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Original Research Article

# Parametric Analysis of an Injection Molding System Performance for PET Products Production

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**Abstract:** Plastic products have taken over most domestic and industrial needs of every nation of the world. The increasing demands of these products required an effective manufacturing output hence the need for an effective cooling, clamping and injection system. This work is critically analyzed with Different Engineering software like SOLIDWORK , Mat lab and COMSO MULTI Physics were utilized to determine the thermal analysis ,cooling and thermal utilization in relation to the geometrical variation in thickness of mold water chamber wall separation thickness and PET thickness, x,(mm) with well- defined boundary conditions cooling water temperature, clamping force, injection pressure, pouring temperature of the molten plastic and material thickness as they affect performance of the injection molding system for quick polyethylene terephthalate (PET) plastic products production.
**Keywords:** Parametric Analysis, Injection Mold Performance, Quick Product Recovery and enhanced production

## INTRODUCTION

Plastic products become relevant in the world for their high demand in domestic, commercial and industrial purposes, food, Pharmaceutical, edible oil, petrol chemical industries etc found plastic products useful to enable storage, packaging, transportation and sales of their products. Many works have been done in plastic production on virgin materials, recycled materials as well as fibre re-inforced plastics but must has not been done on the molding system to analyze the effect of an injection molding system as it affect product characteristics through adequate material selection, clamping force, injection or pouring temperature, water cooling system and temperature, thickness of materials in the cooling chamber as they affect the performance of the injection mold. Injection molding required a good cooling system for quick products recovering. This cooling system efficiency and mold performance has to do with stabilization of water cooling temperature during the production process. In most plastic features, cooling tower are incorporated into the injection molding cooling systems which helps to bring down the temperature of the converted water in the cooling system cycle (Loop). Injection molding system is the most widely used polymeric fabrication process. It originated from metal die casting, however, unlike molten metals, polymer melts have a high viscosity and cannot simply be poured into a mold and a large force must be used to inject the polymer into the cavity of the mold. More melt must also be packed into the mold during solidification to avoid shrinkage in the mold. The injection molding process has a series of operations that are sequentially carried out that lead to the transformation of plastic pellets into a molded part. Cooling makes the plastic to solidify and become dimensionally stable before removal. Heat that has been transferred to the mold by the molten plastic is carried away by a coolant that circulates through cored passages in the mold. Coolant temperature and flow rate determines the efficiency of heat removal. However, factors like thickness of the wall between the mould cavity and coolant chamber and the material of the mould will be investigated .Cooling the moulded components uniformly may mean either, cooling the mould with different flow rates of cooling medium in different areas or, using the same flow rate throughout the mould but with different temperatures of cooling medium. A water cooling system that is environmental friendly is selectected using water cooling tower.

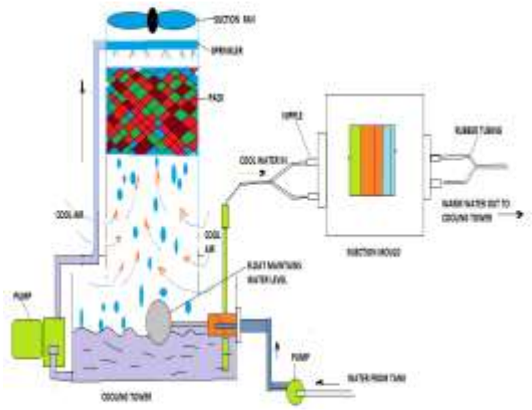

**Fig-1: A schematic diagram of an injection mold cooling system**

The heating system as it affects the amount of heat energy required to melt virgin plastic materials or recycled material is determined on the capacity of the moulding machine as a unit. However, heating element size and steady high Voltage supply could enhance the heat dissipation rate in the bands. The injection system with an irregular pitched screw conveyor can be enhanced by regulating the speed of its prime mover, however, experience has shown that the speed is matched with the capacity of the heating system bands spaced doing the screw housing in the machining injection system.

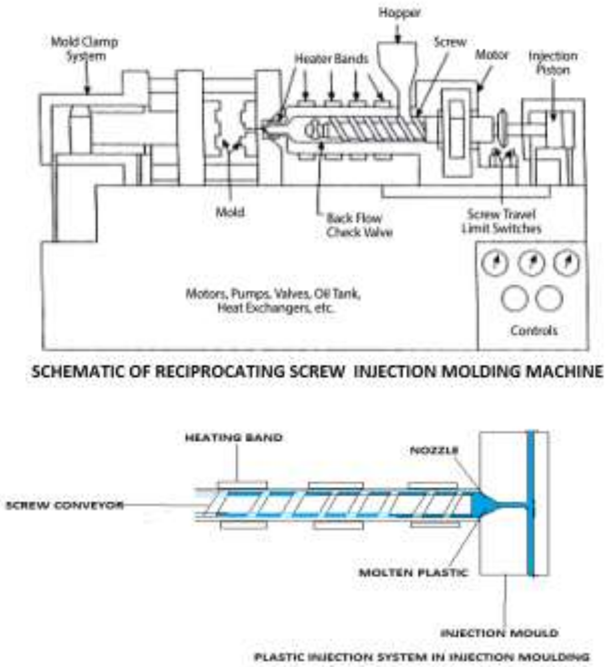


**Fig-2: screw conveyor injection system**

**STATEMENT OF PROBLEM**

Quick products recovery and plastic production becomes necessary factor among others to facilitate the supply of plastic products to satisfy their high demands in the markets of the world. This can be achieved through good material selection, clamping force, effective cooling system, and material thickness of the mold.

**SCOPE**

This work covers the temperature management system of the injection mold and all parameters that can be varied to have effective cooling within the mold will be verified, thickness of the wall of the water chamber, material composition as it affect thermal conductivity and diffusivity of the material and cooling water inlet temperature of the molding system will be investigated using SOLID Works, 2012, COMSOL Multiphysics and Mat lab. There are three main stages in the injection molding cycle; stage 1, injection, followed by stage 2, holding pressure and plasticating, and finally, stage 3, ejection of the molded part. This is to make these three stages so close for quick delivering.

