International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 03 | Mar 2021 www.irjet.net p-ISSN: 2395-0072

Thermal Performance of Minichannel Heat Sink used for Electronic Cooling in Higher TDP applications – CFD approach

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Abstract - *Due to the higher generation of heat in the electronic chips, there has been wide usage of liquid cooling systems. The invention of Nano fluid is quite promising to enhance the effectiveness of the liquid cooling system. In previous work, the thermal performance of minichannel heat sink is analyzed using CFD for cooling of electronic chips using nanofluids instead of pure water at the TDP of 95W. By using the liquid cooling system with heat sink, this temperature is reduced as low as 42.11°C. But the TDP of the processor increases as it runs continuously. So the CFD analysis is carried out for 150W TDP (50% increment) with same design. The processor temperature at higher heat generation of 150W and 0.04 kg/s for water, Alumina(0.1%), Alumina(0.2%), Graphene(0.1%) and Graphene(0.2%) are 49.12°C, 48.18°C, 47.31°C, 46.51°C and 45.68°C respectively. Alumina and Graphene Nanofluids gave 26.80% and 35.06% higher value of convective heat transfer coefficient with the comparison of the deionized water. At the highest volume fraction of 0.2%, Alumina and Graphene Nanofluids gave a decrement of 21.12% and 25.96% of convective thermal resistance with comparison to the deionized water.*

Key Words: *Minichannel heat sink, Electronic cooling, Graphene, and Alumina*.

1. INTRODUCTION

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature. In computers, heat sinks are used to cool CPUs, GPUs, and some chipsets and RAM modules. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light-emitting diodes (LEDs), where the heat dissipation ability of the component itself is insufficient to moderate its temperature. A heat sink transfers thermal energy from a higher temperature device to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction.

Graphene is a two-dimensional allotrope of carbon consisting of a single, flat layer of carbon atoms just one atom thick bonded together in a hexagonal, honeycomb lattice. Each carbon atom is bonded to three other carbon atoms with very strong covalent σ (sigma) bonds which are difficult to break, leaving one of the four electrons in each carbon atom's outer valence shell available for conduction and free to wander or to interact with other atoms or molecules. **Ram Mohan et al.** analyzed the thermal performance of a minichannel heat sink using CFD for cooling of processor chipset using Nanofluids instead of pure water. The effect of different mass flow rates and various volume concentrations of nanoparticles on the overall thermal performance are also analyzed. The Alumina and Graphene water Nanofluids are used as coolants with volume concentrations of 0.1, 0.15 and 0.2%. The cooling fluid is made to flow through an Aluminium mini channel with height 5mm and width 1mm respectively. The maximum allowable temperature that has to be maintained at the chip is below 50 °C. By using the liquid cooling system with a heat sink, this temperature is reduced as low as 41.22°C

2. METHODOLOGY

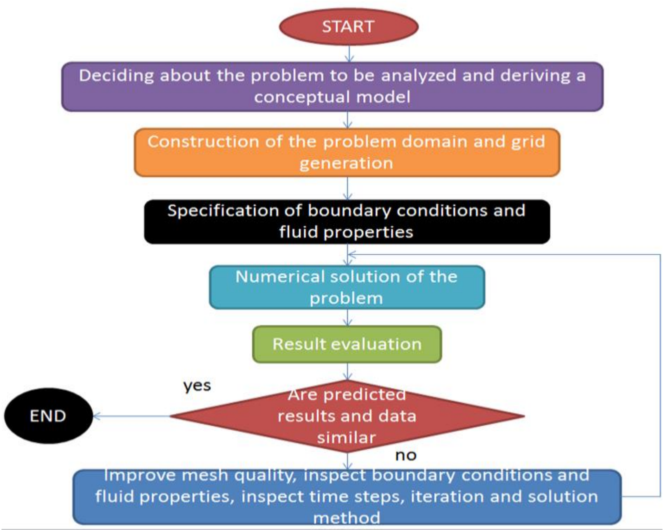

Fig -1: Procss flow chart

3. DESIGN

The design process usually involves the following steps, Identify the model requirements, Conceptualize the model based on the identified needs, develop the model based on the concepts, analyze the model, prototype the model, construct the model and edit the model. The dimensional features of every layer of chipset is being designed as a separate part and assembled into a whole structure by using SOLIDWORKS 16. It is successfully imported to ANSYS in .step file format as shown in the Fig.2.

