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Design and Analysis of a Heat Sink for a High Power LED System

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Abstract **- Recently, the high-brightness LEDs have begun to be designed for illumination application. The enhanced electrical currents accustomed drive LEDs result in thermal problems. Thermal management for crystal rectifier module could be a key style parameter as high operation temperature directly affects their most light-weight output, quality, dependability and life time. during this study a conductor is intended to dissipate heat created by the contact of a high power crystal rectifier light-weight. the look involves a series of crystal rectifier lights in a very industrial setting that required to be cooled. the warmth sinks area unit designed to use water (60psi) because the fluid to cool down the LED's properly. every conductor could be a compact device with semi-circular fins to function buffer plates to reinforce heat transfer. The mass flow rates of the fluid varied because the parameter for explicit fin styles. 3 mass flow rates and 4 fin geometries were investigated parametrically. the ultimate results of the study proposes Associate in Nursing optimum style with minimum pressure drop across every conductor whereas maintain the crystal rectifier junction temperature underneath check.**

Key words: LED, p-n junction, heat sink, heat exchanger, fin etc.

Nomenclature

Φ	Dissipation function due to viscous forces	T	Time scale
S_h	Energy Source	$\overline{v'^2}$	Velocity scale
G	Generation	k	Turbulence kinetic energy
RNG k-Є		CFD	Computational Fluid Dynamics
K	Thermal conductivity	LED	Light Emitting Diode
Є		COB	Chips On Board
G_k	Generation of turbulence kinetic energy due to the mean velocity gradients	Re	Reynolds Number
G_b	Generation of turbulence kinetic energy due to buoyancy	ΔP	Pressure Difference
$C_{1\epsilon}, C_{2\epsilon}, C_{3\epsilon}$	Constants	SM_x, SM_y and SM_z	The source terms
ρ	Density	T	Temperature
u, *v* and *w*	velocity components	α	Thermal Expansion
p, *P*	Pressure	C_μ	Turbulence model constant
S	Source terms	C_L	Co-efficient of lift
T	viscous stress		
μ_t	Eddy-viscosity	L'	Variable length

1. INTRODUCTION

In recent years High power LED's are becoming more popular because of their low power usage. About twenty percent of power input to LED is converted into the light energy and the rest into heat, if the heat could not be dissipated immediately, it will concentrate on the tiny LED chip and cause the junction temperature of the chip to rise to a harmful level. LED is particularly suitable for illumination due to the advantages of lower power consumption, little infrared emission, no UV, and relatively long life. Even though LEDs may have a very long life, poorly designed LED lamps can experience a short life and a poor lighting quality. The lifetime and lighting quality of LED lamps largely depend on junction temperature. LED lamps may experience wavelength shifts, epoxy degradation and low quantum efficiency, under high junction temperature.

Narendran N et al [1]have experimentally verified that the LED life diminish with rise in junction temperature in an exponential manner. Therefore, low junction temperature is essential for LED performance, which is a characteristic feature of LED lamp versus conventional lighting. Since the market requires that LEDs have high power and packaging density, it poses a contradiction between the power density and the operation temperature, especially when LEDs are operated at a normal or higher driver current to obtain the desired lumen output. So heat dissipation becomes a key issue in the application of high-power LED.

Maw-Tyan Sheen et al [2] were stated that micro-tube water-cooling systems rendered an improvement in thermal management that effectively decreases the thermal resistance and provides very good thermal dissipation.

Simulation and experimental results show that the LED module with a water-cooling tube exhibits better thermal performances than the others. Dae-Whan Kim et al [3] demonstrated that the two-phase thermo fluid characteristics of a dielectric liquid data obtained for single-phase water yielded excellent agreement with predictions for the convective heat transfer coefficients, dielectric fluids and therefore the back surface of a full of life electronic part, supply a most promising approach for cooling high-powered LEDs.

T.Cheng et al[4] were demonstrated Increasing pump rate of flow can build a pointy increase of the flow resistance. the fabric of device shell with high thermal physical phenomenon will ameliorate the cooling performance, however the perform is restricted. in line with preliminary tests and numerical optimization, An optimized small jet cooling system is unreal and applied in thermal management of a light-emitting diode lamp. The temperature check demonstrates the cooling system works well.

