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Design and Analysis of Pressure Die Casting Die for Automobile Component

By Y. Abdulfatah Abdu, T. M. Shafii, K. K. Dubey & Prof U. K. Gupta
Kampala International University

Abstract- This paper describes one of the ways for the design and analysis of the die of the technology of pressure die casting process. This paper is to maintain the closest tolerances, reduced all machining and can make the process the optimum choice for small volume production as well. Such exact and light parts are one of the premises for the automobile industry, parts with a lightweight design and exact products directly influence the fuel consumption of an automobile and consequently the users are satisfied. These requirements are met using aluminium alloys, high strength steels and fibre reinforced for the structural components. In this work a die was designed based on factors to be considered in the critical dimensions and filling analysis is used to determine the size, location and to ensure a complete and balanced filling of the part while designing for proper runner system. This work uses different software such as Solid Works, 3-Diamesional Flow, Pro-Engineer respectively. The design, analysis, and testing work are carried at Automotive Private Limited, Gurgaon, Haryana.

Keywords: pressure die casting, automobile industry, aluminium alloys, solid works, 3-diamensional flow, pro-engineer.

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Y. Abdulfatah Abdu [α], T. M. Shafii [σ], K. K. Dubey [ρ] & Prof U. K. Gupta [Ѡ]

Abstract- This paper describes one of the ways for the design and analysis of the die of the technology of pressure die casting process. This paper is to maintain the closest tolerances, reduced all machining and can make the process the optimum choice for small volume production as well. Such exact and light parts are one of the premises for the automobile industry, parts with a lightweight design and exact products directly influence the fuel consumption of an automobile and consequently the users are satisfied. These requirements are met using aluminium alloys, high strength steels and fibre reinforced for the structural components. In this work a die was designed based on factors to be considered in the critical dimensions and filling analysis is used to determine the size, location and to ensure a complete and balanced filling of the part while designing for proper runner system. This work uses different software such as Solid Works, 3-Diamesional Flow, Pro-Engineer respectively. The design, analysis, and testing work are carried at Automotive Private Limited, Gurgaon, Haryana.

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I. Introduction

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies. The die casting process involves the use of a furnace, die casting machine, metal and die. Die casting differs from ordinary permanent-mold casting in that the molten metal is forced into the molds by pressure and held under pressure during solidification. The die casting machines are mainly categorized into two - hot chamber machines are used for alloys with low melting temperatures, such as zinc, and cold chamber machines are used for alloys with high melting temperatures, such as aluminium [1-2]. Most die castings are made from non-ferrous metals and alloys, but substantial quantities of ferrous die castings now are being produced. Because of the combination of metal molds or dies, and pressure, fine sections and excellent detail can be achieved, together with tong mold life. Die-casting dies are usually made from hardened tool steel they are expensive to make [3]. Semisolid die casting process used to improve the mechanical properties of aluminium alloy parts by substituting aluminium alloy for steel to improve the fuel efficiency parts and verified it by experiments [4]. The casting defects that existed include cold fills dross and alumina skins. The batches of specimen varying in runner and sprue design were analyzed. It was found that there were no significant variations in the fatigue strength between the acceptable and non-acceptable components [5]. The integrated system reduced the lead time and shortened the cycle time of die design resulting in an increase in productivity by integrating Computer Aided Design and Manufacturing system [6]. The conventional gating design, casting defects such as shrinkage and gas porosities was found in front axle housing a critical automotive component. This part is made out of spheroid graphite iron. A flawed gating system was considered to be the reason for improper fluid flow and melt solidification which in turn produced casting defects [7-8]. Computer aided die design system that comprises seven modules. The system proved useful to reduce the time required for the design of an ejector, die-base and gating [9]. The quality of the casting was reduced as the density decreases proportionally to the amount of porosity leading to higher rejection rates. It was found that there was non-uniform cooling of the component due to which the present design of the runner and gating system was studied thoroughly, and the flow simulation results had also proven the above said defects [10-11]. The objectives of this project is to design a die, develop tools and gating system to identify defects such as shrinkage cavities, gas defects, pouring material defects, mould material defects and take measures to minimize flaws by using Computer Aided Engineering software. This paper is organized based on different sections; the first section describes the literature survey, followed by problem formulation and objectives. The methodology are slated, the fourth section explores on design calculations for the automotive component, the design are analysed in this section, results and discussion is explained, and the concluding remark is given in this section.

II. Materials and Methods

The material to be used is ADC 12. This material is an international standard composition of aluminium die-casting alloys in Japan, and the composition of the material and properties are LM 24 in British standard, A 383 in American standard and DIN 226 in German standard. All these materials are to be used while

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designing the core and cavity after adding material shrinkage value to the component geometry. The core and cavity are the parts of the die that provide the internal and external shape of the component in which the core is the male part of the die and forms internal shape of the component, and the cavity is the female part of the die it forms the external shape of the component.

Table 1: Component Details

COMPONENT NAME	CYLINDER HEAD COVER
Quantity required	20,000 per month
Material	ADC 12
Density	2.7 g/cm3
Shrinkage	0.5%
Volume of the component	$217.553 cm^3 = 217{,}553\ mm^3$
Weight of the component	330.0 g
Projected area	$7900.0\ mm^2$
Draft angle	5 degrees
Function	Closing the top of the cylinder head

a) *Methods*

These are the following steps used while designing the component:

1. The component is identified and all relevant information required for design is collected.
2. The number of cavities is decided based on yearly requirement.
3. Identical components are grouped in the unit die.
4. The design calculations are done to find the suitable machine
5. Details of machine are collected
6. Component parting line was being decided based on part geometry, ejection, and aesthetics.
7. The runner, gate dimensions and type are selected based on the part geometry, cavity location.
8. The type of ejection will be selected based on aesthetics, parting line location, part geometry, etc.
9. The amount of heat being injected into the die will be calculated and the suitable cooling system is provided.
10. 3-Diamensional modelling of the die, gate design, and core cavity extraction will be conducted using Solidworks software by considering shrinkage of material.
11. Assembly and part drawings are to be made in 2-Diamensional using Solidworks software.
12. Part drawings will be carefully checked at the end and approved.

i. *Design Calculations*

➢ Number of Cavities

Production required per month: 20,000 per month (Die will be loading only for 5days)

Number of component per day: 4000

Number of shifts per day: 3

Number of shots per shift = 8 x 60 / Cycle time.

= 8 x 60 /0.5

= 960 shots

Number of component per shot = 4000/ (3x960)

= **1.0**

Hence we have to use a **single cavity** die.

➢ Tonnage Requirement

Projected area of the component = $7900 mm^2$

Projected area including overflows and feed system

= 7900 x 1.5

= $11850 mm^2$

Specific Injection pressure = 600 kgf/cm2 = 600 x 10-2 kgf/ mm2

Total force acting on the die plate = Projected area x Injection Pressure

= 7900x 600 x 10-2

= 47400 kgf

= 47.4 T

Considering machine efficiency of 80%, Locking tonnage required = 47.4 x 1.2

= **57T**

Hence according to locking tonnage ranges, we can select **80 T** machine.

➢ Shot Weight

Component volume = $217{,}553\ mm^3$

Volume of component + Volume of overflow and feed system (excluding Biscuit)

= 217,553 x 1.2

= $261{,}063.6\ mm^3$

Actual shot volume = $261{,}063.6 + \pi d^2 h/4$

Where **h** is biscuit thickness, and **d** is the plunger diameter Stroke length for 80 T machine = 250 mm

Effective stroke length = 250 – biscuit thickness

= 250 – 25

= 225 mm

Assume fill ratio = 0.50
Volume delivered by machine

$= \pi d^2 \times (225/4) \times 0.5$

$261{,}063.6 + \pi d^2 \times (225/4)\ 0.5 = \pi d^2 \times (225/4)$

$261{,}063.6 = 88.40625\ d^2$

$d^2 = 2953\ mm^2$

d = 54.3 mm

Available plunger sizes in **80 T** machines are 35, 45, and 55 mm Hence we can select **55 mm** plunger tip

Shot volume $= 261{,}063.6 + \pi d^2\ h/4$

$= 261{,}063.6 + \pi\ (54.3)^2 \times 25/4$

$= 261{,}063.6 + \pi\ (54.3)^2 \times 25/4$

$= 261{,}063.6 + 57{,}900.97$

$= 318{,}964.57\ mm^3$

Shot weight = Shot volume x density

$= 318{,}964.57 \times 2.7 \times 10^{-3}$

= 861.2g = **0.9kg**

- Fill Ratio

$$\text{Fill ratio} = \frac{\text{Shot sleeve volume}}{\text{Metal volume}}$$

318,964.57 = π (55)2 x (225/4) x y y = **0.6**
This value for fill ratio is acceptable for the process

- Fill Time

$$\text{Fill Time} = \frac{K[Ti - Tf + sz]\ T}{[\ Tf - Td\ ]}$$

Where
k empirically derived constant = 0.0346
Ti, Temperature of molten metal as it enters the die = 6500c
Tf, Minimum flow temperature of metal = 5700c
Td, Temperature of die cavity surface just before the metal enters = 2000c
S, percent solid fraction allowable in the metal at the end of filling = 30%
Z, Units conversion factor = 3.8
T, casting wall thickness = 3 mm

$$t = \frac{0.0346[650 - 570 + 30 \times 3.8] \times 3}{[570 - 200]}$$

= 0.054 second

= **54 milli seconds**

ii. *PQ2 Calculations*

Maximum (Hydraulic) Accumulator Pressure = 150kgf/cm2
Diameter of (hydraulic) cylinder = 130 mm
Plunger diameter = 55 mm
Dry Shot Velocity (DSV) = 4.5 m/sec

- Maximum Static Metal Pressure

$$= \frac{\text{MAP} \times (\text{Cylinder Dia})^2}{(\text{Plunger Dia})^2}$$

$= 150 \times (130)^2/(55)^2$

= **838.02kgf/cm2**

- Dry Shot Flow Rate

$= (\text{Plunger Dia})^2 \times \pi \times DSV/4$

$= (55)^2 \times \pi \times 4.5 \times 103/4$

= 10,692,618.75 mm3/sec

= **10,692.62 cm3/sec**

- Max. Metal Pressure (lines)

$$= \frac{\text{Density} \times Gv^2}{2g \times Cd^2}$$

Where
Gv is maximum gate velocity = 400cm/s (recommended)
g is acceleration due to gravity = 981 cm/sec
Cd is coefficient of discharge = 0.4

$$= \frac{2.58 \times (4000)2}{2 \times 981 \times (0.4)2}$$

= 131,498.5 gf/cm2

= **131.5 kgf/cm2**

- Min. Metal Pressure (lines)

$$= \frac{\text{Density} \times Gv^2}{2g \times Cd^2}$$

Gv is the minimum gate velocity = 2500cm/s (NADCA recommended)

$$= \frac{2.58 \times (2500)2}{2 \times 981 \times (0.4)2}$$

= 51,366.6 gf/cm2

= **51.4 kgf/cm2**

- Flow rate (fill rate), Q

(A theoretical minimum fill rate that can be used to produce the highest quality casting)
= Volume (casting and overflow) of metal (passing) through Gate /Fill time

= 261,063.6 / 0.054

= 4,834,511.111 mm3 /sec

- Runner Design

Runner Area (A) = 1.3Ag

= 69 x 1.3

= 86.7 mm2

Depth (D) = $\sqrt{(A/0.8)}$

= 10.42mm

Width = 2D = **20.84 m**

P-Q^2 GRAPH

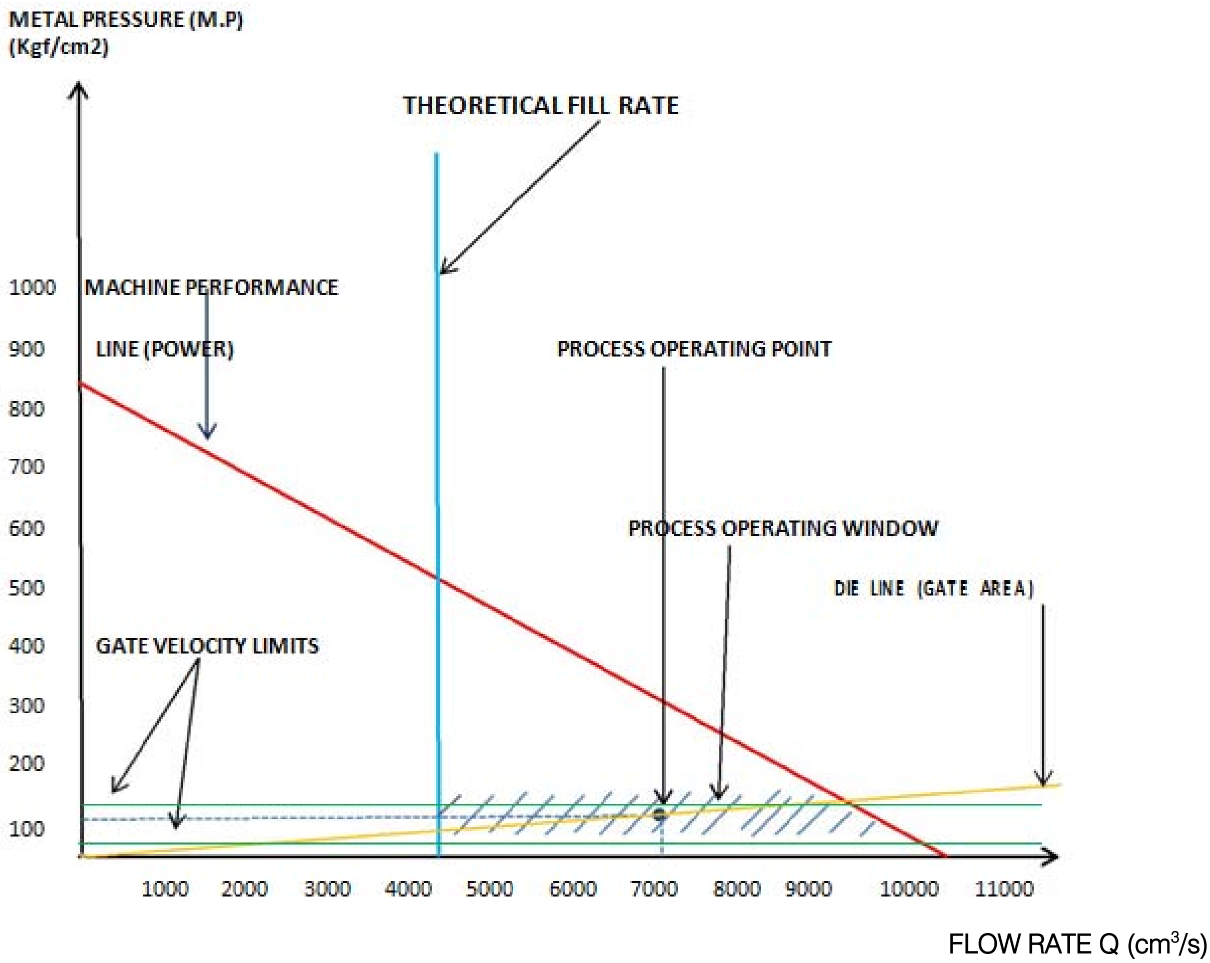

Figure 2.1 : P-Q2 Diagram

From PQ2 graph,

P = 91.5 kgf/ cm2

Q = 7,255.7 cm3/sec

Therefore Ag = Q/ Cd√(p*2g/ρ)