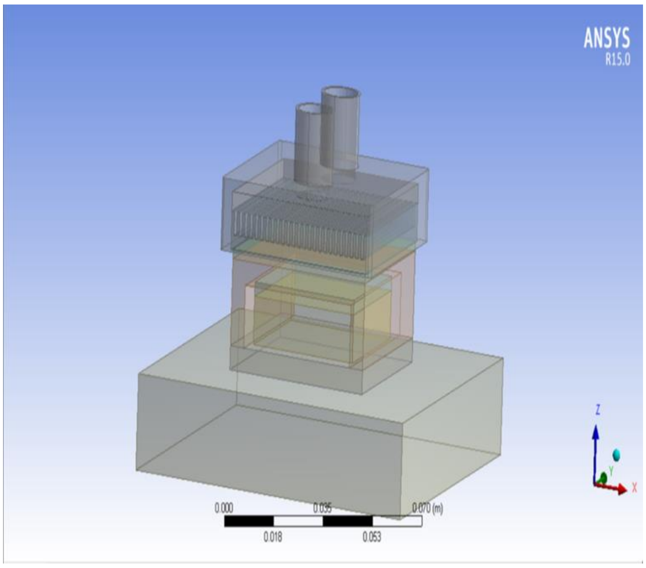

Fig -2: Solid works design

3.1 MESHING

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Furthermore, since meshing typically consumes a significant portion of the time it takes to get simulation results, the better and more automated the meshing tools, the faster and more accurate the solution.

Ansys provides general purpose, high-performance, automated, intelligent meshing software which produces the most appropriate mesh for accurate, efficient multiphysics solutions from easy, automatic meshing to highly crafted mesh. Methods available cover the meshing spectrum of high-order to linear elements and fast tetrahedral and polyhedral to high-quality hexahedral and Mosaic. Smart defaults are built into the software to make meshing a painless and intuitive task delivering the required resolution to capture solution gradients properly for dependable results.

The channels are selected and meshed in special with rectangular elements for better qualitative results. All the connections are given refinements for better linking between elements.

3.2 GRID INDEPENDENCY TEST

Grid independence study is performed to eliminate/reduce the influence of the number of grids/grid size on the computational results. It is always good practice to follow this for individual geometry, which is tedious. Grid independence test has been conducted at a mass flow rate of 0.01kg/s water flowing through the rectangular minichannel with TDP of 150W in ANSYS-FLUENT by decreasing and increasing the size of the elements. The gained results are tabulated in Table 2 for base temperature of heat sink.

Table -1: Grid results

NO.OF ELEMENTS	NODES	BASE TEMPERATURE(^{0}C)
83039	34156	56.36
125033	68436	52.96
214684	129440	51.03
377674	238012	50.43
508803	356479	50.62

3.3 MESH ADOPTION

After the generation of geometry, meshing has to be done for the whole domain in order to get accurately converged results. Before meshing, each surfaces and volume should be named. When the mesh generation is complete, you can transfer the mesh to the solution mode using the Mode tool bar or the command switch-to-solution mode. The remaining operations like setting the boundary conditions, defining the fluid properties, executing the solution and post processing the results are performed in solution mode. From the grid independency results, the below mesh model is adopted for simulation.

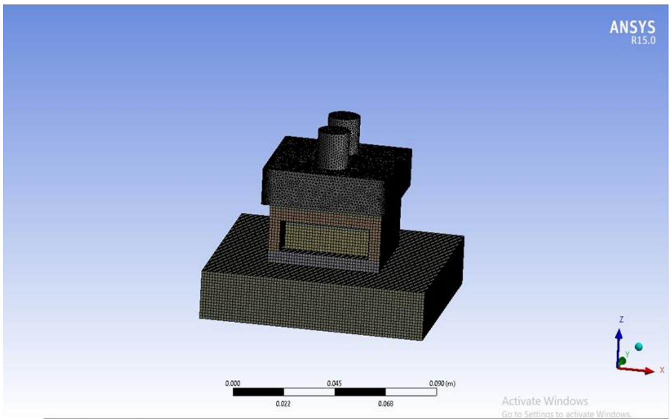

Fig -3: Selected Mesh contour
(Ref: R.Ram Mohan et al, Analysis of heat dissipation in processor chipset with minichannel heat

sink using nanofluids as cooling medium – A CFD approach)