Ming-Tzer Lin et al [5] were explained water-cooling container in the high power LED array gave more efficient convection and the heat created by the LEDs was easily removed in the experiments. It was shown that micro-tube water-cooling systems rendered an improvement in thermal management that effectively decreases the thermal resistance and provides very good thermal dissipation.

2. HEAT GENERATION AND TRANSFER IN LED

LEDs produce light and heat by means of different mechanisms as compared to the incandescent bulb. By supplying electrical energy, the electron energy will be partly transformed into light and fairly into heat. Apparently the research into LED technology is paying attention on optimizing the light emitting efficiency.

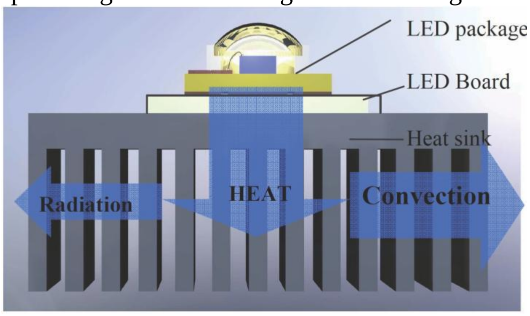

Figure 1. shows various means of heat dissipation from LED

Although each module has a unique structure, generally the LED package consists of a LED chip enclosed in a package of a polymer lens and a plastic carrier holder. Heat is generated by the LED chip inside the package. Although some amount of heat can be dissipated to surroundings by radiation and natural convection along the package surfaces, most of the heat will be conducted to the heat sink. The major part of the heat is transferred to the surroundings by convection from an optimized designed heat sink. On the other hand, radiation on the surface of the heat sink occurs naturally and it cannot be ignored as the average critical temperature of the LED module is high.

2.1 ADHESIVE

Adhesive is commonly used as bonding material between LED and board, and board and heat sinks. Using a thermal conductive adhesive can optimize the thermal performance. Epoxy is costlier than tape, however provides a larger mechanical bond between the heat sink and element, in addition as improved thermal conduction. Most epoxies are two-part liquid formulations that has got to be totally mixed before being applied to the heat sink, and before the heat sink is placed on the element.

The epoxy is then cured for a nominative time, which might vary from a pair of hours to forty eight hours. quicker cure time are often achieved at higher temperatures. The surfaces to that the epoxy is applied should be clean and freed from any residue [6].

2.2 HEAT SINK

Heat flows from the LED source to outside through the Heat sinks. Heat sinks can dissipate heat in three ways: conduction (heat transfer from one solid to another), convection (heat transfer from a solid to a moving fluid), or radiation.

2.2.1 *Material* – The thermal conductivity of the material plays an important role in conduction of heat from the heat sink. Normally this is aluminum (Al), even though copper may be used with an advantage for flat-sheet heat sinks. More advanced materials like thermoplastics that are used when heat dissipation requirements are lower than normal or complex shape would be advantaged by injection molding, and natural graphite solutions which offer better thermal transfer than copper with a lower weight than aluminum plus the ability to be formed into complex 2D shapes. Graphite is considered an interesting cooling solution and does come at a higher production cost. Heat pipes may also be further added to aluminum or copper heat sinks to ease spreading resistance.

2.2.2 ***Shape*** - Heat transfer takes place at the surface of the heat sink. Therefore, heat sinks should be considered to have a large surface area. This goal can be reached by using a large number of fine fins or by increasing the size of the heat sink itself.

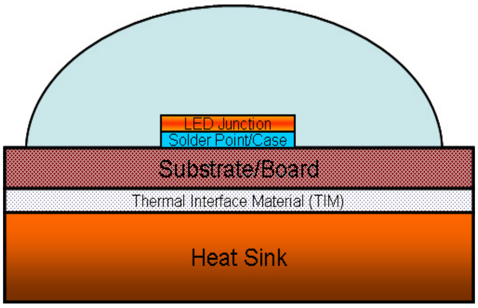

Figure 2 Construction of LED with a Heat Sink

***2.2.3** Surface Finish* - Thermal radiation of heat sinks could be a operate of surface finish, particularly at higher temperatures. A painted surface can have a greater emissivity than a bright, unpainted one. The impact is most outstanding with flat-plate heat sinks, wherever concerning tierce of the heat is dissipated by radiation. Moreover, a perfectly flat contact space permits the employment of a agent layer of thermal compound, which is able to cut back the thermal resistance between the heat sink and LED supply. On the opposite hand, anodizing or etching also will decrease the thermal resistance. Heat-sink mountings with screws or springs are better higher than regular clips, thermal conductive glue or sticky tape.