= 7255.7/0.4 √(91.5x2x981/2.58)

= 0.6877 cm2

= 69 mm2

Therefore area of the gate = 69 mm2

Gate thickness = 3mm (will produce atomization)

Gate length hence = 23mm

iii. *Cooling Calculation*

Heat input = hGn

h is the heat factor = 145 Kcal/kg for Aluminum

n is the number of shots = 120 per hour

G is weight of casting, overflow and feed system

= 705g

= 0.705kg

Therefore Heat input = 145 x 0.705 x 120

= 12,267 kcal/hr

50 % of heat is lost by convection to atmosphere and by spray cooling

Heat accumulated = 12,267 x 50/100

= 6,133.5 kcal/hr

Heat removing capacity = 35 kcal/hr

Length of cooling line = 6,133.5/35

= 175 mm

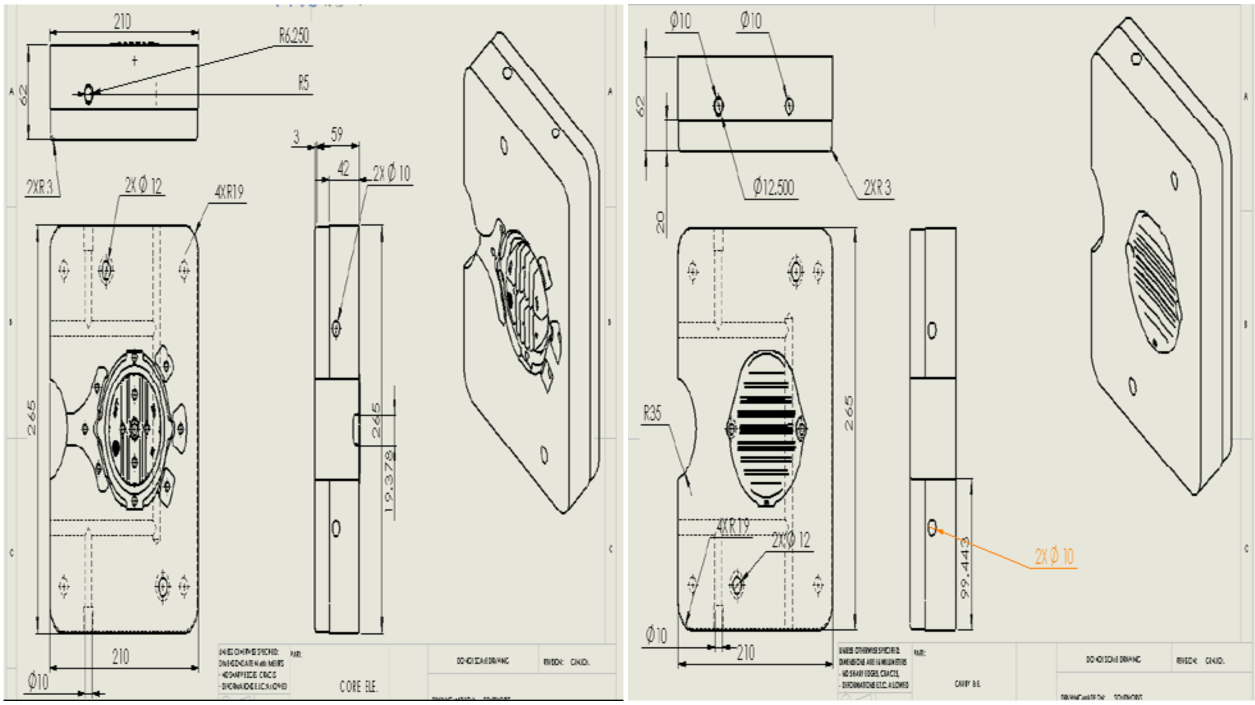

Figure 2.1.1 : Core Insert

Figure 2.1.2 : Cavity Insert

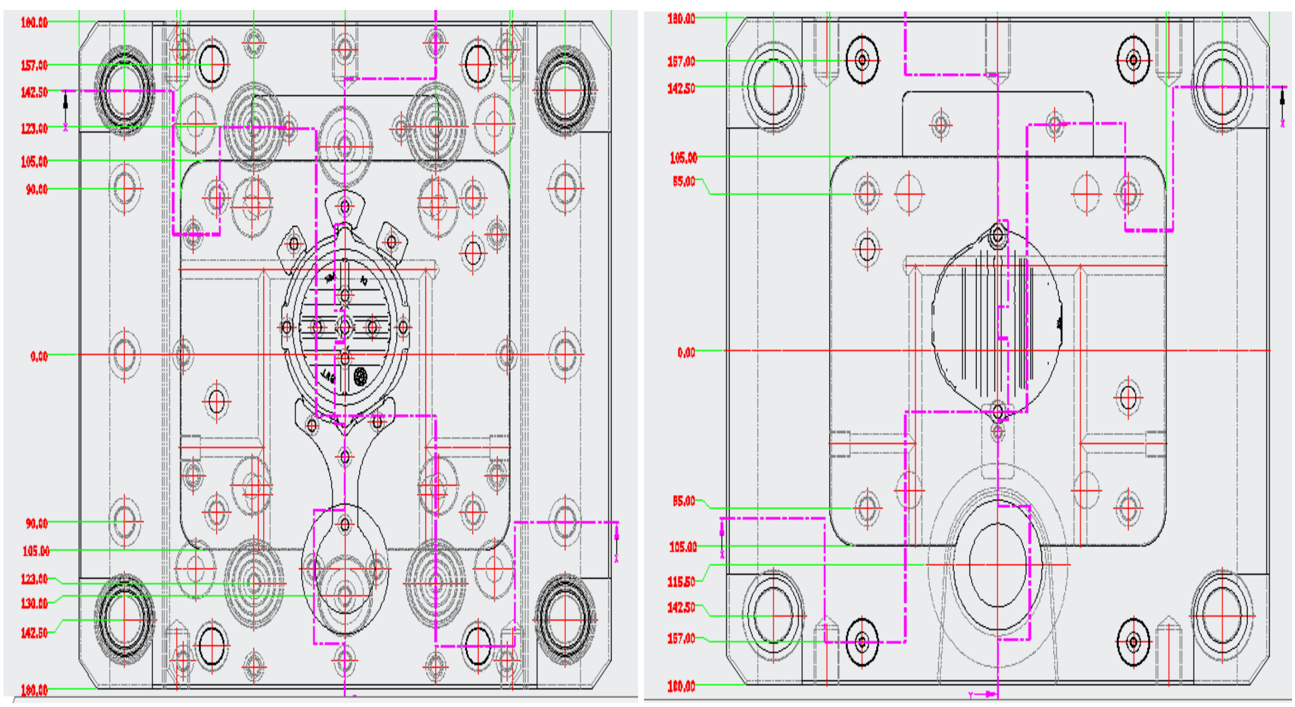

Figure 2.1.3 : Tool Cavity & Core Assembly

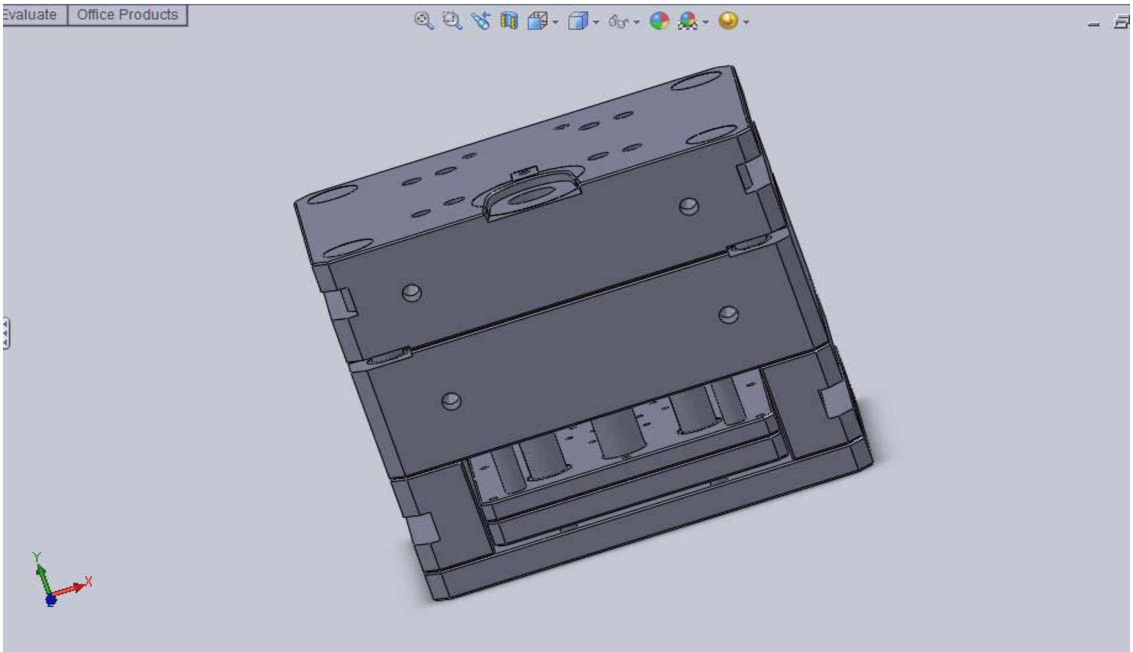

Figure 2.1.4 : Assembled Die Tool

III. Analysis

A comprehensive analysis of each factor entering in the die casting process is needed to be done since each factor is susceptible to affect the ready casting in a negative way. The die casting technology makes the thin-walled castings having a high dimensional and geometrical precision. These are to handle the whole die casting process to control all aspect associated with the process to prevent wastage while casting. The geometrical, structural, dimensional and superficial requests are considered as a waste if the casting which doesn't fulfil the factors to be considered. In this case, a short with vertical and horizontal part ribs arrangement was considered in which the 3Dflow behaviours was analysed. The following results at the different filling time were observed when the process started.

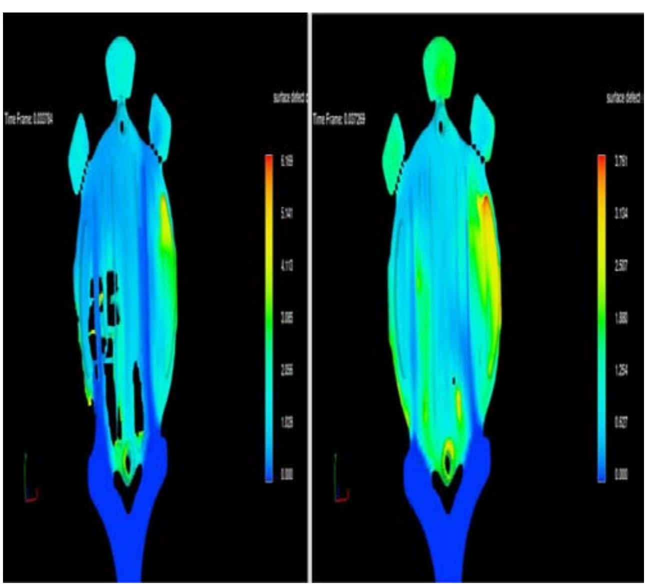

Figure 3.01 : Vertical Arrangements of Part

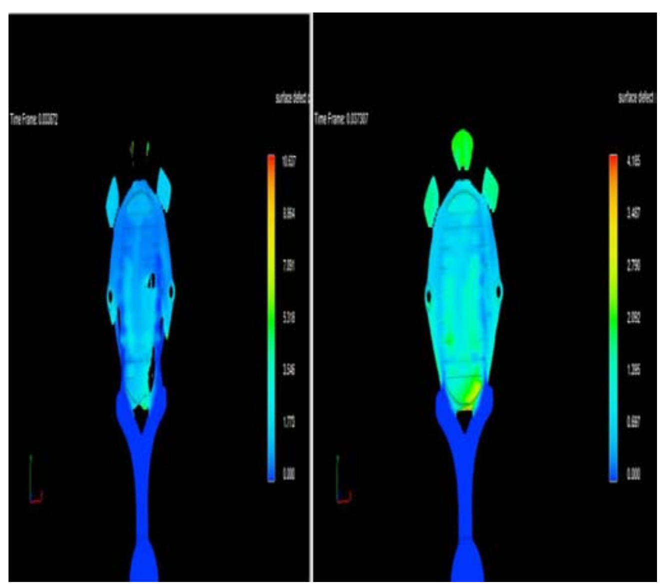

Figure 3.02 : Horizontal Arrangements of Part

IV. Results and Discussion

The process started at initial for both cases and terminated at 3.810 and 4.214 seconds for vertical arrangement and a horizontal one. The analysis shows that the air porosity defect rate is more in the vertical arrangement than the horizontal arrangement. The outstanding volume of the shot sleeve is filled with air. Both design and analysis research shows that the motion of the plunger, the shot sleeve dimensions and the initial amount of metal in the sleeve all affect the types of waves which are created during the process. The results summary of the tool design parameters which are the multiple functions of other design parameters upon which the design was made in Table 2 below.