3.4 SOLUTION SETUP

Every part of the chipset is assigned with its appropriate material from the engineering data sources. All the necessary named selections are provided to get the results at specified points or faces wherever required. The thermo physical properties are added to the fluent database as separate fluidic materials as shown in the fig.5. The Thermal Design power (TDP) of 150W is given as source term to the processor in the cell zone conditions. The mesh interfaces are checked before leading to the simulation.

Table -2: Cell Zone Conditions

DOMAIN	ASSIGNMENT	MATERIAL
PCB board	solid	FR4
Processor	solid	Silicon
TIM1 & TIM2	solid	HC gap pad 5.0
Spreader	solid	Copper
Heat sink	solid	Aluminium
Substrate	solid	Gallium Arsenide

3.3 SIMULATION

The boundary conditions are provided at the inlet for different iterations in the mass flow rate range of 0.01, 0.02, 0.03 and 0.04kg/s. After every iteration, the fluid inlet and outlet, processor and base temperatures are noted down for further analysis. The result values are given to the program written in PYTHON language for heat transfer analysis.

4. RESULTS AND DICUSSIONS

4.1 PROCESSOR TEMPERATURE

The primary objective of the cooling system is to reduce the processor temperature. The effect of alumina Nano fluid is being compared with water in the varying range of Reynolds number is shown in the chart 1.

From the chart, it is clear that with increase in nanoparticle concentration, the processor temperature reduces further. This is mainly due to the increase in the thermal conductivity of fluid and thermal absorptivity with the varying concentration. The alumina Nanofluids provide better performance than the pure water.

From the chart 2, it can be explained that the Graphene nanofluid absorbs more heat compared to the pure distilled water and alumina Nanofluids.

At TDP of 150W, the decrement in processor temperature while using Graphene and alumina Nanofluids is 7% and 3.68% respectively. Also, the addition of volume percentage of the nanoparticle develops the heat absorptivity dramatically