2.3 PCB (Printed Circuit Board)

MCPCB - MCPCB (Metal Core PCB) are those boards which incorporate a base metal material as heat spreader as an integral part of the circuit board. The metal core usually consists of aluminum alloy. Furthermore MCPCB can take advantage of incorporating a dielectric polymer layer with high thermal conductivity for lower thermal resistance.

Separation - Separating the LED drive circuitry from the LED board prevents the heat generated by the driver from raising the LED junction temperature.

2.4 PACKAGE TYPE

Flip chip - The concept is similar to flip-chip in package configuration widely used in the silicon integrated circuit industry. Briefly speaking, the LED die is assembled face down on the sub-mount, which is usually silicon or ceramic, acting as the heat spreader and supporting substrate. The flip-chip joint can be eutectic, high-lead, lead-free solder or gold stub. The primary source of light comes from the back side of the LED chip, and there is usually a built-in reflective layer between the light emitter and the solder joints to reflect the light emitted downwards up. Several companies have adopted flip-chip packages for their high-power LED, achieving bout 60% reduction in the thermal resistance of the LED while keeping its thermal reliability.

3. DESIGN AND CFD SIMULATION

The main objective of this project is analyze the performance of a heat sink which uses tap water to maintain and reduce the junction temperature while providing warm water for heating purpose.

***3.1.** PARAMETERS*

The parameters that affect the study are volume, temperature, time and height of the heat exchanger. How much volume of water is sent into the heat exchanger, water with ambient temperature is sent into the exchanger.

- Heat Input 56 W (20% illumination power of 70W LED)
- Dimensions are according to the drawing.
- Variation of Thickness in the inner cylinder
- Flow rate 0.15kg/s, 0.25kg/s and 0.44kg/s

***3.2.** DESIGN METHODOLOGY*

The commercial LED which we started working on is WHITELION LED product High bay Bridge lux LED 70W, 5400Lm. It is an chip on Board LED suitable for outdoor applications especially for the warehouses and factories. The specifications are as follows

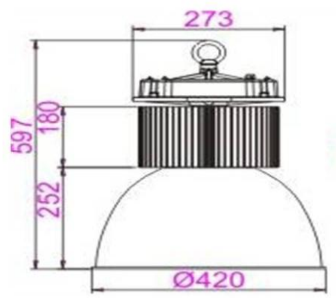

Figure 3 dimensions (mm) of the 70W COB White lion LED light.

- LED High Bay Light 70W as high efficiency replament for 640W Sodium/Metal Halide
- 70W LED High Bay Lights reduces energy savings up to 80%
- LED 70W High Bay reaches full brightness instantly.
- Operating temperature range between -45° and 60°C
- Rated life of 50,000 hours
- 70W COB LED High Bay IP65 is suited to install on the 9-12M height, ideal for warehouse, factory and industry spaces
- Input Voltage: AC85-265V, 50/60Hz

Figure 4 3D view of White lion LED Light

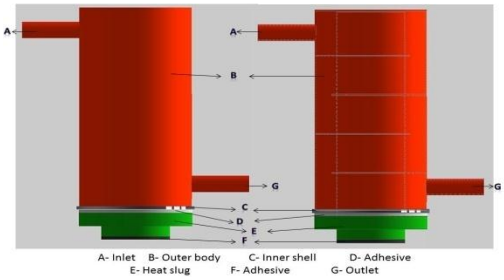

Figure 5 The model and parts

Figure 5 is the diagram for the newly designed heat sink in this project. In the design, inner shell (C) and heat slug(E) are made of Aluminum. The Adhesives(D and F) are CoolPoly® E8103 Thermally Conductive Thermoplastic Elastomer (TPE). The properties of these materials are listed below.