Table 2 : Results Summary

NO. OF CAVITIES	1
TONNAGE REQUIREMENT	80 T
SHOT WEIGHT	0.9kg
FILL RATIO	0.6
FILL TIME	54 milliseconds
MAX. STATIC PRESSURE	838.02kgf/cm2
DRY SHOT FLOW RATE	10,692.62 cm3/sec
MAX. METAL PRESSURE	131.5 kgf/cm2
MIN. METAL PRESSURE	51.4 kgf/cm2
FLOW RATE	4,834.5 cm3/sec
METAL PRESSURE (P)	P = 91.5 kgf/ cm2
FLOW RATE (Q)	Q = 7,255.7 cm3/sec
GATE AREA	69 mm2
GATE LENTH	23mm
RUNNER SIZE	L=86.7 mm2, D= 10.42mm, W= 20.84 mm

V. Conclusions and Future Scope

The aim of this paper has been achieved successfully considering all the critical dimensions. The size of the component is essential to any die design because it gives the actual picture of what a die designer wanted to achieve. Careful gate calculations are made to avoid any turbulent motion of the material.

The filling pattern of the molten aluminium is shown, and melt enters the gate and starts filling the cavity after 0.5s. Then the rest of the mould cavities will be filled up. The simulation demonstrates the importance of calculating the filling of the casting in the aluminium casting process. Simulation gives actual valuable information to the manufacturer what will be the final quality of the product. In this research, few process parameters were considered in the analysis for optimization. But this work can be extended, and other parameters such as molten metal, speed, discharge pressure, temperature and cavity fill rate, cooling rate, pq^2 relations can be considered for the purpose of optimization.

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Application of Pressure Control Type Quasi-Servo Valve to Force Control System

By Yoshinori Moriwake, Shujiro Dohta, Tetsuya Akagi & So Shimooka
Okayama University of Science

Abstract- Today, the aged people are rapidly increasing and the number of children is decreasing in Japan. This social problem causes the demand of the care and welfare equipments to support a nursing and a self-reliance for the senior. For example, a power assist device for reducing the burden of the user has been researched and developed. The purpose of this study is to develop a small and light-weight pneumatic control valve and to apply it to the care and welfare equipments. In our previous study, the small-sized quasi-servo valve using two inexpensive on/off valves was developed and tested. The pressure control type quasi-servo valve was also proposed and tested by using the quasi-servo valve, a pressure sensor and an embedded controller. In this paper, the pressure control type quasi-servo valve is applied to a force control of the pneumatic cylinder, and its control performance is investigated.

Keywords: quasi-servo valve, pneumatic cylinder, force control.

GJRE-A Classification : FOR Code: 290501

APPLICATIONOFPRESSURECONTROLTYPEQUASISERVOVALVETOFORCECONTROLSYSTEM

Strictly as per the compliance and regulations of:

Application of Pressure Control Type Quasi-Servo Valve to Force Control System

Yoshinori Moriwake α, Shujiro Dohta σ, Tetsuya Akagi ρ & So Shimooka ω

Abstract- Today, the aged people are rapidly increasing and the number of children is decreasing in Japan. This social problem causes the demand of the care and welfare equipments to support a nursing and a self-reliance for the senior. For example, a power assist device for reducing the burden of the user has been researched and developed. The purpose of this study is to develop a small and light-weight pneumatic control valve and to apply it to the care and welfare equipments. In our previous study, the small-sized quasi-servo valve using two inexpensive on/off valves was developed and tested. The pressure control type quasi-servo valve was also proposed and tested by using the quasi-servo valve, a pressure sensor and an embedded controller. In this paper, the pressure control type quasi-servo valve is applied to a force control of the pneumatic cylinder, and its control performance is investigated.

Keywords: quasi-servo valve, pneumatic cylinder, force control.

I. Introduction

Today, the care and welfare pneumatic devices to support a nursing care and a self-reliance of the senior and the disabled are actively researched and developed by many researchers [1][2]. These wearable devices require many control valves for multi degrees of freedom and precise control performance of the wearable actuator. However, by increasing the degree of freedom, the total weight load of the wearable devices increases too. Therefore, we aim to develop a small-sized, light-weight and low-cost quasi-servo valve using on/off valves to decrease the burden of the user instead of expensive and bulky conventional electro-pneumatic servo valves. In our previous study [3], an inexpensive pressure control type quasi-servo valve using a low-cost embedded controller and a pressure transducer was proposed and tested. In addition, the compensation for decrease of output flow rate was proposed to improve the pressure control performance of the valve. An analytical model of the pressure control type quasi-servo valve including the embedded controller was also proposed. The control performance of the valve using P and PD controller was investigated theoretically [4]. We also investigated the optimal control parameter of the PD controller by means of simulation. It is easier to realize the force control when the pressure control type valve is used. In this paper, as an application of the pressure control type quasi-servo valve, the force control system is built and tested by using a pneumatic cylinder. The force control system consists of the pressure control type valve, a pneumatic cylinder and an electric linear actuator.

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II. Construction and Operating Principle of Quasi-Servo Valve

Fig. 1 shows the schematic diagram of the quasi-servo valve developed before [5]. The valve consists of two on/off type control valves (Koganei Co. Ltd., G010HE-1) whose both output ports are connected to each other. One valve is used as a switching valve to exhaust or supply, and the other is used as a PWM control valve that can adjust output flow rate like a variable fluid resistance. The valve connected with the actuator is a two-port valve without exhaust port. The other is a three-port valve that can change the direction of fluid flow from the supply port to the output port or the fluid flow from the output port to the exhaust port. The two-port valve is driven by pulse width modulation method in order to adjust the valve opening per time. The size of the on/off valve is 33×19.6×10 mm, and the mass is only 15 g. The maximum output flow rate is 38 liter/min at 500 kPa.

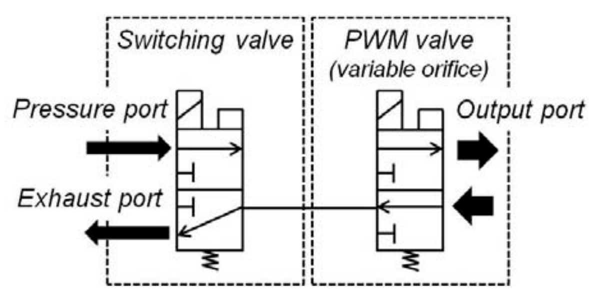

Fig.1 : Schematic diagram of quasi-servo valve

III. Pressure Control Type Quasi-Servo Valve

a) Construction

Fig. 2 shows the schematic diagram of the pressure control type quasi-servo valve. The valve system consists of the above quasi-servo valve, a pressure sensor (Matsushita Electronics Co. Ltd., ADP5160) and an embedded controller (Renesas Co. Ltd. R8C12M). The pressure control is done as follows. The embedded controller gets the sensor output voltage and the reference voltage through an inner 10 bit A/D converter. The manipulated value for the PWM valve, duty ratio, is calculated based on a control scheme by using these AD values.

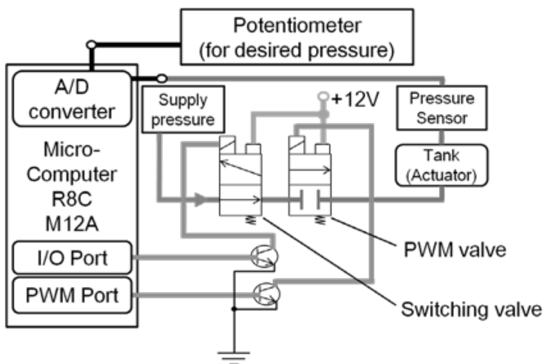

Fig.2 : Schematic diagram of pressure control type quasi-servo valve

b) Compensation of Flow Rate

The supply and exhaust flow rate are not same even if the valve opening is same, because the pressure difference between upstream and downstream at the supply port is different from that at the exhaust port. In order to compensate the flow rate, the following compensation method was proposed [3]. This is a natural phenomenon of fluid flow. This method leads to a linearization of the valve characteristics to the controller.

$$u_s = |u| \frac{f(z)_{max}}{f(z)} + 47.5 \quad , \quad z = \frac{P_L}{P_S} \qquad (1)$$

$$u_e = |u| \frac{P_s}{P_L} \frac{f(z)_{max}}{f(z)} + 47.5 \quad , \quad z = \frac{P_a}{P_L} \qquad (2)$$

Where u_s and u_e represent the input duty ratio for supply and exhaust with the compensation of flow rate, respectively. *f(z)* is the function which expresses the state of fluid flow; sonic flow and subsonic flow [5]. $f(z)_{max}$ represents the maximum value of *f(z)* when the flow is sonic flow which is $f(z)_{max}$=0.484. As the valve has a dead zone, the duty ratio of PWM valve is always added by 47.5%. The duty ratio *u* for PWM valve and the state of switching valve is given by the following equation.

$$u = K_p e_{c(i)} + K_d (e_{c(i)} - e_{c(i\text{-}1)})/T_m . \qquad (3)$$

$$u > 0 \Rightarrow \text{ON (Supply)} ,$$

$$u \leq 0 \Rightarrow \text{OFF (Exhaust)}. \qquad (4)$$

Where $e_c(i)$, K_p, K_d and T_m represent the error from the reference pressure, the proportional gain (0.59%/AD), derivative gain ($=4.73 \times 10^{-3}$%·s/AD) and the sampling time of control(=3.2 ms), respectively.

IV. Pressure Control Type Quasi-Servo Valve

A force control is needed in industrial robots, power-assisted systems and rehabilitation devices [6]. The force control using a fluidic actuator is easier and more inexpensive than that using an electric actuator. This is because the force can be controlled directly by the fluid pressure, and its control system does not need a force sensor. In this section, the force control of the pneumatic cylinder using the pressure control type quasi-servo valve is described.

a) Control System

Fig.3 shows the schematic diagram and a view of the proposed force control system. The system mainly consists of the double action type pneumatic cylinder (Koganei Co., Ltd., PBDA 16x100-1A), an electric linear actuator (SUS Co., XA-50H-300E), a load cell (KYOWA ELECTRONIC INSTRUMENTS Co., Ltd., LUR-A-SA1, maximum force: 100N) for measuring the controlled force and a potentiometer (MIDORI PRECISIONS Co., Ltd, LP-150F-C, stroke: 150 mm) for measuring the position of the cylinder. The tested cylinder has an inner diameter of 8 mm and a stroke of 100 mm. The end of the piston rod of the cylinder is connected with the slide table of the electric liner actuator through the load cell, and the displacement of the piston is given by the electric liner actuator. The output signals from the load cell, the pressure sensor and a potentiometer are recorded by the data logger (HIOKI E.E. Co., MEMORY HiLOGGER 8430).

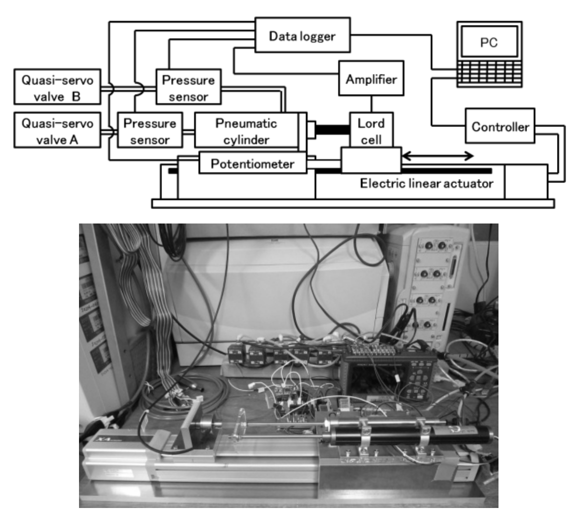

Fig.3 : Schematic diagram of experimental equipment

b) Control Procedure

Fig. 4 shows the block diagram of the control system. The pneumatic cylinder is controlled by using two tested pressure control type quasi-servo valves.

Each chamber pressure of the valve is controlled independently by PD control scheme. One of the valves (Quasi-servo valve B) regulates the constant pressure of 50kPaG, and the other (Quasi-servo valve A) controls the pressure to generate the desired force.

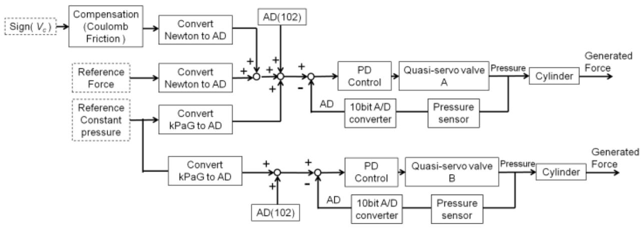

Fig.4 : Schematic diagram of pressure control type quasi-servo valve

c) *Aontrol Results and Discussion*

Fig. 5 shows the control result of the cylinder force. The reference force is 5N. In the figure, the solid and dotted lines show the measured force and displacement of piston, respectively. The displacement of triangle wave with an offset of 40 mm and an amplitude of 20 mm was applied to the cylinder. The piston speed is plus or minus 16 mm/s. From the figure, it is observed that there is a big difference between reference force and measured force. The constant force opposite to the moving direction of the slide table can be found. This is caused by Coulomb friction between the piston and the cylinder. Therefore, the friction characteristic of the cylinder was investigated by the experiment.

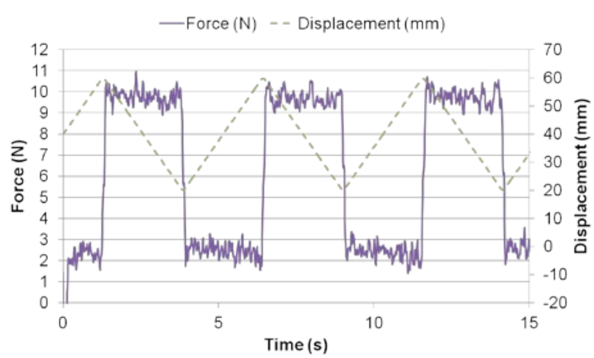

Fig.5 : Control result (without friction compensation)

Fig. 6 shows the relation between velocity of the piston and frictional force. The experiment was carried out three times under the constant velocity of the slide table, and the force was measured at the certain position. From the experimental results, the following relation is obtained.

$$F_c = 13.8V_c + 3.21sgn(V_c) \quad (5)$$

Where F_c [N] and V_c [m/s] represent the frictional force and the velocity of the piston, respectively. From this equation, the coulomb friction of 3.21 N and the coefficient of viscous resistance of 13.8 N/(m･s) are obtained. In the following experiment, based on this result, the force control with friction compensation was tried.