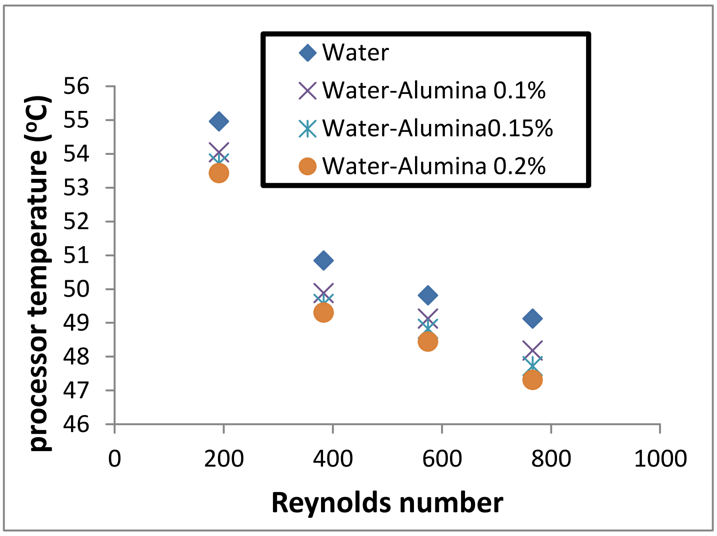

Chart -1: Variation of processor temperature with respect to Reynolds number

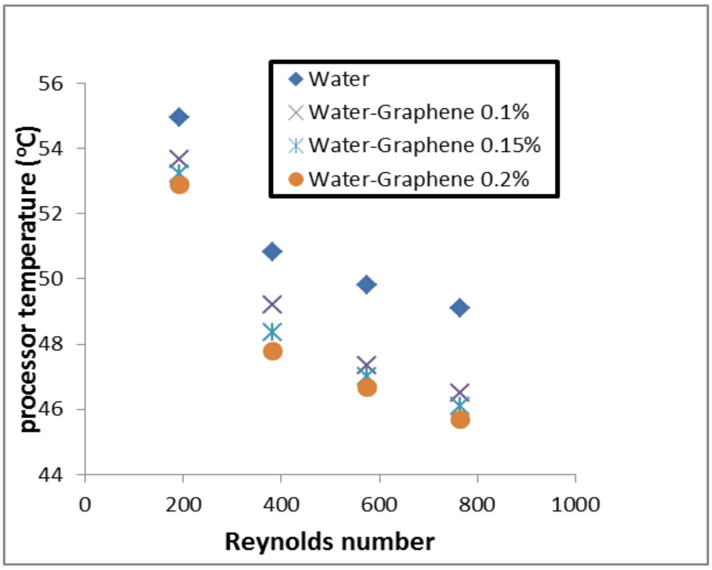

Chart -2: Variation of processor temperature with respect to Reynolds number

4.2 HEAT TRANSFER COEFFICIENT

The thermal performance of the fluid is dependent on its heat transfer coefficient. The h value depends on three temperatures namely average base, fluid inlet and fluid outlet temperatures and the heat carried away by the cooling fluid. Chart 3 and 4 reveals that Alumina and Graphene Nanofluids have higher heat transfer coefficient than pure water. Also the increase in particle concentration gave higher coefficient values which indicate better performances.

For 150W, at the highest volume fraction Alumina Nanofluids gave 26.80% higher value of convective heat transfer coefficient as compared to the deionized water. The Graphene Nanofluids gave around 35.06 % higher value of convective heat transfer coefficient with comparison to the deionized water. As compared to Alumina Nanofluids, the increment in heat transfer coefficient is 6.12% greater for Graphene Nanofluids at 0.2% volume fraction.