Table 1 Material properties of solid materials

Material	Thermal conductivity (W/m-K)	Specific heat (J/kg-K)	Densitykg/ m^3
Adhesive	5	1940	1130
Aluminum	202.4	871	2719

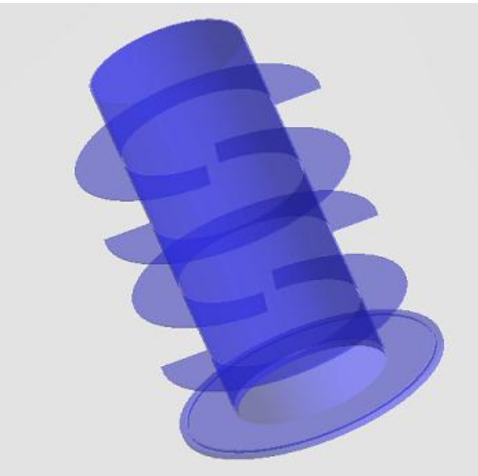

Figure 6 The inner shell, made of Aluminium with fin partitions

Above figure shows the inner shell made of Aluminum with partitions to guide the flow. Each circular fin is designed be segmental to cover 270° C to allow flow to go in a cross flow pattern to take advantage of high heat transfer in the cross flows. There are total 4 fins. The inner shell passes the water with guiding towards outlet. This inner shell is made up of Aluminium material.

3.3. Governing Equations

Numerical simulations are performed to predict the flow and heat transfer characteristics of the designed heat sink. This chapter gives descriptions of the mathematics model used.

3.4. Governing Equations of Fluid Flow

The general form of fluid flow and heat transfer equations of incompressible for a Newtonian fluid in steady state flow is given as follows:

$$mass: \qquad \nabla \cdot (\rho \vec{V}) = 0$$

Momentum equation:

$$\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) - \rho\overline{u_i' u_j'}\right)$$

energy:

$$\frac{\partial}{\partial x_i}\left(\rho u_i c_p T\right) = \frac{\partial}{\partial x_i}\left(\frac{\mu}{\sigma}\frac{\partial T}{\partial x_i} - \rho c_p \overline{u_i'\theta}\right)$$

3.5. RNG k-Є model equations:

RNG turbulence model (Yakhot and Orzag, 1986) differs from the standard k–ε model in few aspects. The RNG model solves an additional term in the ε equation compared to the standard k-ε model and it solves an analytical formula for turbulent Prandtl numbers, while the standard k-ε model uses user-specified, constant values. The RNG model also provides for an option to treat the effective viscosity using the analytically derived formula that accounts for low-Reynolds-number effect (Yakhot and Orzag, 1986). The kinetic energy of the turbulence, k and its dissipation rate, Є are the governed by separate transport equations. The RNG-based k- Є turbulence model contains very few empirically adjustable parameters.

$$\frac{\partial}{\partial x_i}\left(\rho k u_i\right) = P - \rho\varepsilon + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + Sk$$

$$\frac{\partial}{\partial x_i}\left(\rho\varepsilon u_i\right) = \frac{C \in 1P - C \in 2\rho\varepsilon}{T} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + S\varepsilon$$

$$\frac{\partial}{\partial x_i}\left(\rho\overline{v^2} u_i\right) = \rho k f - 6\rho\overline{v'^2}\frac{\varepsilon}{k} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \overline{v'^2}}{\partial x_j}\right] + Sk$$

$$f - L^2 \frac{\partial^2 f}{\partial x_j^2} = (C_1 - 1)\frac{\frac{2}{3} - \overline{v'^2}/k}{T} + C_2 \frac{P}{\rho k} + \frac{5\overline{v'^2}/k}{T} + Sk \qquad 3.3.7$$

where

$P = 2\mu_t S^2$ (i)

$T = \min\left[T', \frac{\alpha}{\sqrt{3}} \frac{k^{3/2}}{\overline{v^2} C_\mu \sqrt{2S^2}}\right]$ (ii)

$L = C_L \max\left[L', C_\eta \left(\frac{v^3}{\varepsilon}\right)^{1/4}\right]$ (iii)

$T' = \max\left[\frac{k}{\varepsilon}, 6\sqrt{\frac{v}{\varepsilon}}\right]$ (iv)

$L' = \min\left[\frac{k^{3/2}}{\varepsilon}, \frac{1}{\sqrt{3}} \frac{k^{3/2}}{\overline{v^2} C_\mu \sqrt{2S^2}}\right]$ (v)

The eddy-viscosity (μ_t) is modeled using one time scale (T) and one velocity scale ($\overline{v'^2}$) instead of the turbulence kinetic energy (k) used in the k-ε model. The velocity variance scale ($\overline{v'^2}$) can be thought of as the velocity fluctuations normal to the streamlines. This distinguishing feature of $\overline{v'^2}$ - f model seems to provide a proper scaling in representing the damping of turbulent transport close to the wall, a feature that k does not provide in other eddy-viscosity model.