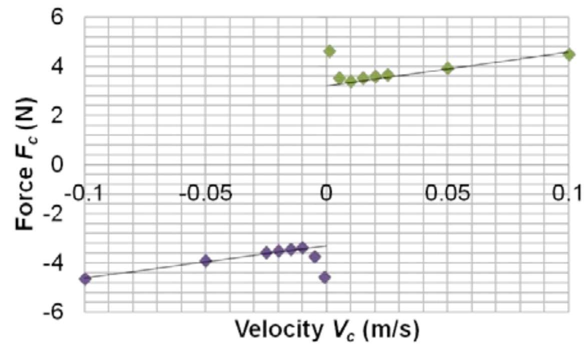

Fig.6 : Friction characteristics

Fig.7 shows the force control result using tested valve with friction compensation. The compensation method is as follows. The sign of piston velocity is detected, and the pressure corresponding to the frictional force of 3.21 N is added or subtracted based on the sign. This control procedure is also shown in the block diagram in Fig. 4. From Fig. 7, it is found that there still exists an error of 1.8 N between reference and measured force. It is also observed that there is a sudden change of measured force when the piston displacement is the maximum and the moving direction is changed. At this position, the cylinder is extended largely and the chamber volume becomes maximum. It is considered that the sudden change is caused by the time delay of the pressure response due to the larger chamber volume. We think that these problems can be solved by improving the control scheme.

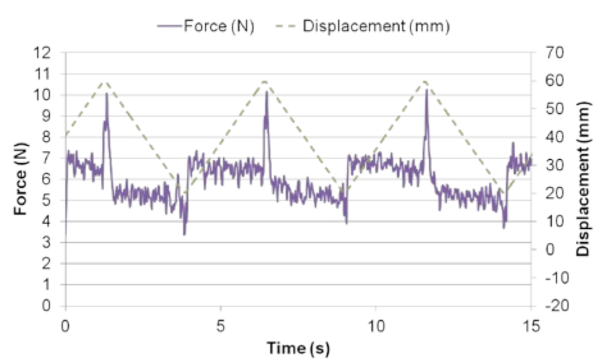

Fig.7 : Control result (with friction compensation)

V. Conclusion

The purpose of this study is to develop a small and light-weight pneumatic control valve and to apply it to the care and welfare equipments. This study can be summarized as follows.

The small-sized quasi-servo valve which consists of two inexpensive on/off valve is explained.

The pressure control type quasi-servo valve is built by the quasi-servo valve, a pressure sensor and an embedded controller. The force control using the pressure control type quasi-servo valve is easier and more inexpensive than others. Therefore, as an application of the tested pressure control type quasi-servo valve, the force control system of the cylinder is built and tested. The force control system consists of a pneumatic cylinder, an electric linear actuator, a load cell and a potentiometer. As a result, a large error between reference and measured force was observed. This is because of Coulomb friction in the cylinder. Then, the friction characteristics were investigated and the control performance was improved by compensating the friction.

VI. Acknoledgements

Finally, we express our thanks that this work was supported in part by MEXT in Japan through a QOL Innovative Research Program (2012-).

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Modeling and Simulation of Bullet Resistant Composite Body Armor

By Yohannes Regassa
Debre Brehan University

Abstract- Composite Ballistic body armor materials has become a better body armor protection as compared to traditional steel body armor in terms of its reduction in weight and an improvement in ballistic resistance[1,2]. However, the complex response of composite materials coupled with high costs and limited amount of data from ballistic testing has lead to modeling and simulation of ballistic body armor with different grade of material becomes the best option to optimize and design the composite body armor with less weight and affordable cost. The long term goal of this research is to develop domestic knowledge, model and simulate capability of composite armors with less cost and weight. As a research methodology there was modeling and simulation by Solid work 2012 and Abaqus 6.10software were used to model and simulate the composite bullet resistant body armor respectively.

Keywords: armor material, aramid fiber, composite body armor, fem.

GJRE-A Classification : FOR Code: 091399p

MODELINGANDSIMULATIONOFBULLETRESISTANTCOMPOSITEBODYARMOR

Strictly as per the compliance and regulations of:

Modeling and Simulation of Bullet Resistant Composite Body Armor

Yohannes Regassa

Abstract- Composite Ballistic body armor materials has become a better body armor protection as compared to traditional steel body armor in terms of its reduction in weight and an improvement in ballistic resistance[1,2]. However, the complex response of composite materials coupled with high costs and limited amount of data from ballistic testing has lead to modeling and simulation of ballistic body armor with different grade of material becomes the best option to optimize and design the composite body armor with less weight and affordable cost. The long term goal of this research is to develop domestic knowledge, model and simulate capability of composite armors with less cost and weight. As a research methodology there was modeling and simulation by Solid work 2012 and Abaqus 6.10software were used to model and simulate the composite bullet resistant body armor respectively. The material used for modeling of composite body armor was Kevlar-29 fiber and polyester resin. The simulation result for 20layers (10mm thick) of woven Kevlar-29 fiber with polyester resin as a matrix shows that there is no penetration through the modeled composite body armor panel by a projectile of 7.62x39mm bullet impact load at 10 and 50meters and the weight of modeled composite body armor was 0.9kg. There is also bullet resistant body armor that modeled as integral armor from16layers and 5mmthick sheet metal steel and it weighs about 1.5Kg. These results were validated against published data and good correlation was observed. By considering the current thickness and weight of modeled and simulated bullet resistant composite body armor there is a recommendation thrown to any researcher to reduce the weight in terms of thickness in any available technique.

Keywords: armor material, aramid fiber, composite body armor, fem.

I. Introduction

Fiber-reinforced composite materials have become important engineering materials used such as marine bodies, aircraft structures and light-weight armor for ballistic protection in military applications. This is due to their outstanding mechanical properties, flexibility in design capabilities, ease of fabrication and good corrosion, wear and impact resistant. Composite Body armor is an item or piece of clothing that is designed to protect the wearer against a variety of attacks. They can be made to stop different types of threats, such as bullets, knives and needles, or a combination of different attacks. There are two types of body armor – soft body armor, which is used in regular bullet and stab proof vests, and hard armor, which is rigid, reinforced body armor, and is used in high risk situations by police tactical units and combat soldiers [1].

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Figure 1 : Hard And Flexible Bullet Resistant Body Armor [3]

II. Literature Review

The first protective clothing and shields were made from animal skins. As civilizations became more advanced, wooden shields and then metal shields came into use. Eventually, metal was also used as body armor, what we now refer to as the suit of armor associated with the knights of the Middle Ages. However, with the invention of firearms around 1500, metal body armor became ineffective [4]. Then only real protection available against firearms was stone walls or natural barriers such as rocks, trees, and ditches. It would not be until the late 1960s that new fibers were discovered that made today's modern generation of cancelable body armor possible. When a handgun bullet strikes body armor, it is caught in a "web" of very strong fibers. These fibers absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Additional energy is absorbed by each successive layer of material in the vest, until such time as the bullet has been stopped. Because the fibers work together both in the individual layer and with other layers of material in the vest, a large area of the garment with composite technology becomes involved in preventing the bullet from penetrating. This also helps in dissipating the forces which can cause non penetrating injuries (what is commonly referred to as "blunt trauma") to internal organs. Unfortunately, at this time no material exists that would allow a vest to be constructed from a single ply of material [5]. People have always attempted to protect themselves against their enemies and the weapons being used, but this has always been balanced by their need to be mobile. The earliest form of armor was not intended to protect any form of transportation but to protect the person. From the middle Ages, the foot soldier was protected with some kind of body vest, a helmet and a shield. When the scale of attack was dramatically increased with the advent of fire arms, any form of protection was easily overmatched and it was soon abandoned in favor of the greater mobility given to the individual. When the need for fighting vehicles was arisen, the importance of achieving lightweight protection has also been recognized [6].

Cristescu et al carried out a detailed computational analysis of the ballistic performance of composite and hybrid armor panels hard-faced with Al2O3 ceramic tiles by using AUTODYN software. The initial simulations were performed to validate the composite material model. In these simulations, there was an agreement between the V50 values obtained from the numerical simulations and those from the experimental results. Next, the simulations were done by considering the whole armor system, i.e. composite panels hard-faced with alumina ceramic tiles [7]. Again the overall agreement between the experimental and computational results is quite good. Fabric based body armors function well against deformable threats by distributing the kinetic energy through the high strength fibers with dissipation modes including fiber shear or fracture, fiber tensile failure or straining and associated delamination or pullout. To provide isotropic properties when laminated, 0o/45° and 0o/90° cross ply arrangements are used [10].High shear stresses cause the delamination between the neighboring layers which is the failure mode of composite material. In addition to delamination, fiber breakage, which is another failure modern fiber composite material under impact loading, occurs in the composite plate. The degree of delamination decreases as the thickness of the backing plate is increased. Energy absorbed during delamination depends on the interlaminar shear fracture energy, the length of delamination and the number of delamination. Progressive delamination causes a ductile material behavior in the composite and significant amount of impact energy is absorbed. For composite failure evaluation method Tsai-Wu's and Hashin failure modes are the most popular methods [8].

Figure 2 : Damage mechanisms occurred in composite materials under ballistic impact[9]

III. Material and Methodology

The modeled composite body armor in this research was consisted of 20layer of plain-woven Hexcel Aramid fiber (polyparaphenylene terephthalamide), impact high performance fabric Style 706 (Kevlar KM-2, 600 denier) with an areal density of 180 g/m2 and a polyester resin as matrix. The designed methodology was computer modeling and simulation, literature review and analytical method was used to validate the obtained result.

IV. Composite Body Armor Modeling and Impact Simulation

In Finite element modeling and simulation there is three stages i.e. pre-processing, solution, post processing stage were well known stage.

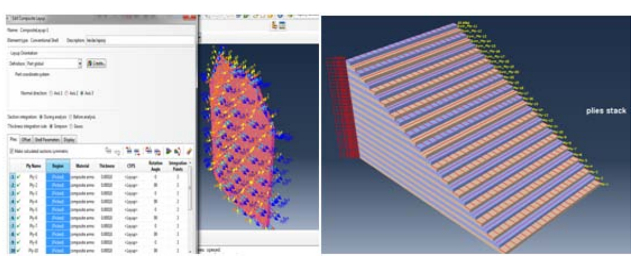

Figure 3 : Defining composite lamina sections and plies stack

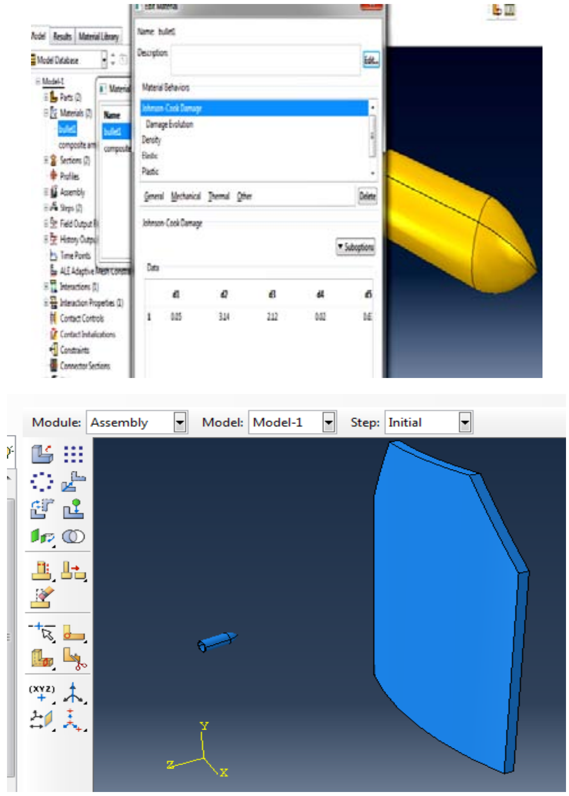

Figure 4 : Elastic and Plastic Modeling of Bullet and dynamic assembling of Bullet with Armor Disk

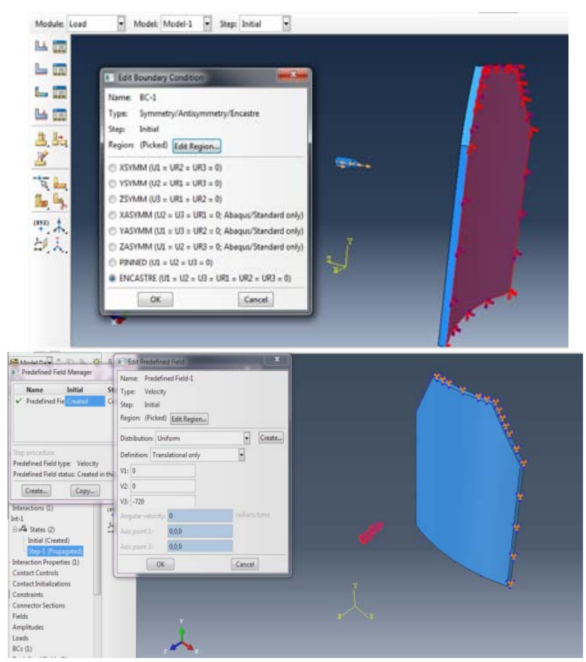

Figure 5 : Boundary condition, load assignment at step module

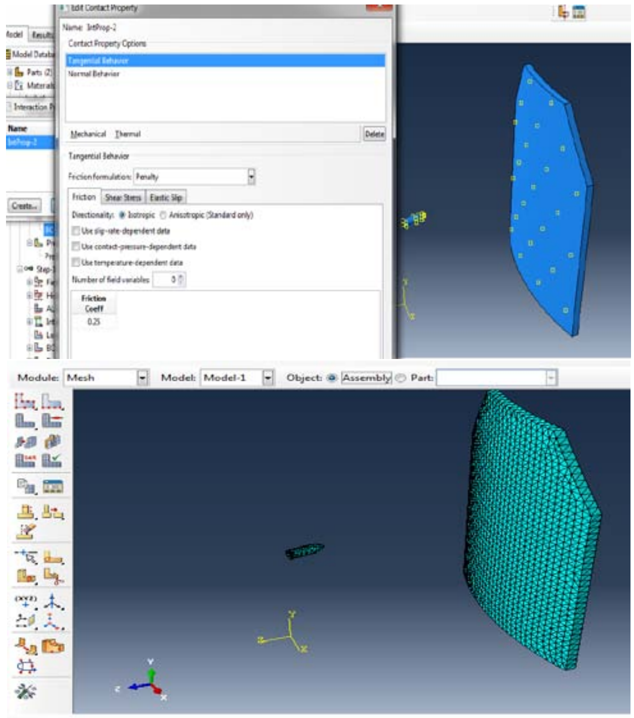

Figure 6 : interaction and meshed body armor at interaction and mesh module.