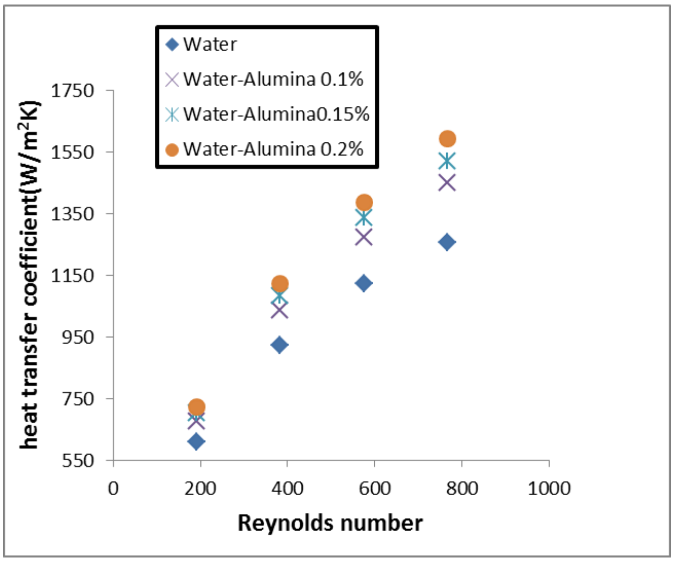

Chart -3: Variation of heat transfer coefficient with respect to Reynolds number

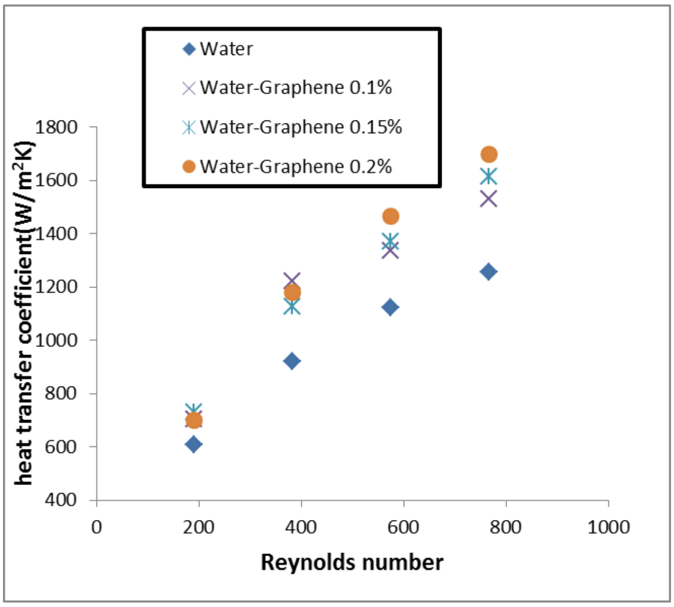

Chart -4: Variation of heat transfer coefficient with respect to Reynolds number

4.3 LOG MEAN TEMPERATURE DIFFERENCE

In chart 5 and 6, increasing the volume fraction shows the decreasing drift of the log mean temperature difference as well as the lowering of the base temperature of the heat sink. Also the developing of the flow rate has the same trend to decrease the log mean temperature difference.

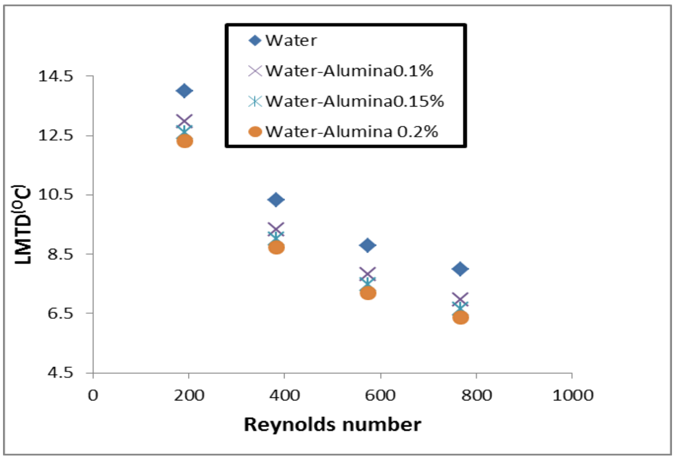

Chart -5: Variation of LMTD with respect to Reynolds number

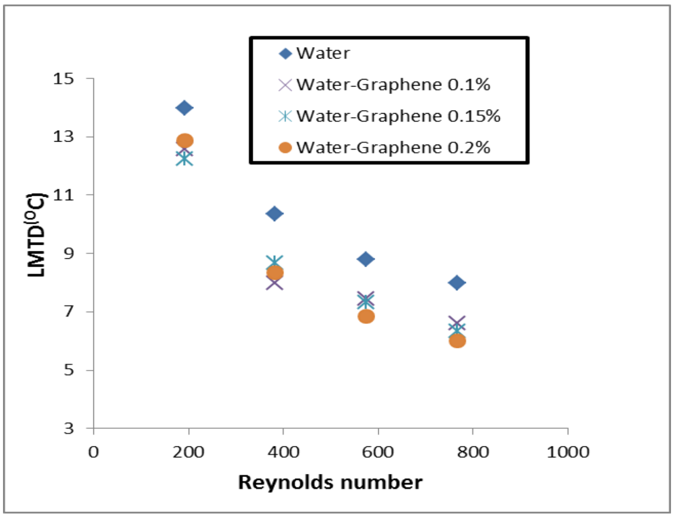

Chart -6: Variation of LMTD with respect to Reynolds number

4.4 THERMAL RESISTANCE

Results show that with increase in the flow rate, the thermal resistance decreases. Also it is evident that by using Nanofluids instead of water, the system has lower thermal resistance. The increase in enhancement of heat transfer coefficient is the main reason for lowering the thermal resistance.

The increase in volume concentration also shows a diminishing trend in the thermal resistance. Developing the volume concentration of the nanoparticle raises the convective heat transfer coefficient and thermal dispersion, which are the main causes for reducing the convective thermal resistance compared to the base fluid.