3.6. PRE-PROCESSING AND MESH

In CFD calculations, there are three main steps.

1) Pre-Processing

2) Solver Execution

3) Post-Processing

Pre-Processing is the step where the modeling goals are determined and computational grid is created. In the second step numerical models and boundary conditions are set to start up the solver. Solver runs until the convergence is reached. When solver is terminated, the results are examined which is the post processing part.

In this study, the aim is to investigate the cooling characteristics of different heat sinks designed to cool the Light Emitting Diode (LED). So, an adequate numerical model is to be created. There are two important points here. The first one is the size of the domain, and the second one is the quality. Model size is the computational domain where the solution is done. It is important to build it as small as possible to prevent the model to be computationally expensive. On the other hand it should be large enough to resolve all the fluid and energy flow affecting the heat transfer around the LED. Inside the LED, Adhesive, and Heat slug are modeled. Since there were no CAD data for the chosen problem geometry, all the devices inside the case are created using ANSYS FLUENT Design Modeler creation tools. A high quality unstructured tetrahedral mesh is generated before the solution of the governing equations.

A top quality unstructured tetrahedral mesh is generated before the solution of the governing equations. A wall is formed between the water and thuslid surface so on have a interface between the two mediums to transfer heat between them. Linear tetrahedral parts are either constant stress parts with four nodes or linear stress parts with ten nodes. These parts area unit developed in 3-dimensional house with three degrees of freedom per node; these area unit the translational degrees of freedom within the X, Y and Z directions, severally. The ten-node part is Associate in Nursing isoparametric part and stresses area unit calculated at the nodes. the subsequent element-based loadings could also be applied:

Uniform or hydrostatic pressure on the element faces. Thermal gradients defined by temperatures at the nodes. Uniform inertial load in three directions.

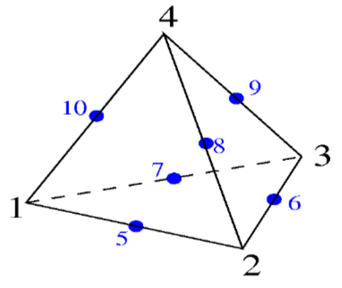

Figure 7 10-Noded Tetrahedral Element

Table 2 Meshing information of each part

Domain	Nodes	Elements
Adhesive	5957	11943
Big Adhesive	8199	16692
Heat slug	67561	193833
Inner shell	187740	406418
Outer body	347414	972142
All parts	616871	1601028

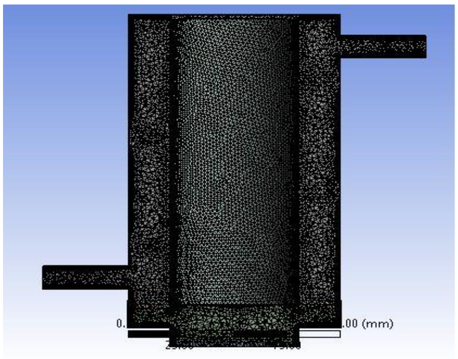

Figure 8 the half section of the mesh

3.7. SOLVER SETTINGS

Settings are applied by ANSYS FLUENT to solve for Temperature variations. The model is having with Pressure based condition, energy condition is enabled for temperature variations, and then atmospheric pressure is taken as 60 psi to solve this analysis. Desired boundary conditions are applied by selecting boundary conditions tab. The wall created for the interface between the Fluid and Solid medium is set as 'Interface' and is coupled. Inlet has different mass flow rates for each case. Pressure velocity coupling method is SIMPLE (Semi Implicit Pressure Linked Equation). For solution methods Solution methods Pressure body force weighted, momentum, turbulent kinetic energy, turbulent viscosity, energy are first order upwind. Solution controls under relaxation factors values are taken as Pressure 0.3, density 1, body forces 1, momentum 0.3, turbulent kinetic energy 0.8, turbulent viscosity 1, energy 0.8. For all cases, since the Reynolds number being greater than transition limit value, a RNG Turbulence model was sufficient. In this analysis flow model is k-ϵ turbulence with RNG model. The residual monitor is checked to print and plot the integration. The iterations are run at least 2000 in each case to ensure convergence of solutions.