**AIMS AND OBJECTIVE**

Mold design and development involve intensive labour and high proficiency on machining skills. This requires having metal plates and rods which are machined with heavy conventional machines. Most mold machinists in Nigeria do not take cognizance of the factors that can enhance mold performance in plastic production. Having poor knowledge about material selection, they are restricted to mild steel materials for their ease machining. This work is done to show case the parameters factors that can enhance performance of injection molding system for quick product recovery. Hence, the following aims and objective are considered

- Effect of material selection on mold making heat performance
- Effect of water chamber wall thickness on heat sink performance
- Effect of cooling water inlet temperature
- Temperature on heat performance of the system.
- Effect of clamping force on mold material and injection pressures

**SIGNIFICANCE**

This work is investigated to suggest parametric factors that can be put into considerations, firstly by mould makers in injection mould design and secondly by injection moulds users in the factories for quick products recovery and facilitated production.

**INJECTION MOLD**

Injection moulding is a manufacturing process for producing parts by injecting material into a mould. In the plastic industries or factories there are basic called blow moulding system for products with cavities e.g 10 litre gallon, GP tanks, Plastic bottle etc and injection moulding system for products like hangers, bottle holders, plastic spoon, covers, plates etc. Products from blow molding system are air cooled and most finishing is done outside. After blow moulding operation completion. A wide variety of products are manufactured using injection molding machine, such as plastics housings, consumer electronics, medical devices including valves and syringes which vary greatly in their size, complexity and application .The injection molding process requires the use of an injection molding machine, raw plastic parts, material, and a mould. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and solidifies into the final part. Injection molding system has a water cool system which is circulating round a closed loop system for an alternate cooling and heating processing. The process is forced convention as the cold water is passed into the mold via the water chamber to extract (gain) heat from the hot mold wall to the outside which is cooled through an evaporative cooling system see. Fig I. this is circulation as aided by centrifugal pumps. This solidification of the molten plastic which deforms into the cavity of the mold is aided and quickened by the cooling water. The rate of solidification as it affects by the rate of cooling is governed by the inlet water temperature. The inlet water temperature is determined also by the cooling efficiency of the water cooling tower. Hence, an effective cooling system is used to recycle cooling water into the injection mold. The injection mold also need good clamping force to withstand the loop stresses that will be induced by the injection pressure in the mold cavity. It is therefore necessary to make sure the clamping force is greater than the injection pressure for effective injection. This also eliminated seams in products of well machined mold.

A good injection mold is characterized with:

(i) Back plate to match the bed of the machine
(ii) Location pins for alignment of the mating mold halves
(iii) Water plates and nipples
(iv) The mold cavity plate
(v) Ejection pins for quick product removal.
(vi) Good assembly

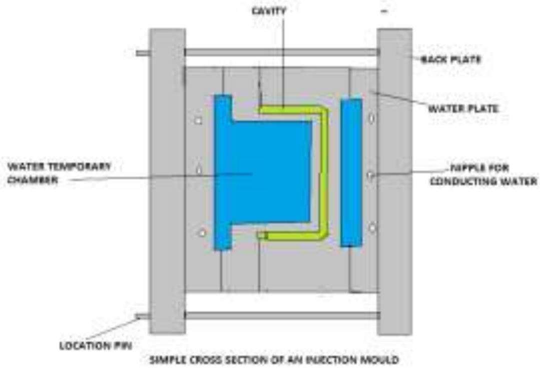


**Fig-3: mold basic parts**

## FACTORS THAT AFFECT THE PERFORMANCE OF AN INJECTION MOLDING SYSTEM

These are categorized as detailed

### SPEED RELATED PROCESS VARIABLES

- Mould opening and closing speeds
- Injection speed
- Screw rotation speed
- Screw recovery speed
- Component retraction speed

### PRESSURE RELATED PROCESS VARIABLES

- Injection pressure
- Holding pressure
- Hydraulic back pressure

### TIME RELATED PROCESS VARIABLES

- Injection time
- Holding pressure time
- Pause (dwell) time
- Cooling time
- Cycle time

### TEMPERATURE RELATED PROCESS VARIABLES

- Melt temperature
- Mold temperature
- Barrel temperature

## MATHEMATICAL MODELING OF COOLING SYSTEM

Some of the assumptions are applied using mathematical model [1, 2]. The objective of mold cooling analysis is to analyses the temperature distribution in the molded part and mold cavity surface during cooling process. When the molding process reaches the steady-state after several cycles, the average temperature of the mold is constant even though the true temperature fluctuates periodically during the molding process because of the cyclic interaction between the hot molten plastic and the cold mold at initial stage. For convenience of CAE analysis, cycle-averaged temperature approach is used for mold region and transition analysis is applied to the molded part [1-3]. The general heat conduction involving transition heat transfer problem is conducted by the partial differential equation. The cycle-averaged temperature distribution can be represented by the steady-state Laplace heat conduction equation. The coupling of cycle-averaged and one dimensional transient approach was applied since it is computationally efficient and sufficiently accurate for mold design purpose [4, 5]. Heat transfer in the mold is treated as cycle-averaged steady state, and 3D FEM CAE simulation was used for analyzing the temperature distribution. The cycle-averaged approach is applied because after a certain transient period from the beginning of the molding operation, the steady-state cyclic heat transfer within the mold is achieved. The fluctuating component of the mold temperature is small compared to the cycle-averaged component so that cycle-averaged temperature approach is computationally more efficient than periodic transition analysis [6]. Heat transfer in polymer (molding) is considered as transient process. The temperature distribution in the molding is modeled by following equation:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial Z^2} \qquad (1)$$