The Mesh module provides a variety of tools that allow you to specify different mesh characteristics, such as mesh density, element shape, and element type. We meshed our components, the bullet with C3D4 element type which describes a four node tetrahedral element with mesh size of 2.5 and armor disk with SR4 - a four node doubly curved thin or thick shell reduced integration quadrilateral element with mesh size of 3.5.

Table 1 : Fem Formulated Procedure Information

No	Parameter	Value and types
1	Mesh type	Solid Mesh with 2.5 size
2	Mesher Used:	Standard mesh
3	Jacobian points	4 Points
4	Element Size	7.51878 mm
5	Tolerance	0.375939 mm
6	Mesh Quality	High
7	Total Nodes	15616
8	Total Elements	7738
9	Maximum Aspect Ratio	14.353

The Job module: Job>Create job>continue>Ok

After defining our model, know we are ready to analyze it. Analyzing a model involves some steps. Once you have finished all of the tasks involved in defining a model (such as defining the geometry of the model, assigning section properties, and defining contact), you can use the Job module to analyze your model.

Visualization Stage Module: The Job module allows you to create a job, to submit it to ABAQUS/Explicit for analysis, and to monitor its progress; then last visualization stage which is post analysis stage.

V. Result and Discussion

As seen in the fig. 7below the Von Mises stresses induced in the composite body armor at projectile speed of 720m/s and at a shooting distance of 50meters, that is, the muzzle velocity can't damage the harder armor. As fig. 7 shows that the dynamical interaction of bullet and composite armor starts to deform at the first instance with the projectile, the bullet where fired at distance of 50meter from target.

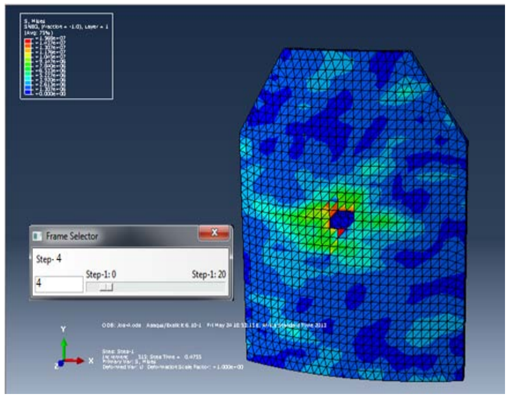

Figure 7: First instance of bullet strike with disk panel of armor

As fig. 8 shows that the dynamical interaction of bullet and Kevlar-29 composite armor at the last instance moment where the projectile ends to strike the panel and resulted there is more energy distribution over the body armor, there is no penetration over the sample. The bullet where fired to the target at distance of 50meter.

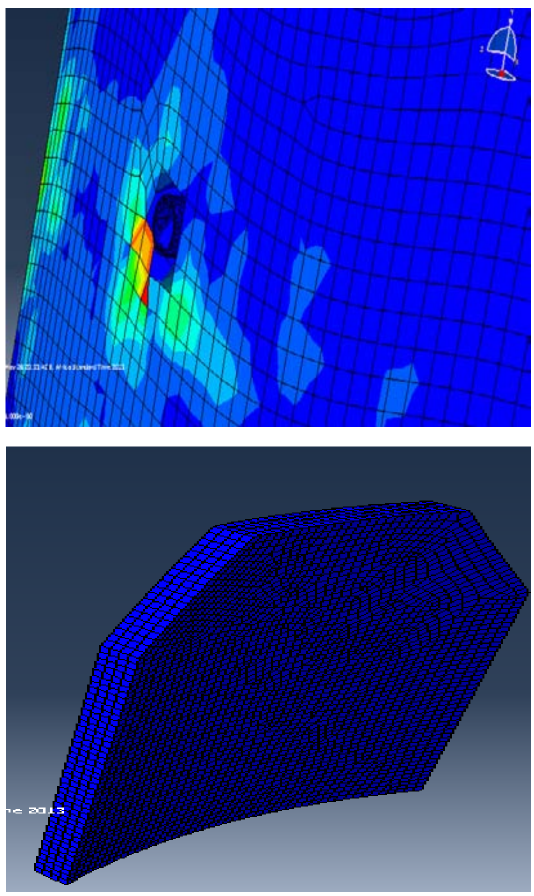

Figure 8 : Front face of armor composite disk of bullet impact area and back side with zero penetration

a) Result by graphical interpretation

As fig. 9: shows, the bullet strikes the integral composite body armor and there is slow drop of kinetic energy absorption which indicates us there is more deformation of the specimen rather than the bullet and this will cause severe trauma. The bullet where fired to the target at distance of 50meter.

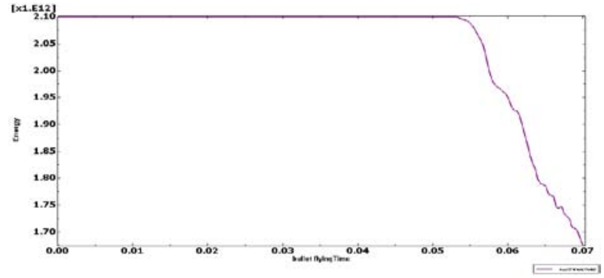

Figure 9 : Kinetic energy absorbed composite body armor (by kevla-29)

As figure 10: of below shows, the bullets strike the integral composite body armor at 0.065second and ends at 0.1seconds and this simulation result show that there is sharp drop of kinetic energy absorption which indicates us there is higher deformation of the bullet rather than the specimen and less trauma will developed over the body of wearers with weight limitation.

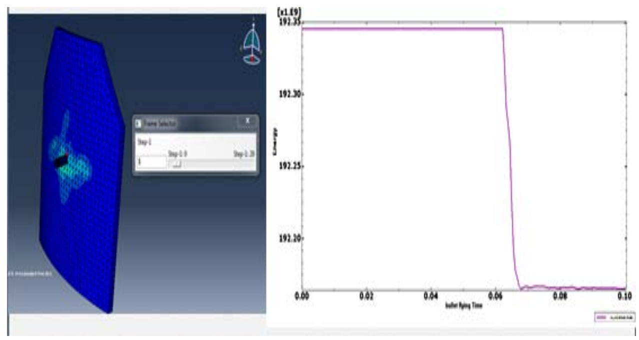

Figure 10 : Kinetic energy absorbed by integral armor, (sandwiching of 5mm thick steel by Kevlar fiber)

As figure-11: shows, the simulation that made over Kevlar-29 fiber with polyester resin and the result obtained indicates that there was more deformation of the modeled armor which indicates that there is less energy absorption by the modeled sample and can cause some amount of trauma over wearers body.

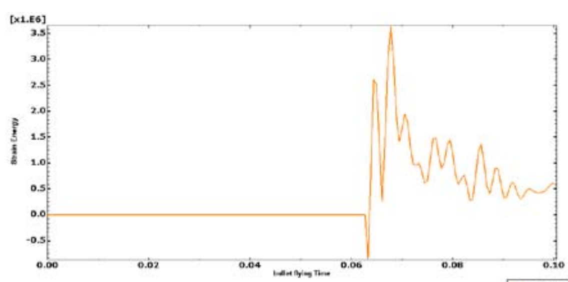

Figure 11 : Strain energy vs time graph of integral body armor

As fig 12: shows, the sample that made from Kevlar-29 were exposed to take 0.07second to absorb and stop the bullet energy which indicates that there is more energy absorption by the armor and this will cause severe trauma over wearer body. Kevlar-29 armor sample were thick about 10mm and the bullet where fired to the target at distance of 50meter.

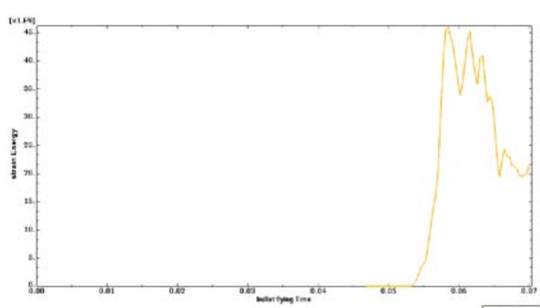

Fig. 12 : Strain energy vs time graph of body armor made by Kevlar-29.

VI. Conclusion and Recommendations

In this study, the modeling and simulation of composite body armor that modeled from Kevlar-29 and polyester resin were studied and compared with a body armor that made as integral armor body and the following conclusion has been made.

It was found that 20layers of a Kevlar-29fiber with a polyester resin can stand impact energy of 7.62x39mm bullet type that fired at a distance of 10meter with a muzzle velocity of 720m/s.

The authors' used the commercial finite element software, ABAQUS/CAE; to analyze and simulate the dynamic deformations of laminated composite body armor caused by the impact of a 7.62x39mm copper coated bullet.

From the simulation of composite body armor under dynamic explicitly condition, there was an observation that, of bullet that strike the body armor at kinetic energy of about 1.9e9joule have been absorbed by the composite body armor which have been shown by Fig 10.

The researched bullet resistant integral composite body armor cost about 6500birr and have a weight of about 1.5Kg, if back and front were to used at combat field it weighs up to 3Kg.

The composite bullet resistance body armor that made from 20layers of Kevlar-29 fiber with polyester resin weighs only about 0.45kg and if back and front side were used it is only weighs about 0.9Kg which is the most recommended and preferable for foot solider due to its mobility advantageous, but there is some trauma that can be recoverable.

The cost comparative study shows that for localization of body armor there is 63.8% cost reduction.

As per the Standerd for the united states of state of America under UL-752, the researched bullet resistant body armor was classified under level 5.

VII. Recommendation

There is a recommendation that the Ethiopian national ministry of defence have to be agreeing to open their door to any both external and internal researcher that will upgrade the capacity of military organization in terms of technology to form a modern army with modern military gear.

The authors' highly recommend that any interested researcher to deal with ballastic property of kevlar-29 fiber with epoxy or other thermoset resin as a body armor.

For the design and manufacturing of body armor there should be a consideration of mobility, safety and cost to the customer.

Lastly the authors of this paper that entitle modeling and simulation of bullet resistant composite body armor forward an idea to any researcher to deal with the optimization for weight and thickness of body armor.

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By Omholua, Anthony Omokhudu, Ujam. A. J & Uviesherhe Okiemute Edijana

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Abstract- Nigerian grown species of bamboo called bambusa vulgaris which was examined to analyze its tensile strength. The fibre characteristics and tensile strength were investigated at three different fibre lengths and fibre loadings i.e 10, 30,50mm and 10, 30, 50 wt.% respectively. Fibre length was varied in each fibre loading from 10mm to 50mm, the tensile strength of the three different series of composites varies from 28.32Mpa to 38.10Mpa. The predicted optimum tensile strength is 44.51Mpa. Generated results have been validated by the confirmation of experiments at three replications, when the control factors were set at 30mm and 30% wt or (level 2, level 2), using Taguchi's design of experiments approach. It was observed from the analysis of variance of the samples that there is a variation in the increase of tensile strength of the bamboo that are dependent on the fibre length and fibre loading used. The percentage contributions of parameter according to the pooled ANOVA for signal-to- Noise ratio showed that the fibre length (36.61%) in controlling variation and mean strength is significantly smaller than the fibre loading (44.15%).

Keywords: bamboo, bambusa vulgaris, tensile strength, taguchi's experimental design, fibre length, fibre loading.

GJRE-A Classification : FOR Code: 290501

ANALYSISOFTENSILESTRENGTHOFBAMBOOREINFORCEDPOLYESTERCOMPOSITE

Strictly as per the compliance and regulations of:

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I. Introduction

Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. The different systems are combined judiciously to achieve a system with more useful structural or functional properties no attainable by any of the constituent alone [Shaw et al. 2010]. The strength of bamboo is greater than many timber products, but lesser than the tensile strength of steel. Bamboo is readily available and is emerging as low cost, light weight, and environmentally friendly. Tensile test is the most basic type of mechanical test. It is not difficult to perform and it is not expensive compared to other mechanical tests.

II. Materials and Methods

General purpose grade unsaturated orthophathalic polyester resin (RGP 67G), was obtained from Center for Composite Research and Development, JuNeng Nigeria Limited, Nsukka. The bamboo fibres were extracted mechanically from the young stem of bamboo plant, shredded and air-dried for about a week until constant mass. The dried fibres were chopped into 10mm, 30mm and 50mm fibre lengths and 10%, 30% and 50% weight fraction used as reinforcement materials in the composite preparation, by hand lay-up method using a three-piece stainless steel mould having dimensions 200x 150x30mm. Methyl ethyl ketone peroxide (MEKP) and cobalt napthenate of commercial grade were used as the catalyst and accelerator respectively for resin curing.

a) Volume Fraction and Density of Fibre

The density and volume fraction of fibres used for the sample preparation was calculated by a method which enables the rule of mixtures analysis of measured composite properties. The picnometric procedure was adopted for measuring the density pc of the composite of mass M_c at a given mass fraction of resin M_r. Volume fraction V_r of resin was calculated using the following relationships:

$$V_r = \frac{M_r\,\rho_c}{M_c\rho_r} \quad [1]$$

Where ρ_r is the resin density then, the volume fraction V_f and density ρ_f of fibre where calculated using the following equations: [1]

$$V_f + V_r = 1 \quad [2]$$

$$\rho_r = \frac{M_f\rho_c}{M_cV_f} \quad [3]$$

The density of fibre was also measured using archimedes principle. Both results produced similar results and an average value of 960kg/m^3 was obtained as fibre density.

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Table 1 : Mass of Fibre and Volume of Resin used for Samples Preparation

Fibre Volume Fraction (%)	10.70	31.70	52.00
Fibre Weight Fraction (%)	10.00	30	50.00
Mass of Fibre (g)	86.40	259.00	432.00
Volume of the Resin (cm^3)	804.00	615.00	432.00
Mass of Resin (g)	843.00	656.00	468.00

Source: Field experiment

b) The Taguchi Approach to Robust Parameter Design

In the early 1980s, Genichi Taguchi, a Japanese engineer, introduced his approach to using experimental design for: designing products or processes so that they are robust to environmental conditions; designing/ developing products so that they are robust to component variation; and minimizing variation around a target value.

In parameter design, there are two types of factors that affect a product's functional characteristic: control factors and noise factors, at this stage of design, the specific values for the system parameters are determined. Usually, the objective is to specify these nominal parameter values such that the variability transmitted from uncontrollable or noise variables is minimized.

