsilon$ model in ANSYS Fluent falls within this class of models and has become the workhorse of practical engineering flow calculations since Launder and Spalding proposed it. Robustness, economy, and reasonable accuracy for a wide range of turbulent flows explain its popularity in industrial flow and heat transfer simulations. It is a semi-empirical model, and the derivation of the model equations relies on phenomenological considerations and empiricism.

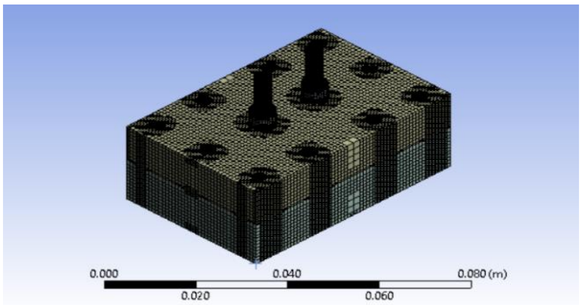

Figure 4. *Mesh result of H-MCHS*

The modeled transport equations [13] for k and e in the realizable $k-\varepsilon$ model is

$$\frac{\partial\varepsilon}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (1)$$

And

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial t}(\rho\varepsilon k_j)=\frac{\partial}{\partial t}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \quad (2)$$

This part should describe in detail the ways or methods, materials, and devices necessary to solve the research problems. They should be described with sufficient detail so that other researchers can replicate and build on published results. New methods and protocols should be described in detail, while well-established methods can be briefly described and appropriately cited. The approach might be by theoretical development, empirical research, surveying, etc. The applied approach should be explained the advantages and, if possible, be compared with previous studies. In the case of theoretical development research, it should present theoretical bases to find solution to research problems. The thermophysical properties of coolants and substrate materials of the microchannel are shown in Table 3.

Table 3. *Thermophysical properties of coolants and substrate materials of the H-MCHS*

Materials	ρ (kg/m^3)	$C_ρ$ (J/kg.K)	K_f (W/m.K)
Water	322	4187	0,587
Aluminum	2698	900	210
Steel	7800 - 8000	479	44 - 52
Bakelite	1300	1590	0.2
Glass	1180	840	1.05

3. Results and Discussion

3.1. Simulation result

The simulation results can be achieved through the value of the temperature, pressure, and velocity, which are shown for each case in the figures below. Model temperature field value in this study, on the one hand, show the difference between the maximum temperature of the H-MCHS and the minimum temperature of the all model to help this study have an overall prediction, which is shown in Figure 5. On the other hand, the contour temperature described the difference contour of the outlet temperature was considered to study the effect of the factors on the fluid temperature which show in figure 6.

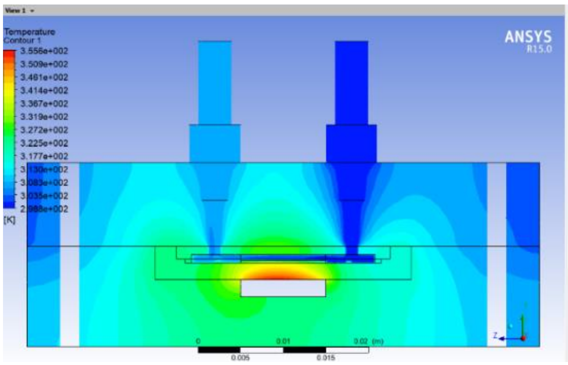

Figure 5. *The overall Temperature field of H-MCHS*

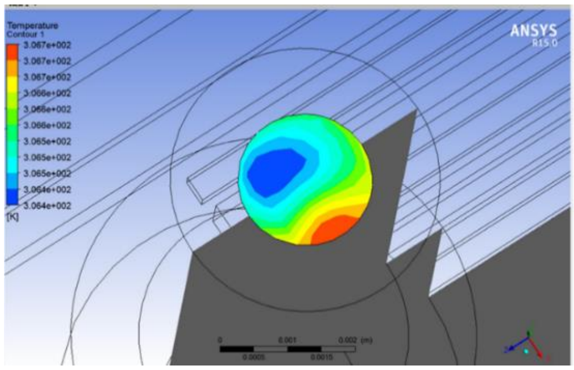

Figure 6. *Outlet temperature field of H-MCHS*

The model Pressure Field Value response to pressure value was generated by comparing the maximum pressure of the overall H-MCHS in the fluid region to study the effect of parameters on the pressure drop. Also, the different pressure of the inlet and outlet shown in figure 7.