The nature of thermal contact resistance between polymer and mold, a convective boundary condition was applied instead of isothermal boundary condition [7].

$$h_C[T_{ps} - T_m] = -K_p \frac{\partial T}{\partial z} \qquad (2)$$

Where

$T_{ps}$ = molded part surface temperature

$T_m$ = mold temperature, respectively;

$k_p$ = the thermal conductivity of polymer.

$$TCR = \frac{1}{h_c} \qquad (3)$$

TCR =thermal contact resistance

*hc* =heat transfer coefficient

The TCR between the polymer and the mold is not negligible. TCR is the function of a gap, roughness of contact surface, time, and process parameters. The values of TCR are very different [8-15] and they are often obtained by experiment. The heat flux across the mold-polymer interface is expressed as follows.

$$q = -K_p \frac{\partial T}{\partial n} \qquad (4)$$

where *n* is the normal vector of the surface. The cycle-averaged heat flux is calculated by the equation:

$$\bar{q} = \frac{1}{t_c}\int_0^{t_c} q\,dt \qquad (5)$$

The required cooling time *tc* is calculated as follows [16, 17]

$$t_c = \frac{s^2}{\pi\alpha} In\left[\frac{4}{\pi}\left(\frac{T_i - T_m}{T_e - T_m}\right)\right] \qquad (6a)$$

S=the part thickness

But, The Wubken equation allow us to estimate the cooling time [24]

$$t_k = \frac{s^2}{\pi\alpha} In\left[\frac{8}{\pi^2}\left(\frac{T_W - T_a}{T_W - T_b}\right)\right] \qquad (6b)$$

$$\alpha = \frac{K_m}{\rho C_p} \qquad (7)$$

Where α is the material thermal diffusivity; s is the part thickness'; $T_a$ is the injec-tion temperature; $T_b$ is the ejection temperature and $T_w$ is the medium mould temperature.

The Injection moulding system temperature and heat flux analysis will be visualised using Equations (1) to (6) for a PET product using MATLAB and COMSOL Multiphysics

The heat flux supplied to the mold and the heat flux removed from the mold must be in equilibrium. Figure 7 shows the sketch of configuration of cooling system and heat flows in an injection mold. The heat balance is expressed by equation

$$\dot{Q}_m + \dot{Q}_c + \dot{Q}_e = 0 \qquad (8)$$

The heat flux from the melt, $\dot{Q}_m$ the heat flux exchange with coolant, $\dot{Q}_c$ and environment $\dot{Q}_e$.

The heat from the molten polymer is taken away by the coolant moving through the cooling channels and by the environment around the mold's exterior surfaces. The heat exchanges with the coolant is taken place by force convection, and the heat exchanges with environment is transported by convection and radiation at side faces of the mold and heat conduction into machine platens. In application, the mold exterior faces can be treated as adiabatic because the heat lost through these faces is less than 5% [1, 6]. Therefore, the heat exchange can be considered as solely the heat exchange between the hot polymer and the coolant. The equation of energy balance is simplified by neglecting the heat loss to the surrounding environment.

$\dot{Q}_m + \dot{Q}_c = 0$ (9)

Heat flux from the molten plastic into the coolant can be calculated as [18]

$\dot{Q_m} = 10^{-3}\left[C_p(T_M - T_E) + i_m\right]\rho\frac{S}{2}x$ (10)

Heat flux from the mold that changes with coolant in the time *tc* amounts to [1]:

$\dot{Q}_c = 10^{-3}t_c\left(\frac{1}{10^{-3}\alpha\pi d}^{-1}\frac{1}{K_{st}S_e}\right)^{-1}(\bar{T}_W - \bar{T}_C)$ (11)

The total time that the heat flux transfers to coolant should be cycle time including filling time $t_f$ cooling time $t_c$ and mold opening time $t_o$. By comparing the analysis results .The under-estimation or over-estimation is considerable when the filing time and mold opening time is not a small portion compared to the cooling time, especially for the large part with small thickness [19]. For this reason, the formula [9] is adjusted approximately based on the investigation of the mold wall temperature of rectangular flat parts by using both practical analytical model and numerical simulation

$\dot{Q}_c = 10^{-3}\left(\frac{1}{2}t_f + t_c + \frac{1}{3}t_o\right)\left(\frac{1}{10^{-3}\alpha\pi d}^{-1}\frac{1}{K_{st}S_e}\right)^{-1}(\bar{T}_W - \bar{T}_C)$ (12)

The influence of the cooling channels position on the heat conduction can be taken into account by applying shape factor $S_e$ [20]

$S_e = \frac{2\pi}{In\left[\frac{2x\sinh(2\pi y/x)}{\pi d}\right]}$ (13)

The pitch *x*, depth *y* and diameter *d*. are used for the shape factor analysis. Heat transfer coefficient of water is calculated by [17]

$\alpha = \frac{31.395}{d}Re^{0.8}$ (14)

where the Reynolds number

$Re = u\frac{d}{V}$ (15)

The cooling time of a molded part in the form of plate is calculated as [16, 17]:

$t_C = \frac{S^2}{\pi^2 a}In\left[\frac{4}{\pi}\left(\frac{T_M - \bar{T}_W}{T_E - \bar{T}_W}\right)\right]$ (16)

From the formula (14), it can be seen that the cooling time only depends on the thermal properties of a plastic, part thickness, and process conditions. It does not directly depend on cooling channels configuration. However, cooling channels' configuration influences the mold wall temperature $T_W$, so it indirectly influences the cooling time.