4. RESULTS AND DISCUSSION

4.1. *Effect of Heat Sink Thickness*

With the increase in the thickness of the inner cylinder of the heat sink the amount of aluminum increases and volume of water passing through decreases. So an optimum solution is considered by minimum thickness of the material and maximum heat transfer to the water. Several thickness 0.1-0.25 inches with an interval of 0.5 inches are tested and the results are shown below with a constant mass flow rate of 0.15kg/s and varying thickness. All other are maintained as follows

Inlet Temperature	293K
Inlet Pressure	60 psi
Heat	56Watts

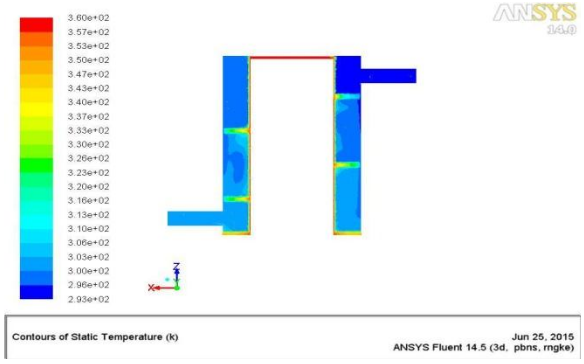

Figure 9 the temperature contour for 0.1inch thickness inner cylinder with 0.15kg/s mass flow rate

Fig.9 shows the temperature contour variation for 0.1 inch thickness inner cylinder with 0.15kg/s mass flow rate. Temperature variation at the outlet is 299.35 K.

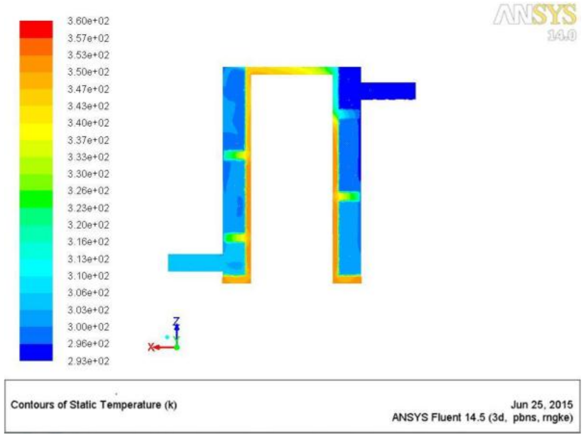

Figure 10 the temperature contour for 0.2 inch thickness inner cylinder with 0.15kg/s mass flow rate

Figure 10 shows the temperature contour variation for 0.2 inch thickness inner cylinder with 0.15kg/s mass flow rate. Temperature variation at the outlet is 302.35 K.

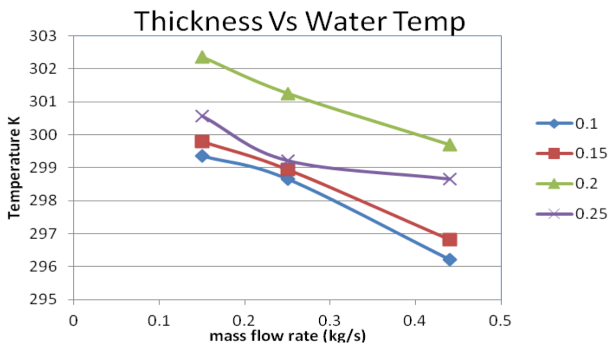

Figure 11 Variation of Water Temperature with mass flow rate and thickness of Inner Cylinder

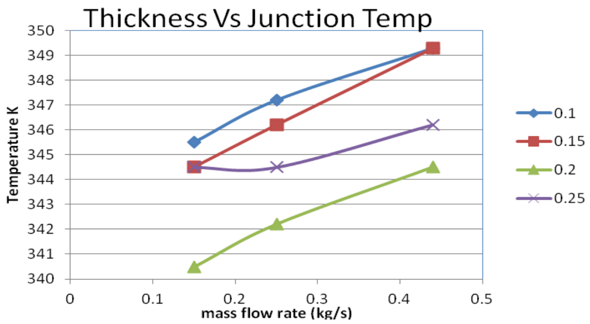

Figure 12 Variation of Junction Temperature with mass flow rate and thickness of Inner Cylinder

The above graph shows at different thickness to temperature variation graph at different mass flow rate. Here mass flow rate and thickness varies, then the temperature variation is increasing and then decreasing at different thickness. For 0.15kg/s case with 0.1 inch thickness temperature (299.35 K) variation is minimum, at 0.2 inch thickness temperature is maximum (302.35 K), and then it is decreasing to up to minimum (300.56 K). With increase in the thickness the volume of material increase and there is a decrease in the volume of water, in turn resulting less contact with heated surface.