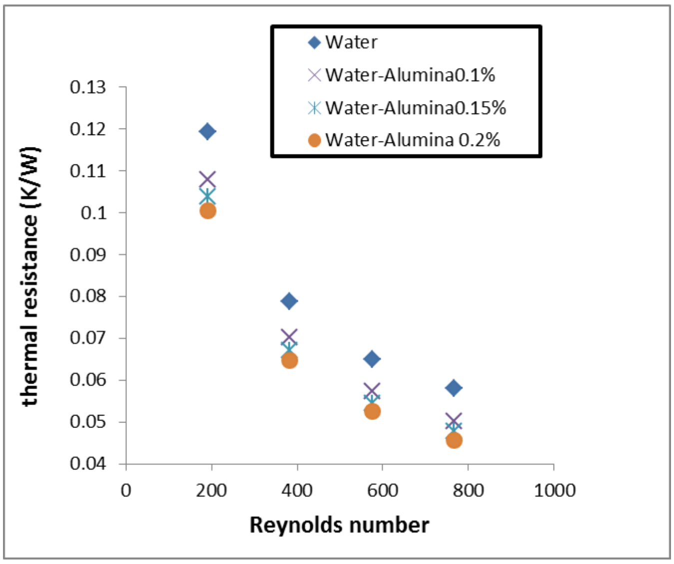

Chart -7: Variation of thermal resistance with respect to Reynolds number

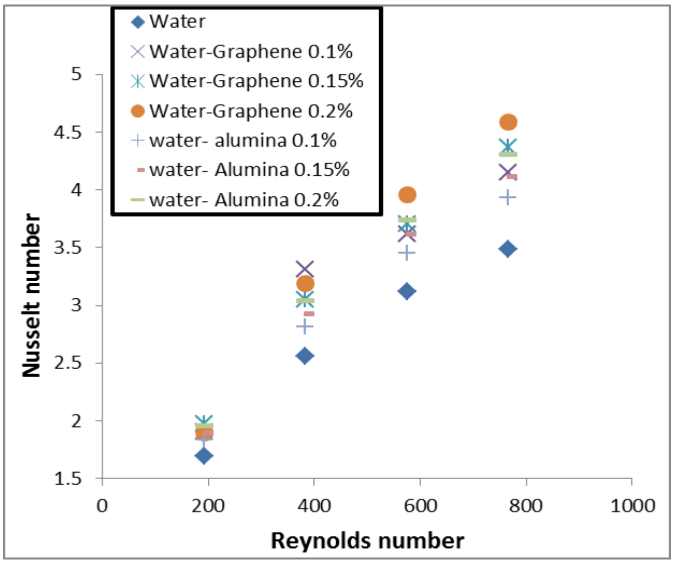

Chart -9: Variation of Nusselt number with respect to Reynolds number

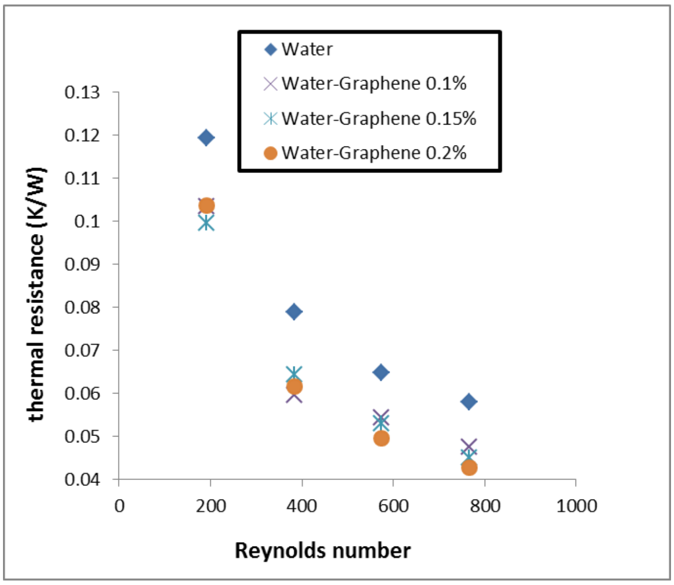

Chart -8: Variation of thermal resistance with respect to Reynolds number

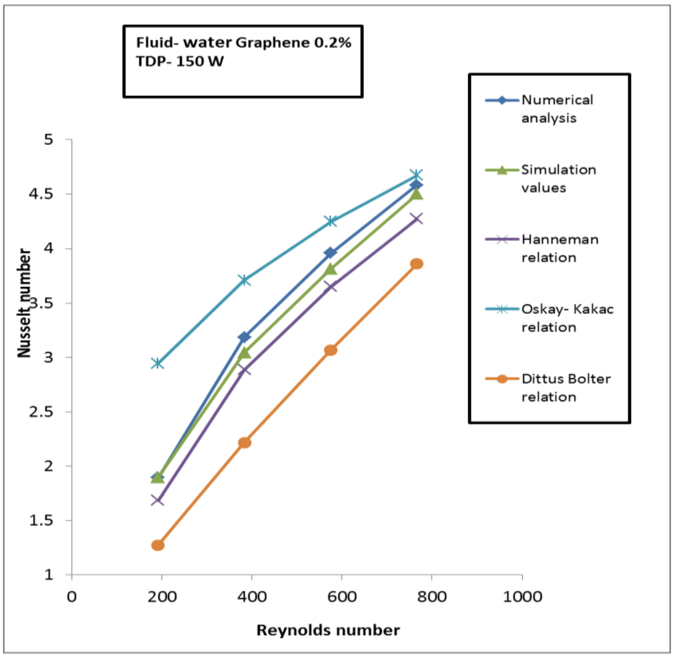

Chart -10: Validation Plot

4.5 NUSSELT NUMBER

For the same dimensions and material of the heat sink, the conductive heat transfer is almost same but the convective heat transfer changes according to the fluid passing through the sink and its flow conditions. The Nusselt number provides the convective thermal performance of the system. Chart 9 shows the Nusselt number plot for different concentrations of alumina and Graphene Nanofluids at 150W TDP.