$\frac{[C_p(T_M - T_E) + i_m]\rho\frac{S}{2}x}{\bar{T}_W - T_C}\left[\frac{1}{2\pi K_{st}}In\left[\frac{2x\sinh\left(2\pi\frac{y}{x}\right)}{\pi d}\right] + \frac{1}{0.03139\pi Re^{0.8}}\right] = \frac{S^2}{\pi^2 a}In\left[\frac{4}{\pi}\left(\frac{T_M - \bar{T}_W}{T_E - \bar{T}_W}\right)\right] + \frac{1}{2}t_f + \frac{1}{3}t_o$ (17)

Equation (17) is a combination of the equations treated previously

The $T_M$, $T_E$, $T_W$ , mathematically predefined $t_f$ and $t_o$, and others thermal properties of material, equation (17) presents the relation between cooling time $t_c$ and the variables related to cooling channels configuration including pitch *x*, depth *y* and diameter *d*. In reality, the mold wall temperature $T_W$ is established by the cooling channels configuration and predefined parameters $T_M$, $T_E$, $t_f$, $t_o$, and thermal properties of material in equation (17). The effect of material section on an injection mold performance is analysed using variable like strength, thermal conductivity and diffusivity, expancivity and ease of mold manufacturing

## DESIGN ANALYSIS

Cooling water temperature Parameter setting

(i) Water inlected temperature ($T_0$) = $25^0$C

(ii) Injection Molten Plasting ($T_1$) = $250^0$C

(iii) Heat on the mould plate (Q = MC$\theta$)

MC$\theta$

M = Mass of injected plastic

C = Specific heat capacity of plastic PET

Q = Temperature difference ($200^0$ – $250^{0)}$

Stress

(i) Thermal Stresses on the plates

(ii) Structural stresses

(a) Clamping force = 2KN

(b) Injection pressure = 1.8 barr

Mould Materials-Aluminium alloy

Injection molding machines are often classified by the maximum clamp force that the machine can generate. This is the forc e that pushes the two mold halves together to avoid opening of the mold due to internal pressure of the plastic melt in the mold. The clamping force of typical injection molding machines range from 200 to 100,000 kN.

**CONDUCTION**

For heat conduction in isotropic materials, assuming no heat generation within the material itself

$$\frac{\partial T}{\partial t} = \alpha\nabla^2 T \qquad (18)$$

where T is the interior temperature distribution, t is the time, and

$\alpha = K/\rho C_p$ (19)

$\alpha$ is called the thermal diffusivity and k is the thermal conductivity, $\rho$ is the density, and Cp is the specific heat

In isotropic domain the heat transfer is described by the energy conservation equation [23]: Where ρ, $C_p$ and k represent the density, the specific heat and the thermal conduc-tivity of the material, respectively. T represents the local temperature in each instant moment t and in each spatial coordinate, whereas represents the energy generated/dissipated by unit of time and by unit of volume in the material. $\nabla^2$ defines the coordinates system in used for the heat transfer analysis

**CARTESIAN COORDINATES**

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \qquad (20)$$

Cylindrical coordinates

$$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \theta^2} + \frac{\partial^2}{\partial z^2} \qquad (21)$$

$x = rcos\theta$ , $y = rsin\theta$ , $z = z$

Spherical coordinates

$$\nabla^2 = \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\frac{\partial}{\partial r}\right] + \frac{1}{r^2}\frac{\partial}{\partial \varphi}\left[sin\varphi\frac{\partial}{\partial \varphi}\right] + \frac{1}{r^2 sin^2\varphi}\frac{\partial^2}{\partial \emptyset^2} \qquad (22)$$

$x = rsin\varphi cos\emptyset$ , $y = rsin\varphi sin\emptyset$ , $z = rcos\varphi$

**HEAT FLOW THROUGH AN INFINITE SLAB**

Consider an infinite (in y and z directions) slab with thickness s in the x direction and temperatures [T.sub.1] and [T.sub.2] on its two faces. In the steady state the heat conduction equation for this system becomes <see equation 5>

$$\frac{\partial T}{\partial t} - \alpha\frac{\partial^2 T}{\partial x^2} = 0 \qquad (23)$$

This has solutions of the form

$$T = ax + b \qquad (24)$$

Applying the boundary conditions analysis from equation (24)

Considering when

$$x = 0; T = T_{2,}$$

If

$$x = s; T = T_2$$

Hence

$$b = T_1 \,; a = \frac{T_2 - T_1}{s}$$

From

$$T = ax + b$$

$$T = \left(\frac{T_2 - T_1}{s}\right)x + T_1 \qquad (25)$$

The Fourier conduction law gives
$Q = -KA\frac{dT}{dx}$ (26)

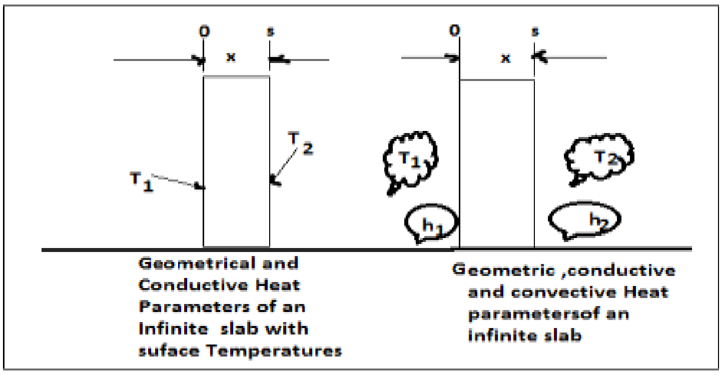


**Fig-4: Boundary conditions on an intermediate wall between mold and water cavities**

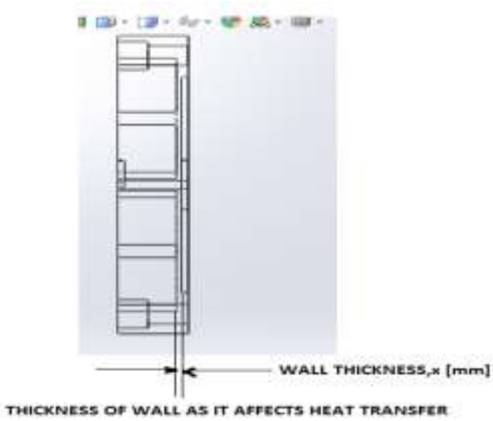


**Fig-5: Heat analysis at the interface wall between mold cavity and cooling water cavity**

Now considering the case of an infinite slab with a hot molten platic on one side and a coldwater on the other side.