III. Selection of an Orthogonal Array

In selecting an appropriate OA, the pre-requisites are: (a) selection of process parameters and interactions to be evaluated and (b) selection of number of levels for the selected parameters [2] The process parameters were already decided and are given in Table 1. It was also decided to study each selected parameter at three levels. With two parameters each at three levels, the total degree of freedom (DOF) required is 4 [= 2(3-1)]. As per Taguchi's DOE approach, the total DOF of t selected OA must be greater than or equal to the total DOF required for the experiment. So, an L_9 (2^3) orthogonal array was selected for the present work.

IV. Experimental-Analysis and Discussion

The tensile tests were performed according to ASTM D638 standard using Universal Testing Machine at a crosshead speed of 5 mm/min. Specimens for each sample were tested and the tensile strength and tensile modulus were expressed as:

$$\text{Tensile strength (MPa)} = P/bh \qquad [4]$$

Where; P = Pulling force (N), b =Specimen width (m), and h = Specimen thickness (m)

Robust design is an "engineering methodology for improving productivity during research and development so that high-quality products can be produced quickly and at low cost" [3]. The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult or too expensive to control). Nine trial conditions with three repetitions are used in this work. The selected quality characteristic, tensile strength, is 'higher the better' (HB) type, the S/N (signal to noise) ratio, for 'higher the better' type of response was used as given in the following equation:

$$(S/N)_{HB} = -10\log\left[\frac{1}{n}\left(\frac{1}{{y_1}^2}+\frac{1}{{y_2}^2}+\cdots\frac{1}{{y_n}^2}\right)\right] \qquad [5]$$

Where y_1, y_2 ……y_n are the responses of quality characteristic for a trial condition repeated n times.

The S/N ratios were computed using equation 5 for each of the 9 trials and mean response for each factor at the three levels is presented in Table 3. [4] Along with the raw data. The average value of the tensile strength for each parameter at levels 1, 2 and 3 are plotted in figure 2. The average values of S/N ratios of various parameters at levels 1, 2 and 3 are plotted in figure 1.

The summary of the responses and ranking for tensile strength of bamboo fibre reinforced Polyester composites on the bases of the larger the better quality, for Signal to Noise Ratio, and mean of means lead to the conclusion that factor combination of A_1 B_1 gives the minimum strength while A_2 B_2 gives the maximum strength as shown in Figure 1 and Figure 2. It is found that as far as the tensile strength is concerned; B and A have significant effect on the composite. The range (Delta) is the difference between higher and lower response. The larger the (Delta) value for a parameter, the larger the effect the variable has on the tensile strength of the composites. This is because the same change in signal causes a larger effect on the output variable being measured. It is clear from table 4 and 5 that the fibre weight fraction is ranked 1st and fibre length 2nd.In order to confirm Taguchi's design of experiment and to study the significance of the parameters in affecting the quality characteristic of the mechanical properties analysis of variance (ANOVA) was performed. The pooled ANOVA of the raw data (tensile strength) is given in Table 6. The S/N ANOVA (pooled version) is given in Table 7. It is clear from ANOVAs that the parameters A and B (fibre length and fibre weight) significantly affect both the mean value as well as the variation of the tensile strength because these are significant in both the ANOVAs. The percent contributions of parameters as quantified under column P of Table 6 and Table 7 reveal that the fibre weight (B) in controlling the mean and variation is significantly larger than the fibre length (A). [5] Software MINITAB 16 was used to analyze the Taguchi design of experiment, and the linear regression equations.

Table 2 : Experimental Outlay and Variable Sets for Mechanical Properties

S/N	Processing Factors	Factor's designation	Level		
			1	2	3
1	Fibre Length (mm)	A	10	30	50
2	Fibre Weight Fraction (%)	B	10	30	50

Source: Field experiment

Table 3 : Experimental Design Matrix for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites.

Expert. Run	Fibre Length (mm)	Fibre Weight. Fraction (%)	Measure Response (Mpa)			Mean Tensile Response	SN Ratio (dB)
			Trial 1	Trial 2	Trial 3		
1	10	10	28	27.83	29.13	28.32	29.03655249
2	10	30	41.40	39.50	39.70	40.20	30.07877224
3	10	50	37.80	37.51	35.69	37.00	31.34769209
4	30	10	38.80	38.40	38.30	38.50	31.70880621
5	30	30	45.20	44.92	44.88	45.00	33.06412024
6	30	50	41.60	40.32	41.08	41.00	32.25352731
7	50	10	35.80	35.00	34.20	35.00	30.87682137
8	50	30	38.33	37.00	36.63	37.32	31.43392063
9	50	50	39.20	38.20	36.90	38.10	31.61049495
Total			346.13	338.68	336.51		

$\bar{T}_{TS}$ = Overall mean of TS $= \frac{346.13+338.68+336.51}{3\times 9} = 37.83 Mpa$

TS= Tensile strength.

Table 4 : Summary of the Responses and Ranking for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites on the Bases of the Larger the Better Quality. (Signal to Noise Ratio)

Responses	Signal to Noise Ratio	
Levels	A: Fibre Length (mm)	B: Weight Fraction (%)
1	30.83	30.54
2	32.34	32.20
3	31.31	31.75
Delta	1.51	1.65
Rank	2	1

Source: Field experiment

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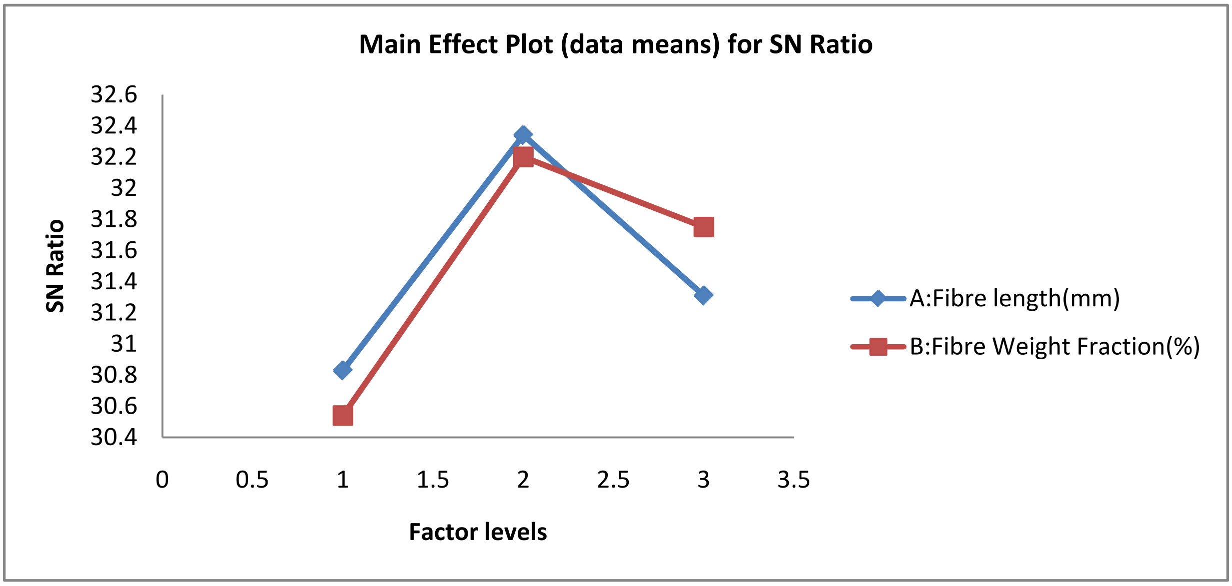

Fig. 1 : Graph of Signal-to-Noise Ratio against Factor Levels (1,2and3) for Tensile Strength

Table 5 : Summary of the Responses and Ranking for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites on the Bases of the Larger the Better Quality. (Mean of Means)

Responses	Means	
Levels	A:FibreLength (mm)	B: Weight Fraction (%)
1	35.17	33.94
2	41.50	40.84
3	36.81	38.70
Delta	6.33	6.90
Rank	2	1

Source: Field experiment

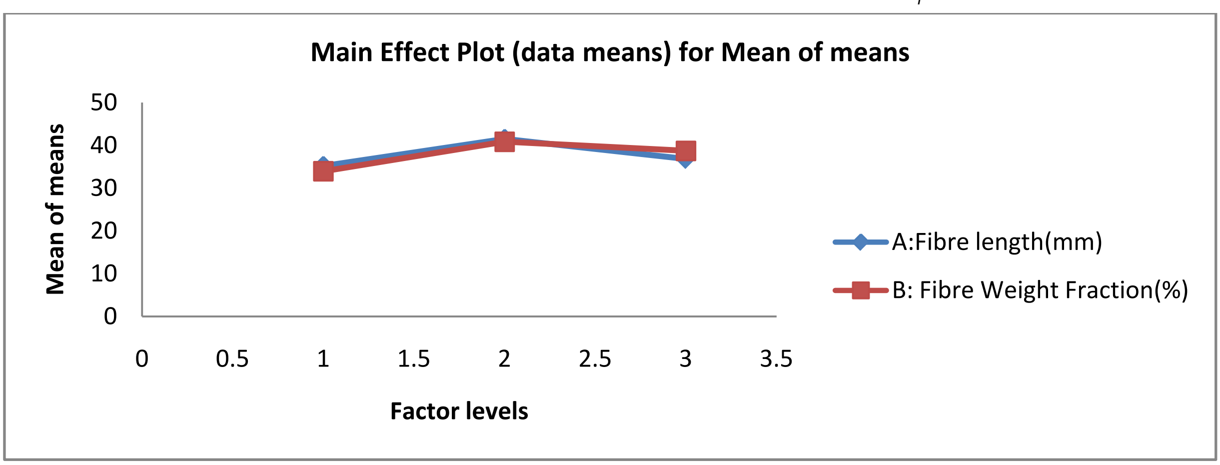

Fig. 2 : Graph of Mean of Means against Factor Levels (1, 2 and 3) for Tensile Strength

Regression Analysis: Tensile Strenght versus A: Fibre Length, B: Fibre weight

The regression equation is

Tensile strength = 33.0 + 0.0408 A + 0.119 B

Predictor	Coef	SE Coef	T	P
Constant	33.032	4.303	7.68	0.000
A	0.04083	0.09465	0.43	0.681
B	0.11900	0.09465	1.26	0.255

S = 4.63692 R-Sq = 22.7% R-Sq(adj) = 0.0%

a) Estimating Optimal Tensile Strength

The optimal tensile strength (μTS) is predicted at the selected optimal setting of process parameters. The significant parameters with optimal levels are already selected as: A2B2. The interaction effects are not being considered in estimating mean and confidence interval around the estimated mean due to poor additivity between parameters and interactions. The estimated mean of the response characteristic can be computed as [4]:

$$\mu TS = \bar{A}_2 + \bar{B}_2 - \bar{T}_{Ts} \qquad [6]$$

Where:

$\bar{T}_{Ts}$ = overall mean of Tensile strength = 37.83 Mpa From (Table 3)

$\bar{A}_2$ = mean value of Tensile strength with parameter at optimum level : $\bar{A}_2$ = 41.50 From (Table 5)

$\bar{B}_2$ = mean value of Tensile strength with parameter at optimum level : $\bar{B}_2$= 40.84 From (Table 5)

Hence;

μTS= 41.50 + 40.84 – 37.83 = 44.51 Mpa

A confidence interval for the predicted mean on a confirmation run can be calculated using the following equation [3]:

$$C.I = \sqrt{F_{\propto}(1, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \qquad [7]$$

Where; $F_{\propto}(1, f_e) =$ F ratio required for α; α=risk; f_e= error DOF; V_e= error variance n_{eff} = effective number of replications.

$$n_{eff} = \frac{N}{1+[\text{Total DOF associated in the estimate of mean}]} \qquad [8]$$

R = number of repetitions for confirmation experiment;

N = Total number of experiments.

Using the values;

Ve = 6.855, and fe = 12 From (Table 6)

Total DOF associated with the mean (μTS) = 2x2= 4

Total trials = 9; N = 3x9 = 27

α = 0.05; $F_{0.05}$ (1, 12) = 4.75 (tabulated value, from F- tables)

$$n_{eff} = \frac{27}{1+4} = 5.4$$

$$C.I = \sqrt{4.75 \times 6.855 \left[\frac{1}{5.4} + \frac{1}{3}\right]} = \pm 4.109$$

The calculated C.I. is: C.I = ±4.109

The predicted optimal Tensile strength is: μTS = 44.51Mpa

The 95% confidence interval of the predicted optimal tensile strength is:

$$(\mu TS - C.I) < \mu TS(Mpa) < (\mu TS + C.I).$$

$$40.401 < \mu TS \text{ (Mpa)} < 48.619$$

b) Experimental Validation

The last stage of Taguchi's robust technique is the confirmation of the experiment. Three confirmation experiments were conducted at the optimal setting of the process parameters. The average value of tensile strength was found to be 44.54Mpa. This result was within the confidence interval (95 %) of the predicted optimal tensile strength.

Table 6 : Pooled ANOVA (Raw Data: Tensile Strength) for mean

source	DOF	SS	V	F ratio	P(%)
A	2	64.72	32.36	1.90	38.75
B	2	74.86	37.43	2.44	44.83
Total	8	167	-	-	100
e(pooled)	4	27.42	6.855		16.42

DOF=Degree of freedom, SS=sum of squares, V=Variance, P= Percentage contribution, e = error, A- Fibre length, B- Fibre Weight fraction

Tabulated F-ratio at 95% confident level: $F_{0.05:1:12}$ = 4.75, $F_{0.05:2:12}$ = 3.88

Table 7 : Pooled ANOVA (Raw Data: Tensile Strength) for (Signal to Noise ratio)

source	DOF	SS	V	F ratio	P(%)
A	2	3.620	1.810	1.73	36.61
B	2	4.366	2.183	2.37	44.15
Total	8	9.889	-	-	100.0
e(pooled)	4	1.903	0.476		19.24

Source: ANOVA generated output

V. Conclusions

The experimental investigations on the analysis of tensile strength of bamboo reinforced polyester composites were conducted. The experiments lead us to the following conclusions obtained from this study:

The successful fabrication of a new class of polyester based composites reinforced with short bamboo fiber is possible by simple hand lay-up technique; and The bamboo reinforced composite has an optimum tensile strength of 44.51MPa when the control factors (Fibre length, Fibre loading) are set at (30mm and 30%wt) or (level 2, level 2);

The percent contribution of parameters in affecting variation in tensile strength:

parameter	Percent Contribution on Tensile strength
Fibre length (A)	36.61
Fibre Weight Fraction(B)	44.15

The predicted optimal range at 95% confidence interval of the Tensile strength is: $40.401 < \mu TS$ (Mpa) < 48.619

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Optimization of Effectiveness for a Cylindrical Fin

By Abdullah Al Mamun
Khulna University of Engineering and Technology

Abstract- A numerical study was performed to provide information about the temperature distribution of three dimensional cylindrical fin in steady state and homogeneous material properties. A brief literature review shows that much of work on fins has been carried out analytically and numerically in one dimensional and two dimensional conditions. This study is concerned about the three dimensional temperature distributions on a cylindrical fin, optimum dimensions and heat transfer from the fin, the fin efficiency and fin effectiveness of the cylindrical fin when fin base was maintained at a constant temperature. The necessary equations are solved by finite difference method and iteration method using FORTRAN code. The whole investigation was done using different material and different dimensional fins to find out the optimum effectiveness and efficiency for predefined condition.