4.2. Effect of Reynolds number

With the increase in the Reynolds number (flow rate) for the fixed thickness inner cylinder the temperature of the outlet water decreased. This is because of more velocity and less time of contact between the water and inner cylinder.

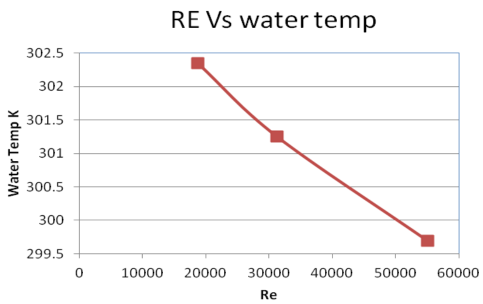

Figure 13 Temperature variation at 0.2 inch thicknesses.

The above graph shows at different Reynolds number to temperature variation graph at 0.2 inch thickness. Here thickness is constant mass flow rate is varying, and then the temperature variation is increasing and then decreasing at different mass flow rate. At Re = 18768 (0.15 kg/sec) the temperature variation is maximum (302.35 K), at Re = 55052(0.44 kg/sec) mass flow rate the temperature is minimum (299.69 K). With decrease in the mass flow rate the temperature will further increase, but the water moving needs to maintain pressure in order to get the flow all along the pipes. So the further reduction of mass flow rate is not considered.

With increase in the mass flow rate for the constant pressure 60psi, the pressure drop is calculated and the graph below shows the variation of Reyonlds number with the pressure drop.

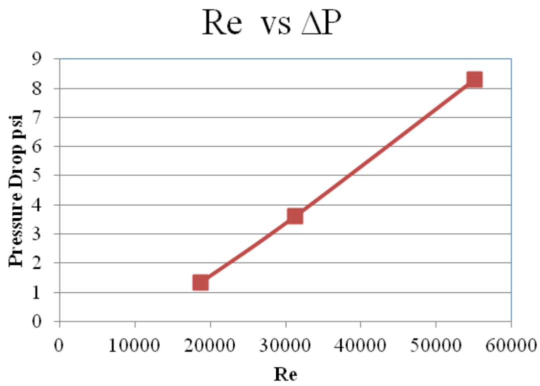

Figure 14 Variation of pressure drop with Reynolds number for a 0.2 inch thick inner cylinder

Fluent results for the cases, with all the input parameters and the desired output values are documented in the table below. Final Junction temperature shows the junction temperature of the LED light after the Heat Sink addition.

Table 3 the output values of all the cases

Mass-flow inlet (kg/s)	Thickness (inches)	Water Temp (K)	Final Junction temp (K)
0.44		296.2	349.38
0.25	0.1	298.65	347.26
0.15		299.35	345.5
0.44		296.82	349.31
0.25	0.15	298.95	346.25
0.15		299.8	344.51
0.44		299.69	344.56
0.25	0.2	301.25	342.21
0.15		302.35	340.59
0.44		298.65	346.2
0.25	0.25	299.21	344.54
0.15		300.56	344.55

5. CONCLUSIONS

With this study a new heat sink is proposed for a 70W COB (chip on board) to improve the thermal management of LED light. Additionally heat slug and adhesives are designed. The performance is numerically simulated with 4 different flow rates from 0.44 – 0.15kg/s and thickness of the heat sink from 0.1 - 0.25 inch while keeping the pressure 60psi constant. The conclusions are drawn:

The chip junction temperature decreases as as a function of thickness. Pressure drop across each heat sink increase with Reynolds number.

The results indicate that 0.15kg/s mass flow rate and 0.2 inch thickness is found to be optimal to give the lowest junction temperature.

The temperature rise for the water at 293K initially is 9.65K. With the introduction of heat sink the junction temperature is kept at 340K which is bellow the junction temperature of 360K without a heat sink.

The simulation results shows that the introduction of Heat sink could lead to significant reduction the LED junction temperature .

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