$$\frac{\partial^2 T}{\partial x^2} = 0$$

There are solutions of the form from eqn (24)

$$T = ax + b$$

Now the boundary conditions for convective heat transfer of the two surfaces

$K\frac{dT}{dx} = h_1(T - T_1)|_{x=0}$ (27)

$K\frac{dT}{dx} = h_2(T - T_2)|_{x=S}$ (28)

where $h_2$ and $h_1$ are the surface convective heat loss coefficients and the equations are to be evaluated at x=0 and x=s, as indicated. The difference in sign between the two surfaces is determined by whether heat flow is in the direction of or opposite to the surface normal.

Applying

$\frac{dT}{dx} = a$ (29)

from equation (29) and Evaluating this equation (24)

$T = ax + b$

At x=0, x=s

T=ax+b at x=0, x=s

$$a = \frac{-(T_1 - T_2)}{\frac{K}{h_2} + s + \frac{K}{h_1}} \quad (30)$$

$$b = \frac{Ka + h_1 T_1}{h_1} \quad (31)$$

Applying the Fourier conduction law

$$q = \frac{Q}{A} = -K\frac{dT}{dx} \quad = K\left(\frac{(T_1 - T_2)}{\frac{K}{h_2} + s + \frac{K}{h_1}}\right) \quad (32)$$

where q is the heat flux. Typical values for the surface heat loss coefficient h for low temperature differences in still air to over mold and a more moderate speed of wind

**Table-1: Simulation Parameters**

| PARAMETER | VALUE | UNIT |
|---|---|---|
| Melte temperature TM | 250 | $^0$C |
| Ejection temperatureTE | 247 | $^0$C |
| Average mould temperature TW | 100 | $^0$C |
| Filling time *tf* (obtained by simulation | 1.9 | s |
| Cooling time *tc* | 6.3 | s |
| Mold opening time *to* | 3 | s |
| Velocity of cooling water *u* | 1.0 | m/s |
| Temperature of cooling water *TC* | 24 | $^0$C |

**Table-2: Properties of Assumed Material for the Mold**

| | |
|---|---|
| Name: | **1060 Alloy** |
| Model type: | **Linear Elastic Isotropic** |
| Default failure criterion: | **Max von Mises Stress** |
| Thermal conductivity: | **2 W/(cm.K)** |
| Specific heat: | **215.105 Cal/(kg.C)** |
| Mass density: | **2700 g/cm^3** |

**MALE MOLD MESH DETAILS**

**Table-3: Mesh Properties**

| | | |
|---|---|---|
| Total Nodes | Aspect Ratio | Jacobian Points |
| 19086 | 10.303 | 4 Points |
| Total Elements | Mesh Type | Element Size |
| 10659 | Solid Mesh | 9.14455 mm |