Keywords: *pin-fin, cylindrical fin, 3d fin, effectiveness of a fin, efficiency of pin-fin.*

GJRE-A Classification : FOR Code: 091399p

Optimization of Effectiveness for a Cylindrical Fin

Abdullah Al Mamun

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Keywords: pin-fin, cylindrical fin, 3d fin, effectiveness of a fin, efficiency of pin-fin.

I. Introduction

The term extended surface or fin in commonly used to depict an important special case involving heat transfer by conduction within a solid and heat transfer by convection from the boundaries of the solid. Different types of fin such as rectangular fin, triangular fin, trapezoidal fin, parabolic fin, cylindrical fin, pin fin, annular fin etc are commonly used to enhance the heat dissipation rate from primary surfaces to its surrounding fluid medium in order to meet the ever-increasing demand for high performance, light weight and compact heat transfer equipments. Because of many more engineering applications heat transfer characteristics of fins of different geometry have been subject of continued research.

Fins are used to increase the heat transfer from a surface by increasing the effective surface area. However the fin itself represents a conduction resistance to heat transfer from the original surface. For this reason, there is no assurance that the heat transfer rate will be increased through the use of fins. An assessment of this matter may be made by evaluating the fin effectiveness. It is defined as the ratio of the fin heat transfer rate to the heat transfer rate that would exist without the fin. In general the use of fins may rarely be justified unless $\varepsilon_f \geq 2$.

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a) Objectives

The main objectives of this study are:

a) To investigate the temperature distribution along the dimension of a cylindrical fin for different thermal conductivity of fin material.
b) To determine the rate of heat transfer through the cylindrical fin.
c) To determine the fin effectiveness and efficiency of the cylindrical fin.
d) To determine the optimum dimension for the cylindrical fin.

II. Mathematical Formulation

a) Approximation

The problem is solved, subjected to following assumptions:

Three-Dimensional cylindrical fin, steady state conduction, constant thermal conductivity, homogeneous material, uniform cross section and convection heat transfer coefficient is uniform across the cylindrical fin surface, radiation from the surface is negligible so it is neglected. Fin base and ambient temperature also assumed to be constant.

b) Governing Equation

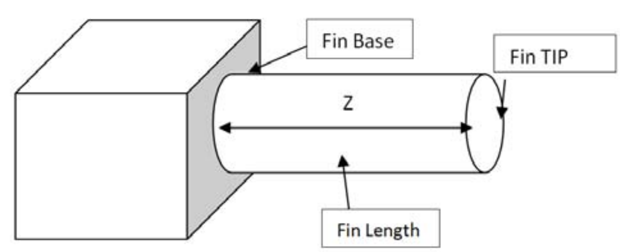

Fig 1 : Three dimensional view of the cylindrical fin

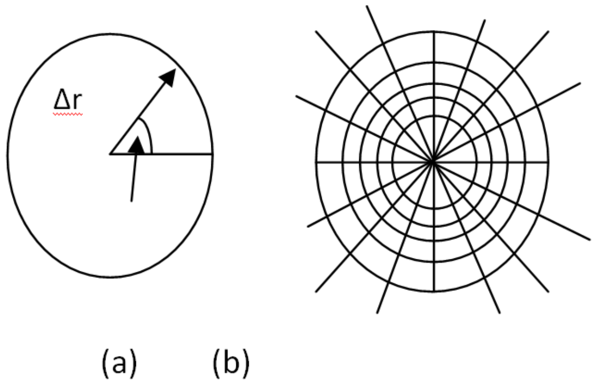

Fig. 2 : a) Front View of the cylindrical fin b) Front view with grid

The Governing equation for the cylindrical fin is:

$$\frac{1}{r}\frac{\delta}{\delta r}\left(r\frac{\delta T}{\delta r}\right)+\frac{1}{r^2}\left(\frac{\delta^2 T}{\delta \Phi^2}\right)+\left(\frac{\delta^2 T}{\delta z^2}\right)+\frac{g}{k}=\frac{\delta T}{\alpha \delta t}$$

For steady state condition

$$\frac{1}{r}\frac{\delta}{\delta r}\left(r\frac{\delta T}{\delta r}\right)+\frac{1}{r^2}\left(\frac{\delta^2 T}{\delta \Phi^2}\right)+\left(\frac{\delta^2 T}{\delta z^2}\right)+\frac{g}{k}=0$$

Now by Finite Difference method we get:

1) $\frac{1}{r}\frac{\delta}{\delta r}\left(r\frac{\delta T}{\delta r}\right)=\frac{1}{r}\left(\frac{\delta T}{\delta r}\right)+\frac{\delta^2 T}{\delta r^2}=$
$$\frac{1}{r}\left(\frac{T_{(i,j,k)}-T_{(i+1,j,k)}}{\Delta r}\right)+\left(\frac{T_{(i+1,j,k)}+T_{(i-1,j,k)}-2T_{(i,j,k)}}{\Delta r^2}\right)$$

2) $\frac{1}{r^2}\left(\frac{\delta^2 T}{\delta \Phi^2}\right)=\frac{1}{r^2}\left(\frac{T_{(i,j+1,k)}+T_{(i,j-1,k)}-2T_{(i,j,k)}}{\Delta \Phi^2}\right)$

3) $\left(\frac{\delta^2 T}{\delta z^2}\right)=\left(\frac{T_{(i,j,k+1)}+T_{(i,j,k-1)}-2T_{(i,j,k)}}{\Delta z^2}\right)$

So the total equation for the conduction in the fin is General conduction equation:

$$T_{i,j,k}=\left(\frac{T_{i+1,j,k}}{r_i\Delta r}+\frac{T_{i+1,j,k}+T_{i-1,j,k}}{\Delta r^2}+\frac{T_{i,j+1,k}+T_{i,j-1,k}}{r_i^2\Delta\theta^2}+\frac{T_{i,j,k+1}+T_{i,j,k-1}}{\Delta z^2}\right)\Big/\left(\frac{1}{r_i\Delta r}+\frac{2}{\Delta r^2}+\frac{2}{r_i^2\Delta\theta^2}+\frac{2}{\Delta z^2}\right)$$

i. *At the tip of the Fin*

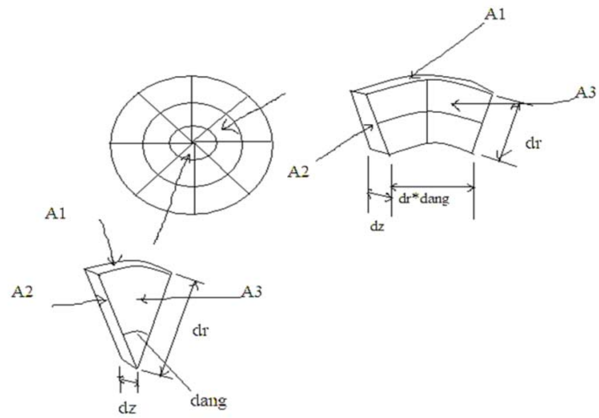

Fig. 3 : Grid elements of the tip surface of the fin.

At the central grid which is at r1. The grids are triangular so here is the equation of energy balance:

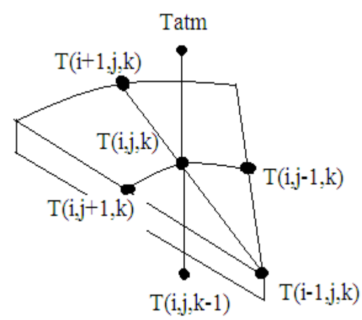

Fig. 4 : central grid section.

$$-\frac{k\Delta r\Delta\theta\Delta z}{2\Delta r}\left(T_{i,j,k}-T_{i-1,j,k}\right)-\frac{k\Delta r\Delta\theta\Delta z}{2\Delta r}\left(T_{i,j,k}-T_{i+1,j,k}\right)-\frac{k\Delta z\Delta r}{2\Delta r\Delta\theta}\left(T_{i,j,k}-T_{i,j+1,k}\right)-\frac{k\Delta z\Delta r}{2\Delta r\Delta\theta}\left(T_{i,j,k}-T_{i,j-1,k}\right)-\frac{k\Delta\theta\Delta r^2}{2\Delta z}\left(T_{i,j,k}-T_{i,j,k-1}\right)=\frac{h\Delta\theta\Delta r^2}{2\Delta z}\left(T_{i,j,k}-T_{\infty}\right)$$

By simplification:

$$T_{i,j,k}=\frac{\frac{k\Delta\theta\Delta z}{2}\left(T_{i-1,j,k}+T_{i+1,j,k}\right)+\frac{k\Delta z}{2\Delta\theta}\left(T_{i,j-1,k}+T_{i,j+1,k}\right)+\frac{k\Delta\theta\Delta r^2}{2\Delta z}\left(T_{i,j,k-1}\right)+\frac{h\Delta\theta\Delta r^2}{2}T_{\infty}}{\left(\frac{2k\Delta\theta\Delta z}{2}+\frac{2k\Delta z}{2\Delta\theta}+\frac{k\Delta\theta\Delta r^2}{2\Delta z}+\frac{h\Delta\theta\Delta r^2}{2}\right)}$$

The below energy conservation equation is only applied for elements those are after the first circle, which means from the r2 this equation applies.

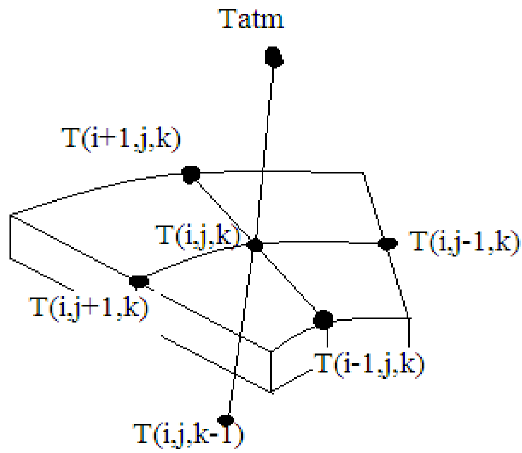

Fig. 5 : Grid section at 2nd and later circles.

$$-\frac{kr_i\Delta\theta\Delta z}{2\Delta r}\left(T_{i,j,k}-T_{i-1,j,k}\right)-\frac{kr_i\Delta\theta\Delta z}{2\Delta r}\left(T_{i,j,k}-T_{i+1,j,k}\right)-\frac{k\Delta z\Delta r}{2r_i\Delta\theta}\left(T_{i,j,k}-T_{i,j-1,k}\right)-\frac{k\Delta z\Delta r}{2r_i\Delta\theta}\left(T_{i,j,k}-T_{i,j+1,k}\right)-\frac{kr_i\Delta\theta\Delta r}{\Delta z}\left(T_{i,j,k}-T_{i,j,k-1}\right)=hr_i\Delta\theta\Delta r\left(T_{i,j,k}-T_\infty\right)$$

By simplification:

$$\mathrm{T_{i,j,k}}=\frac{\frac{kr_i\Delta\theta\Delta z}{2\Delta r}\left(\mathrm{T_{i-1,j,k}}+\mathrm{T_{i+1,j,k}}\right)+\frac{k\Delta z\Delta r}{2r_i\Delta\theta}\left(\mathrm{T_{i,j-1,k}}+\mathrm{T_{i,j+1,k}}\right)+\frac{kr_i\Delta\theta\Delta r}{\Delta z}\left(\mathrm{T_{i,j,k-1}}\right)+\mathrm{T_\infty}hr_i\Delta\theta\Delta r}{\frac{2kr_i\Delta\theta\Delta z}{2\Delta r}+\frac{2k\Delta z\Delta r}{2r_i\Delta\theta}+\frac{kr_i\Delta\theta\Delta r}{\Delta z}+hr_i\Delta\theta\Delta r}$$

ii. *At the Fin Surface*

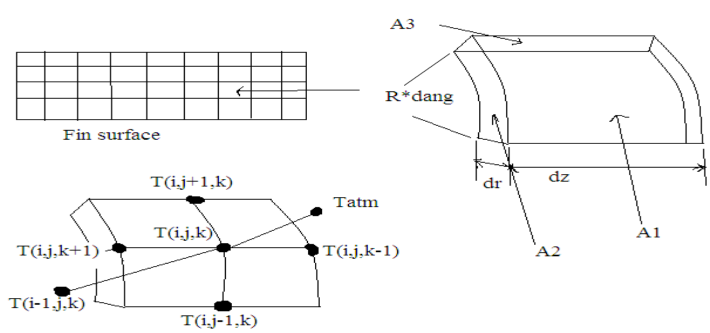

Fig. 6 : Grids at the surface of the fin.

$$-\frac{\mathrm{kr_L}\Delta\theta\Delta z\left(T_{i,j,k}-T_{i-1,j,k}\right)}{\Delta r}-\frac{\mathrm{k}\Delta z\Delta r\left(2T_{i,j,k}-T_{i,j-1,k}-T_{i,j+1,k}\right)}{2\mathrm{r_L}\Delta\theta}-\frac{\mathrm{kr_L}\Delta\theta\Delta r\left(2T_{i,j,k}-T_{i,j,k-1}-T_{i,j,k+1}\right)}{2\Delta z}=\mathrm{hr_L}\Delta\theta\Delta z\left(\mathrm{T_{i,j,k}}-\mathrm{T_\infty}\right)$$