Velocity value was considered more in this H-MCHS through two cases. The first case going to compare the maximum value and the minimum value of all H-MCHS in fluid regions to predict which location can cause the increase and decrease of the velocity. The second case was considered the deferent value between the inlet and the outlet in fluid region to analyze the flow field get in and out of the H-MCHS which show in figure 8, 9 and figure 10, respectively.

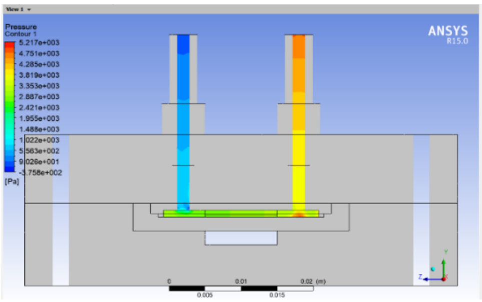

Figure 7. *Overall Pressure field of H-MCHS*

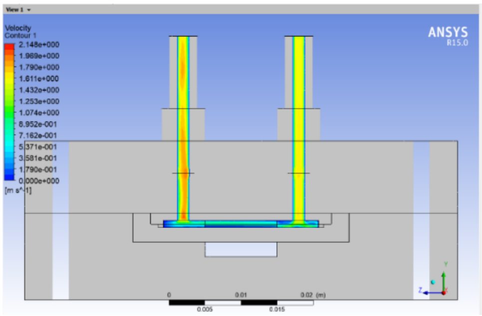

Figure 8. *Overall Velocity field of H-MCHS*

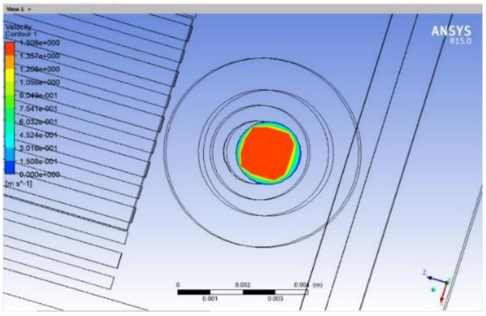

Figure 9. *Inlet velocity field of H-MCHS*

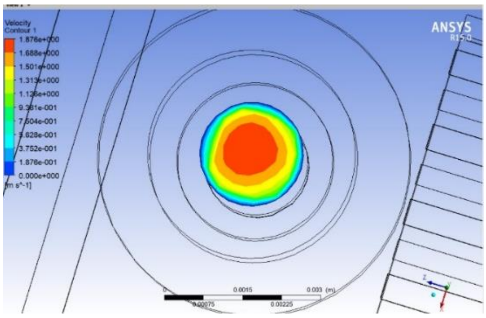

Figure 10. *Outlet velocity field of H-MCHS*

3.2. Analyzing data

To predict the phenomenon, the values of the temperature, pressure, and velocity were generated. With the temperature, the difference between the inlet and outlet temperature (ΔT) and the difference of the overall temperature (ΔT_{all}) were considered, for pressure the contrast of the maximum pressure and the minimum pressure (ΔP_{all}) was calculated. The velocity value is carried out through the changing velocity of all H-MCHS (V_{max}) and the different velocities of the inlet and outlet (V_{outmax}). Taguchi and ANOVA analyses were employed for each case to predict and verify the significant factor and the optimized model. Then, Minitab software is used to analyze simulation results after being collected and processed. with matrix table L9, there are a total of 9 simulations performed with the number of repetitions of 3 times, creating a parameter table with 27 cases. These cases are analyzed separately by Minitab without using the mean method, which had many disadvantages leading to significant errors, the responses are initially analyzed independently of the independent factors, then the correlation of the responses is of interest, and in this study, the relationship of the two responses, pressure, and velocity, will be discussed. Data processing according to Taguchi for the temperature criterion ΔT was established. First, the processing and analysis are applied to the temperature difference between the inlet and the outlet of the liquid area to evaluate the heat exchange efficiency of the device, with the higher temperature difference criterion. This means more heat is carried away to support the cooling of the device and the results are depicted in the figures and table below.