**MODELS**

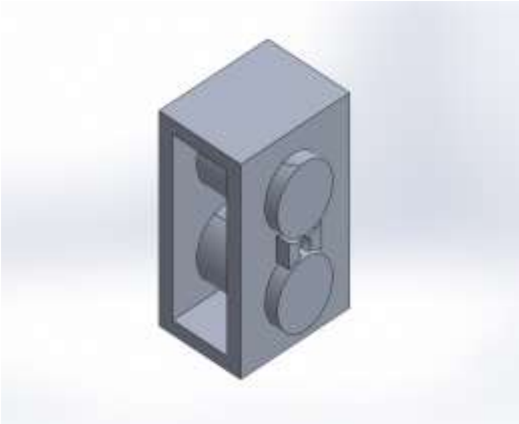

**Fig-6: 3-D Solid Model of Male Mold**

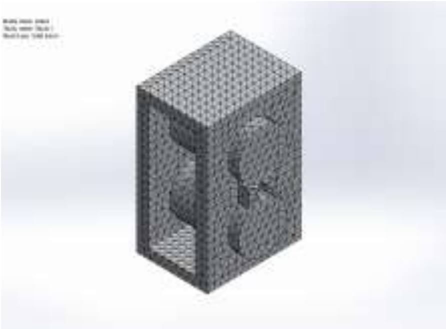

**Fig-7: 3-D Solid Model of Male Mold Mesh**

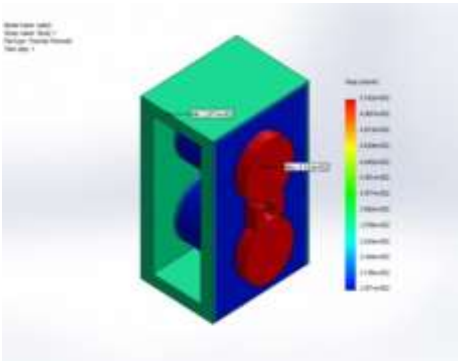

**Fig-8: 3-D Solid Model of Simulated Male Mold**

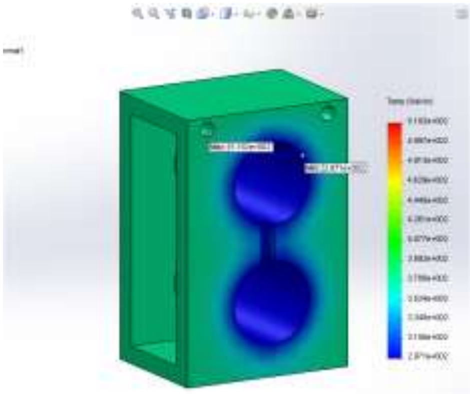

**Fig-9: 3-D Solid Model of Male Mold Cooling Water Chamber**

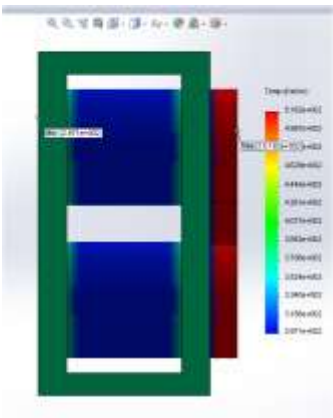

**Fig-10: 3-D Solid Model of Simulated Male Mold Side View**

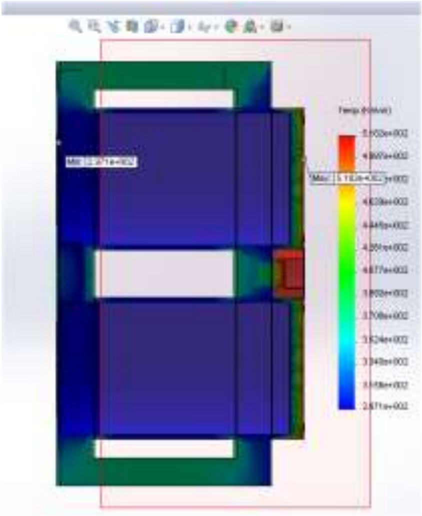

**Fig-11: 3-D Solid Model of Simulated Male Mold Cross Section**

**FEMAL MODEL MESH DETAILS**

**Table-4: MESH PROPERTIES**

| | | |
|---|---|---|
| Total Nodes | Aspect Ratio | Jacobian Points |
| 17499 | 13.199 | 4 Points |
| Total Elements | Mesh Type | Element Size |
| 10554 | Solid Mesh | 7.56151 mm |

**FEMALE MODELS**

3-D SOLID MODsEL OF MALE MOLD

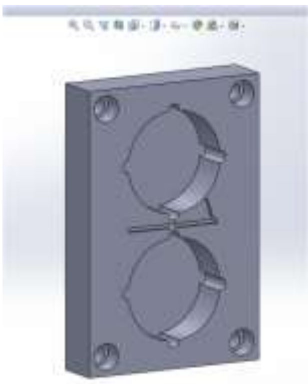

**Fig-12: 3-D Solid Female Model Mold Cavity**

**Fig-13: 3-D Solid Model of Female Water Chamber**

**Fig-14: solid mesh of the female mold (water cavity)**

**Fig-15: Mesh of Female Mold Cavity**

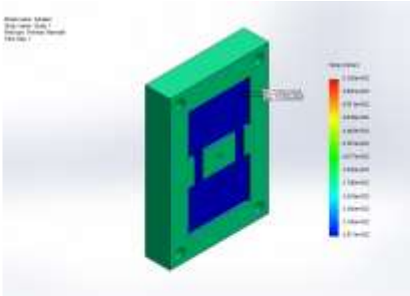

**Fig-16: Simulated Female Mold Model Water Chamber**

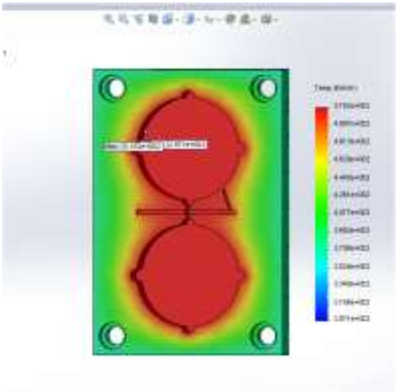

**Fig-17: Simulated Female Mold Cavity**

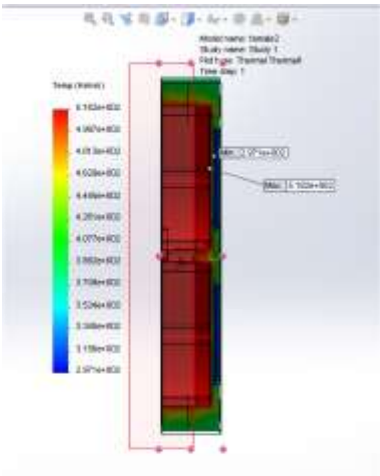

**Fig-18: CROSS SECTION of the female mold**

**PET PRODUCT**

**Table-5: Material Properties**

| | |
|---|---|
| Name: | **PET** |
| Model type: | **Linear Elastic Isotropic** |
| Default failure criterion: | **Unknown** |
| Thermal conductivity: | **0.00261 W/(cm.K)** |
| Specific heat: | **272.467 Cal/(kg.C)** |
| Mass density: | **1420 g/cm^3** |