5. VALIDATION

To validate the results of simulation various numerical correlations are used. Some of them are Oskay-kakac relation, Dittus Boelter relation and Hanneman equations.

OSKAY-KAKAC CORRELATION

$$Nu = 1.86\left(\frac{Re\ Pr\ D}{L}\right)^{0.333}$$

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Volume: 08 Issue: 03 | Mar 2021 www.irjet.net p-ISSN: 2395-0072

DITTUS BOELTER EQUATION

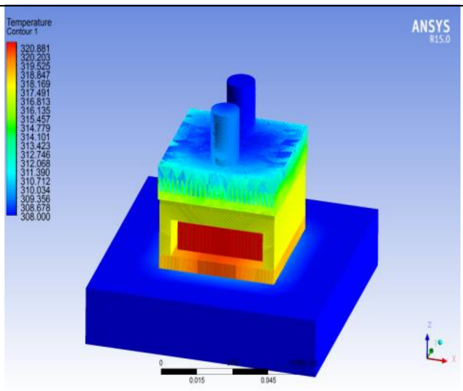
$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$$

HANNEMAN RELATION

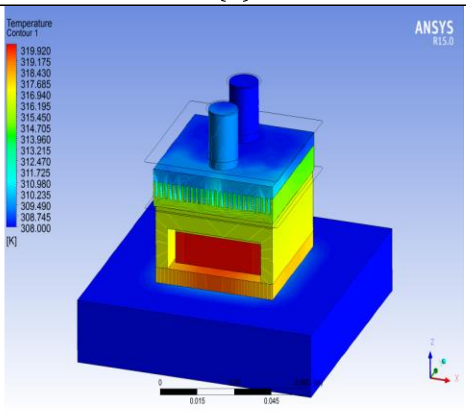
$$Q = \dot{m}C_p\left(T_{out} - T_{in}\right) = \bar{h}A_s\left(T_w - T_f\right)$$

$$\beta = \left(\frac{\bar{h}A_s}{\dot{m}C_p}\right)$$

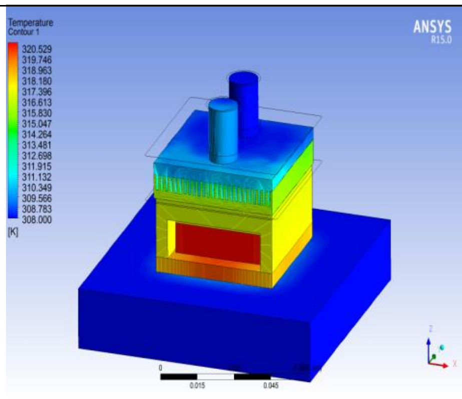
$$h_{eq} = \frac{\dot{m}C_p}{A_s}\left(1 - e^{-\beta}\right)$$