Table 4. *Response Table for Signal to Noise Ratios, Larger is better*

Level	**W**	**H**	**S**
1	17.87	17.91	17.82
2	17.90	17.90	17.93
3	17.86	17.82	17.88
Delta	0.04	0.08	0.11
Rank	3	2	1

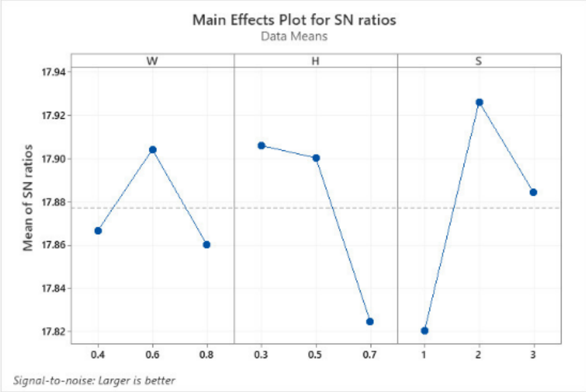

Figure 11. *Influence according to SN value*

The Main Effects Plot for the SN ratios graph is shown in Table 4 and Figure 11. The selection criteria for ΔT as large as possible can choose the best combination is Model W2H1S2. Equivalent to Width P1: W = 0.6 mm, Height P2: H = 0.3 mm, Section P3: S = Trapezoidal, Selected model designation: W2H1S2. To test the above results, we choose the ANOVA variance analysis method to analyze the Means value which shown in table 5

Table 5. *Regression Analysis of ΔT versus W, H, S by Analysis of Variance*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.039930	0.013310	1.6	0.217
W	1	0.000139	0.000139	0.02	0.898
H	1	0.024421	0.024421	2.94	0.100
S	1	0.015371	0.015371	1.85	0.187
Error	23	0.191352	0.008320		
Lack-of-Fit	5	0.083162	0.016632	2.77	0.050
Pure Error	18	0.108190	0.006011		
Total	26	0.23122			

From ANOVA's theory on hypothesis testing, P < α < 5%. We conclude that the S factor has the most significant influence on the model's ΔT. From the SN graph and Taguchi graph combined with ANOVA Minitab analysis, we come to the following conclusions of the best model with the Width P1: W = 0.6 mm, Height P2: H = 0.3 mm, Section P3: S = Trapezoidal, Selected model number: W2H1S2, The S factor has the most influence on ΔT. Apply the similar performance to the above analysis steps for ΔT_{all}, ΔP_{all}, V_{max}, and V_{outmax}, the selected best criteria are W3H1S3, W1H1S3, W3H2S1, and W1H1S2, respectively.

After analyzing all the responses, the results gave the optimal models for each case and the most influential factors. However, due to the complexity and difficulty in terms of time and equipment, this study cannot cover all the responses but will prioritize the relationship between pressure responses and velocity to strengthen the reliability and proceed to experiment. The multi-respond analysis has been performed and verified by the numerical simulation software Minitab with highly satisfactory results presented by the figures and tables below. The pressure and velocity parameters of the H-MCHS are reviewed and mentioned first. The first is the V_{max}value, this value is collected based on the most significant velocity difference inside the channel to evaluate the heat exchange process because previous studies have mentioned the influence of velocity in the channel to increase the efficiency of the heat exchange process. Next, the maximum outlet velocity value is analyzed (V_{outmax}) to study the effect of the output velocity value on the heat transfer efficiency, the velocity distribution process, and especially the influence on the temperature. The reliability of the whole device is because, in this region, pressure is relatively small, cavitation phenomenon is easy to occur when the fluid flows at high speed.

Finally, the pressure difference across the model is mentioned (ΔP_{all}), because the pressure loss on the model will be directly related to the cooling pump system, especially the capacity and power consumption of the pump, so this is a matter of concern to research the optimal solution for energy use for micro channel devices. The optimal cases will be established, initially the optimal between $V_{max}$and ΔP_{all}, then the pair V_{outmax} and ΔP_{all}, V_{outmax} and V_{max}, and finally, the multi response relationship of all three parameters, V_{max}, V_{max}, will be considered. V_{outmax} and ΔP_{all}. Figures 12 and 13 show that after running response optimization for V_{max} and ΔP_{all}, V_{outmax} and ΔP_{all}, the optimal model achieved is W(0.8mm), H(0.3mm), S(2.91), W(0.4mm), H (0.3mm), S(1.67), respectively.