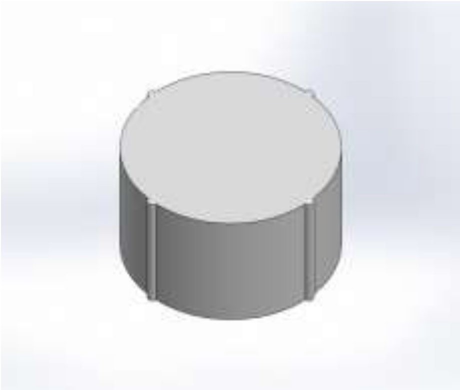

**Fig-19: 3-D Model of PET Product**

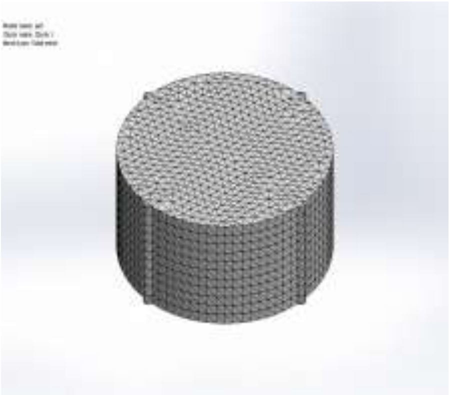

**Fig-20: Mesh of PET Product**

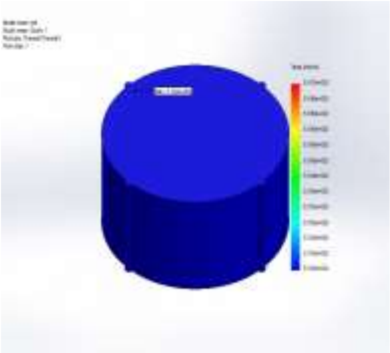

**Fig-21: Simulated PET Produt with Injection Parameters**

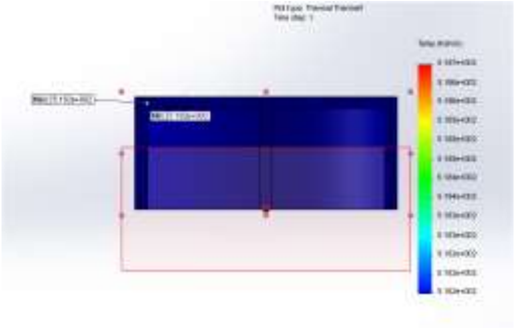

**Fig-22: Simulated PET Produt with Injection Parameters Cross Section**

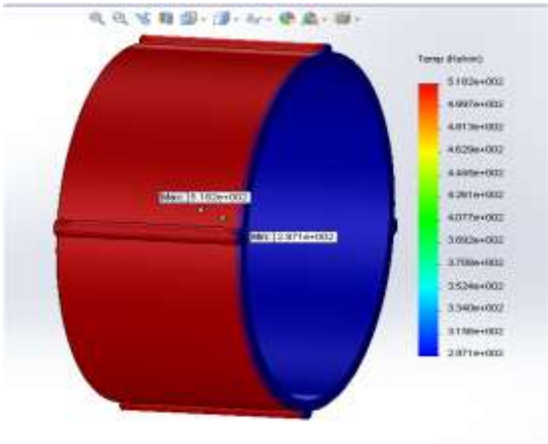

**Fig-23: Simulated PET Produt with Cooling Parameters**

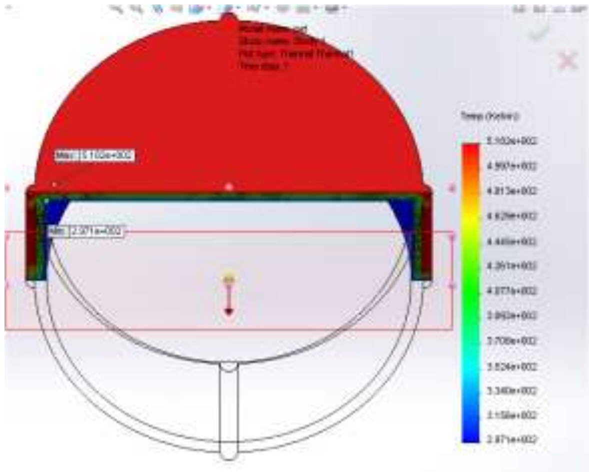

**Fig-24: Simulated PET Produt with Cooling Parameters Cross Section**

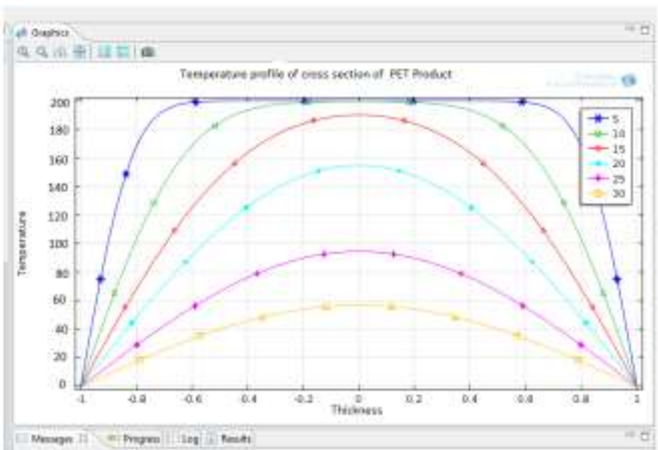


**Fig-25: Temperature variation across of the thickness, x, mm of PET product**

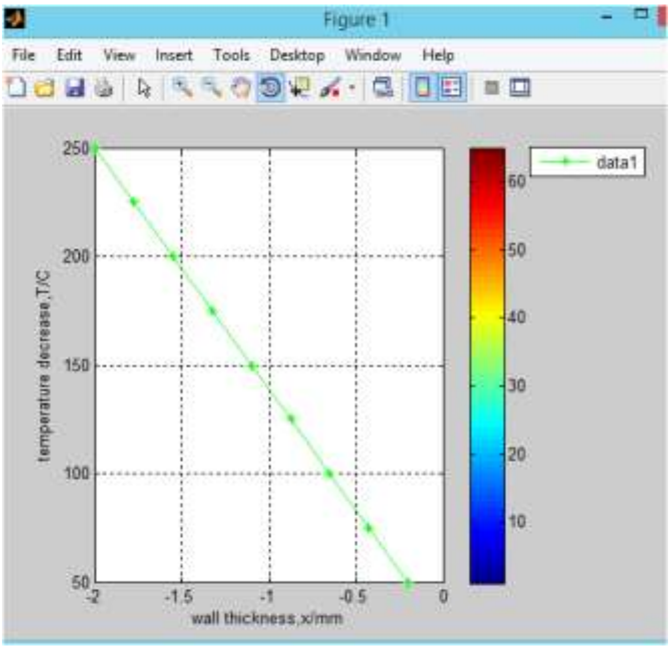


**Fig-26: Cooling across the wall thickness of the mold**

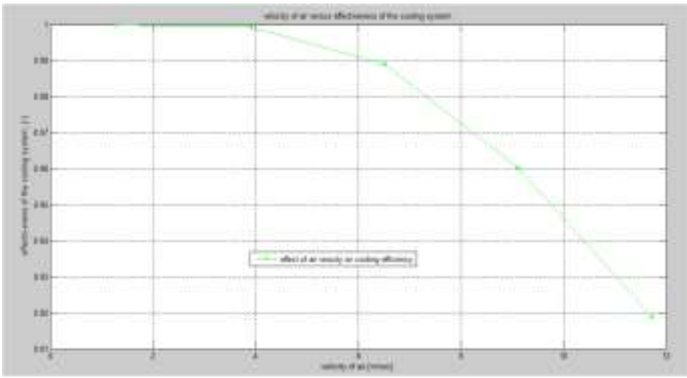

**Fig-27: Effect of air velocity on effective cooling tower**

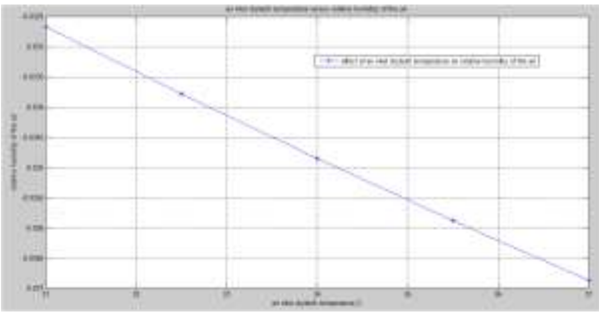

**Fig-28: Effect of air inlet drybuld temperature on relative humidity in cooling tower**

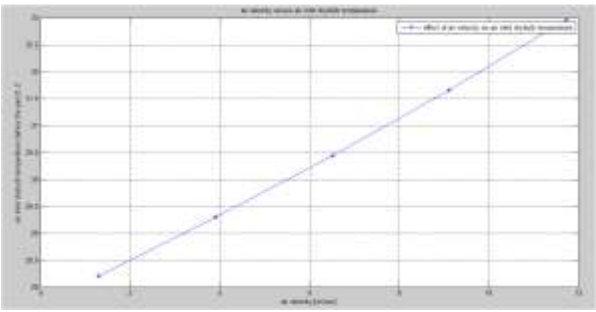

**Fig-29: Effect air velocity on air inlent drybulb temperature in cooling tower**

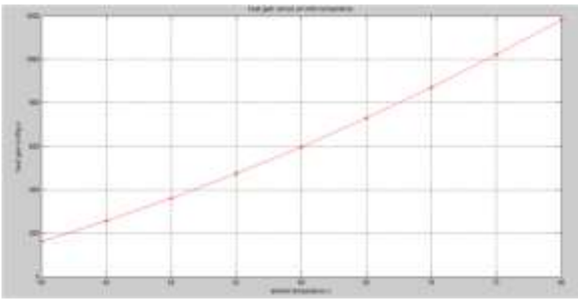

**Fig-30: Heat gain by water versus air inlet temperature**

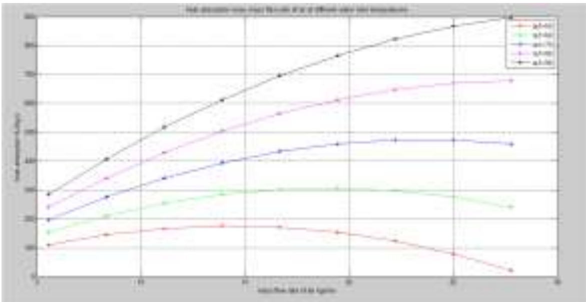

**Fig-31: Heat absorption versus mass flow rate at different water inlet temperatures in cooling tower**

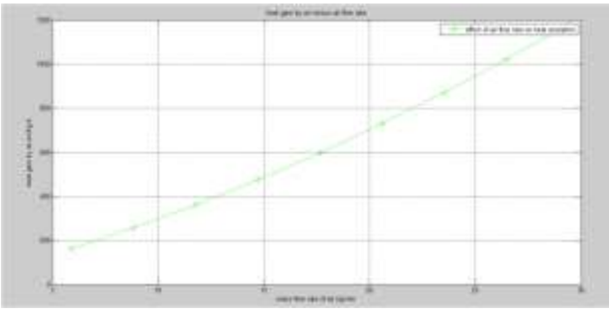