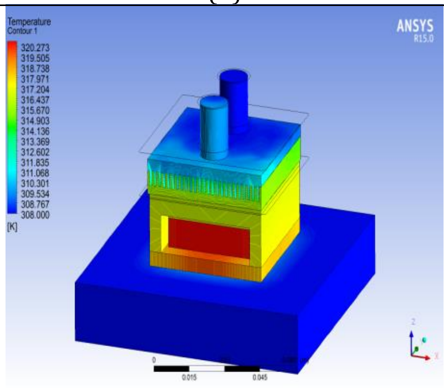
(A)



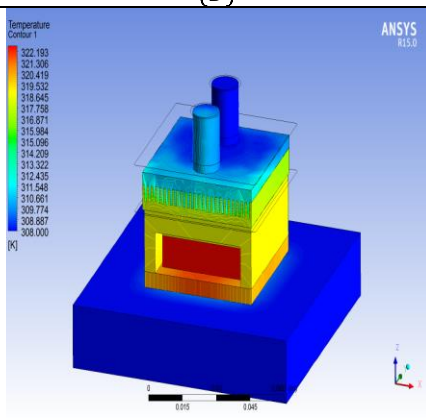
(B)



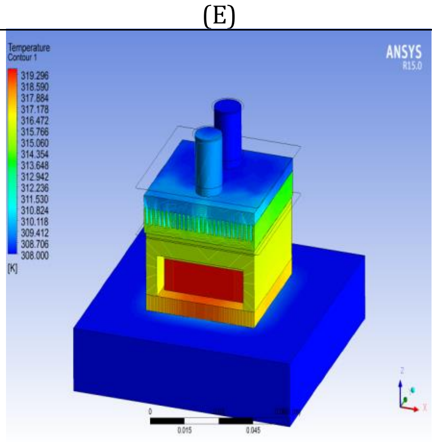
(C)



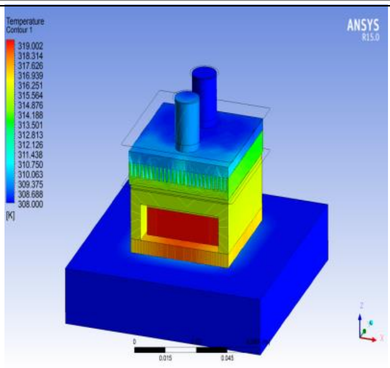
(D)



(E)



(F)



(G)

Fig- 4: Temperature profiles of processor chipset for various fluids (A) Water (B) Water- Alumina 0.1% (C) Water- Alumina 0.15% (D) Water- Alumina 0.2% (E) Water- Graphene 0.1% (F) Water- Graphene 0.15% (G) Water- Graphene 0.2%

6. CONCLUSIONS

From the results it is clear that the processor temperature is maintained at maximum allowable temperature by using Aluminium minichannel heat sink with Graphene Nanofluids flowing through it. The inclusion of nanoparticles increases the thermo physical properties of the base fluid to greater extent. The decrement in processor temperature by using Graphene and Alumina Nanofluids is 7% and 3.68% respectively as compared to water at 150W TDP.

The processor temperature at higher heat generation of 150W and 0.04 kg/s for water, Alumina(0.1%), Alumina(0.2%), Graphene(0.1%) and Graphene(0.2%) are 49.12°C, 48.18°C, 47.31°C, 46.51°C and 45.68°C respectively.

For 150W, alumina and Graphene Nanofluids gave 26.80% and 35.06% higher value of convective heat transfer coefficient with the comparison of the deionized water. As compared to Alumina nanofluids, the increment in heat transfer coefficient is 6.12% greater for Graphene Nanofluids at 0.2% volume fraction

At the highest volume fraction of Alumina and Graphene Nanofluids gave a decrement of 21.12% and 25.96% of convective thermal resistance with comparison to the deionized water. As compared to Alumina Nanofluids, the decrement in thermal resistance is 6.12% lower for Graphene Nanofluids at 0.2% volume fraction.

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