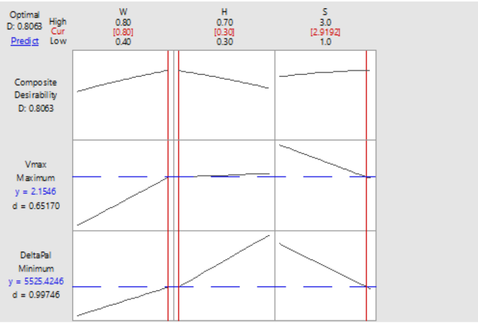

Figure 12. *Response Optimization for* V_{max}, $\Delta Pall$

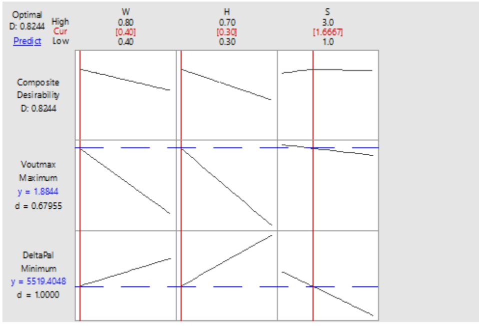

Figure 13. *Response Optimization for* V_{outmax}, $\Delta Pall$

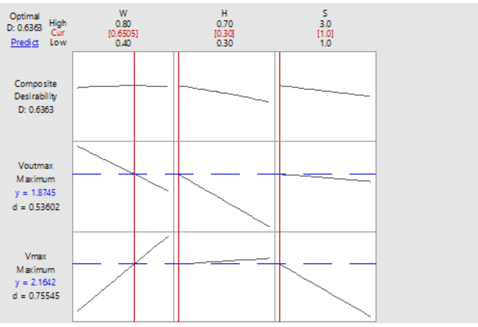

Figure 14. *Response Optimization for* V_{outmax}, V_{max}

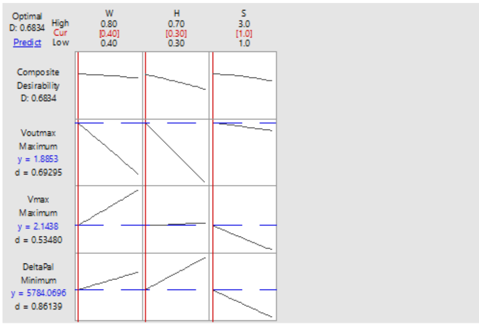

Figure 15. *Response Optimization for* V_{outmax}, V_{max}, $\Delta Pall$

Analysis for V_{outmax} and V_{max}, Voutmax, V_{max} and ΔP_{all}, the results are W(0.65mm), H(0.3mm), S(1), and W(0.4mm), H(0.3mm), S(1). Although these are the first steps in the combined analysis of multiple responses, the results show the positiveness of this study and will pave the way for more research in the future through figures 14 and 15.

4. Conclusions

In this study, on one hand, the research selected the 5 best model results from using Taguchi software, Minitab, to conduct the analysis and finally selected the best models and then analyzed the effect on a single response.

The best model for pressure and velocity has been chosen to run the multi-responses. The results achieved the model that satisfies the set conditions. With the optimal model for temperature difference (ΔT) being W2H1S2 and the temperature difference across the model (ΔT_{all}), the pressure difference across the model (ΔP_{all}), maximum velocity in the channel (V_{max}) and maximum outlet velocity (V_{outmax}) are W3H1S3, W1H1S3, W3H2S1, and W1H1S2, respectively.

The analysis results for multi-response between the two values of velocity and pressure also achieved reasonable results with precisely defined parameters with response optimization for V_{max} and ΔP_{all}, V_{outmax} and ΔP_{all}, the optimal model achieved is W(0.8mm), H(0.3mm), S(2.91), W(0.4mm), H (0.3mm), S(1.67), respectively. Analysis for V_{outmax} and V_{max}, V_{outmax}, V_{max}, and ΔP_{all}, the results are W(0.65mm), H(0.3mm), S(1), and W(0.4mm), H(0.3mm), S(1).

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