**Fig-32: Effect of mass flow rate of air on heat gain in cooling tower**

## DISCUSSIONS

The parametric factors are used to determine the thermal performance, thermal stress induced by the injection temperature ($T_1$), cool water inlet temperature ($T_0$) and ambient conditions respectively. This thermal performance of the mold is appreciated by the aluminum with its high thermal conductivity and diffusivity which will give high cooling rate as a measure of heat removal form the mold. Hence, the aluminum alloy was selected for the model.

## CONCLUSION

The process cycle time in injection molding process depends greatly on the cooling time of the plastic part, which is facilitated by the cooling channels in the injection mold. Effective cooling channel design in the mold is important because it not only affects cycle time but also the part quality. Traditional cooling channels are normally made of straight drilled holes in the mold, which have limitations in geometric complexity as well as cooling fluid mobility within the injection mold. An efficient design analysis of an injection molding system has unveiled the parametric factors that must be considered to manufacture and selected injection mold for an injection molding system in plastic products making for quick product recovery and production.

Solid Works, COMSOL Multiphysics and Mat Lab tools used for the CAE analysis reveals the heat and temperature management as it influence the emtire system. The simulated results shows heat distribution as it affects cooling ability and efficiency with regards to the wall thickness of the product and the intermediate wall between the mold and water cavities.

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