By simplification:

$$\mathbf{T_{i,j,k}}=\frac{\left(\frac{\mathbf{kr_L}\Delta\theta\Delta z\left(T_{i-1,j,k}\right)}{\Delta r}+\frac{\mathbf{k}\Delta z\Delta r\left(T_{i,j-1,k}+T_{i,j+1,k}\right)}{2\mathbf{r_L}\Delta\theta}+\frac{\mathbf{kr_L}\Delta\theta\Delta r\left(T_{i,j,k-1}+T_{i,j,k+1}\right)}{2\Delta z}+\mathbf{T_\infty hr_L}\Delta\theta\Delta z\right.}{\frac{\mathbf{kr_L}\Delta\theta\Delta z}{\Delta r}+\frac{\mathbf{k}\Delta z\Delta r}{\mathbf{r_L}\Delta\theta}+\frac{\mathbf{kr_L}\Delta\theta\Delta r}{\Delta z}+\mathbf{hr_L}\Delta\theta\Delta z}$$

iii. *At the edge of the fin*

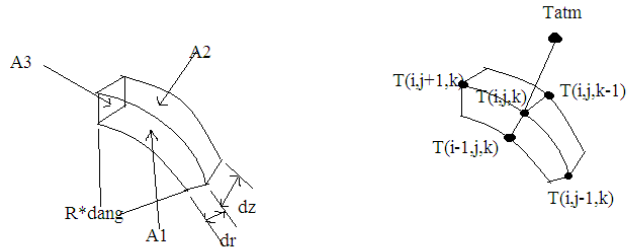

Fig. 7: Grid at the edge of the fin.

$$A1 = (\Delta r/2)(r_l\Delta\theta - \Delta r\Delta\theta/4);\ A2 = \left(\frac{r_l\Delta\theta\Delta z}{2}\right); A3 = (\Delta z\Delta r/4)$$

$$-$$

$$\frac{k * A1(T_{i,j,k} - T_{i,j,k-1})}{\Delta z} - \frac{k * A2(T_{i,j,k} - T_{i-1,j,k})}{\Delta r} - \frac{k * A3(2T_{i,j,k} - T_{i,j-1,k} - T_{i,j+1,k})}{r_L\Delta\theta}$$
$$= h * A1\left(T_{i,j,k} - T_\infty\right) + h * A2(T_{i,j,k} - T_\infty)$$

By simplification:

$$T_{i,j,k} = \frac{\frac{k * A1\left(T_{i,j,k-1}\right)}{\Delta z} + \frac{k * A2\left(T_{i-1,j,k}\right)}{\Delta r} + \frac{k * A3\left(T_{i,j-1,k} + T_{i,j+1,k}\right)}{r_L\Delta\theta} + h * A1 * T_\infty + h * A2 * T_\infty}{\frac{k * A1}{\Delta z} + \frac{k * A2}{\Delta r} + \frac{2k * A3}{r_L\Delta\theta} + h * A1 + h * A2}$$

Fin convective heat transfer from the end:

$$q_f = (hPkA_{cross-section})^{1/2}(T - T_\infty)\frac{\tanh(ml) + (\frac{h}{mk})}{\left(\frac{h}{mk}\right)\tanh(ml) + 1}$$

Convective heat transfer from the fins surface:

$$q_f = \sum h\Delta z(T - T_\infty)$$

Effectiveness of the Fin:

$$\varepsilon_f = \frac{q_f}{hA(T - T_\infty)}$$

Efficiency of the cylindrical fin:

$$\eta_f = \frac{q_f}{hA_{fin}(T - T_\infty)}$$

III. Result and Discussion

The governing three dimentinal differential equation of cylindrical fin was transfomed into linear algebric equations by finite difference methods and these equations were solved by using a program written in FORTRAN language. This code was used to determine the temperatre at each node in the computatinal domain. The material Aluminium, Stainless Steel, Aluminum –Bronze (Alloy), Copper having thermal conductivity (k) 200, 14, 76, 250 and 400 w/m-k respectively were chosen for the analysis of cylindrical fin. The convective coefficient of the surrounding 10 w/sqm-k .The fin base was maintained at a constant base temperature (400°C) 673.15K and the surrounding or ambient fluid temperature was considered at (25°C)298.15K.

For testing the Programe a Referance ^ ([11]) temperature distribution is taken and compared with the result obtained in the figure 8. Similarly another comparison was done for the temperature distribution along the radius. The results are shown in the figure 10.

Variation of effectiveness and effciency due to the variation of material is shown in table 1 and Figure 12 and Figure 13. From the table 1 we can see that copperhas maximum effectiveness and efficiency so it was selected as the material of the fin.

The variation of effectiveness and effciency due to the variation of length and radius is shown in Section 3.1 and Section 3.2 respectively.

At Section 3.3 table 4 shows the changes of effectiveness and efficiency due to change of length and radius simultaneously, thus providing us the optimum dimension of cylindrical fin which is .001m radius and .02m length.

At reference condition: k=206W/m°C, h=17W/sq-m°C, Atmosphere temp=26 °C, Fin base temp=120°C, L=.9m, R=.0127m

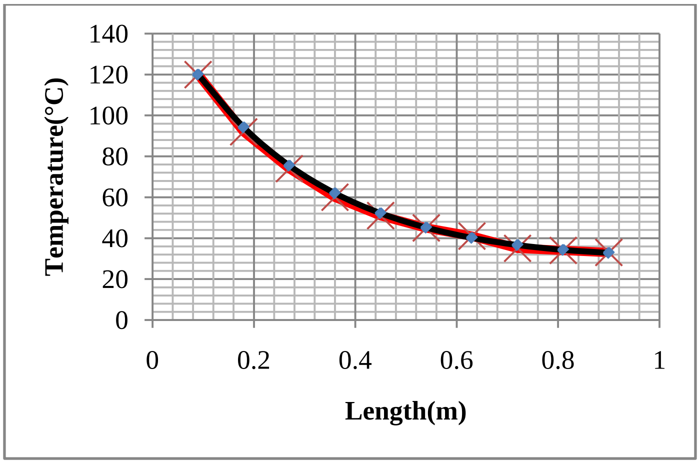

Fig. 8 : Comparison of result with reference [12](red line) to simulation result (black line)

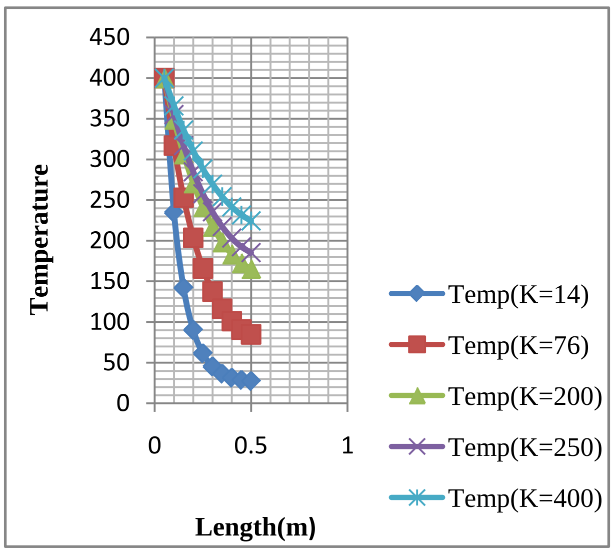

Fig. 9 : Temperature Distribution along the length of the fin at centre line for different Thermal conductivity (w/m-K)

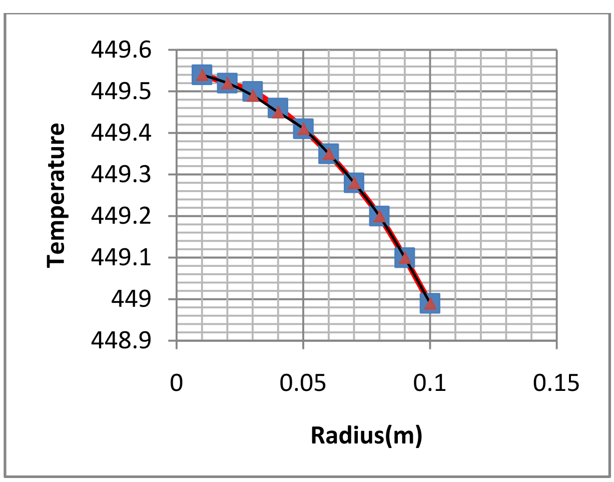

Fig. 10 : Comparison of Temperature distribution along the radius with the Reference[10] (black line) and simulation result (red line)

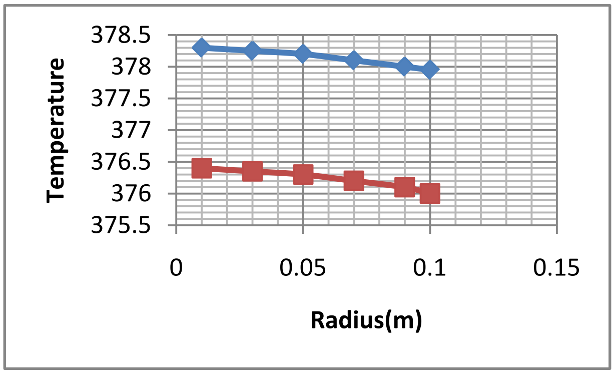

Fig. 11: Comparison of temperature distribution of Copper (blue line) and gold (red line)

Table 1 : Variation of Efficiency and Effectivness with increasing thermal conductivity for same dimension of the fin

Thermal conductivity, k	Efficiency(%)	Effectivness
14	38.0184	15.5875
76	72.098	29.5604
200	84.1667	34.508
250	85.98	35.253
400	88.8646	36.4345

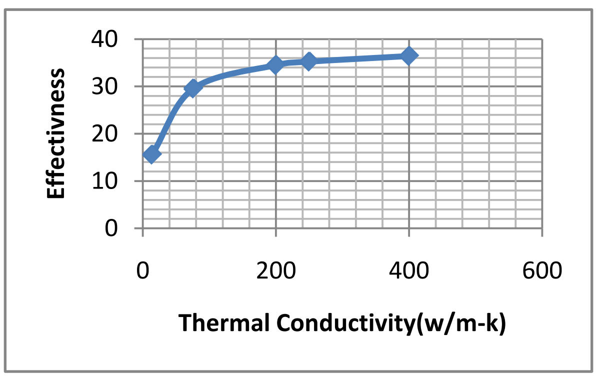

Fig. 12 : Variation of effectivness with thermal conductivity of material

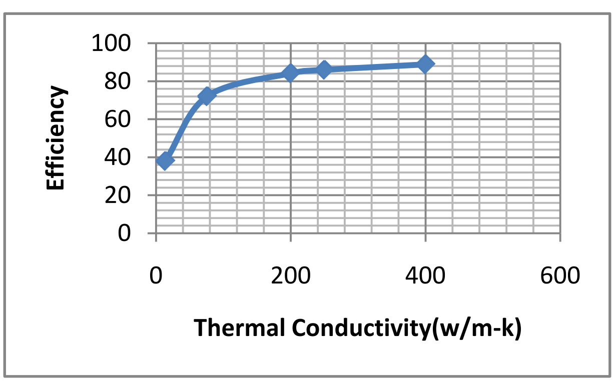

Fig. 13 : Variation of Efficiency with thermal conductivity of material

a) Variation of Effectiveness and Efficiency with variation of Length for fixed Radius

Table 2 : For Copper (k=400 w/m-k)

Length (m)	Radius (m)	Effectiveness	Efficiency(%)
0.02	.01	5.204659	99.6
0.04	.01	9.147603	99.5
0.06	.01	12.92411	99.41621
0.08	.01	16.55999	97.4117
0.1	.01	20.08848	95.65945
0.2	.01	36.4345	88.86464
0.3	.01	50.26515	82.40189
0.4	.01	61.10419	75.43728
0.5	.01	69.24301	68.55745

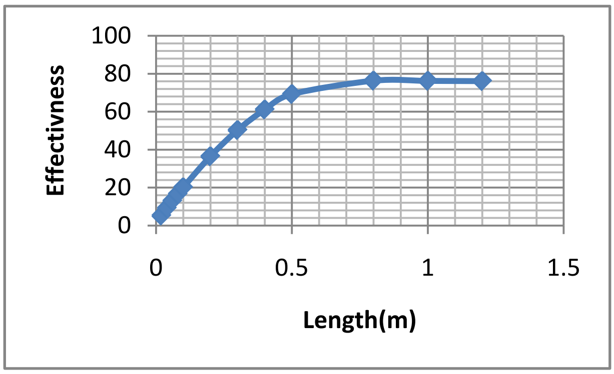

Fig. 14 : Variation of effectivness with variation of length.(copper)

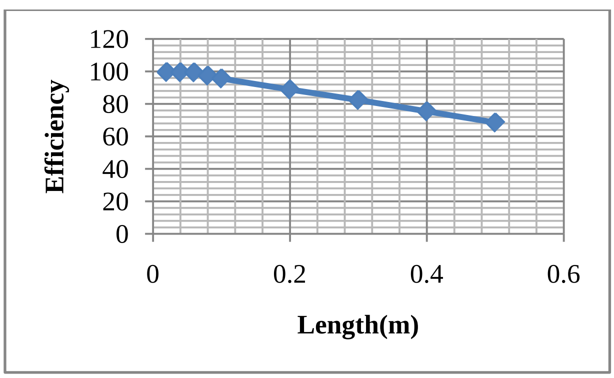

Fig. 15: Variation of efficiency with variation of length.(Copper)

b) Variation of Effectiveness and Efficiency with variation of Radius for fixed length

Table 3 : For Copper (k=400 w/m-k)

Radius (m)	Length (m)	Effectivness	Efficiency(%)
0.008	.5	68.07667	54.0291
0.01	.5	69.24301	68.55745
0.02	.5	40.38728	79.19074
0.04	.5	22.73259	87.43302
0.06	.5	16.20367	91.71889
0.08	.5	12.75182	94.4579
0.1	.5	10.59521	96.32011

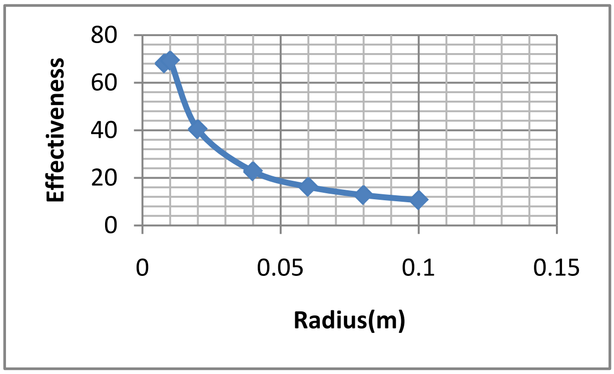

Fig. 16: Variation of Effectivness with variation of radius. (Copper)

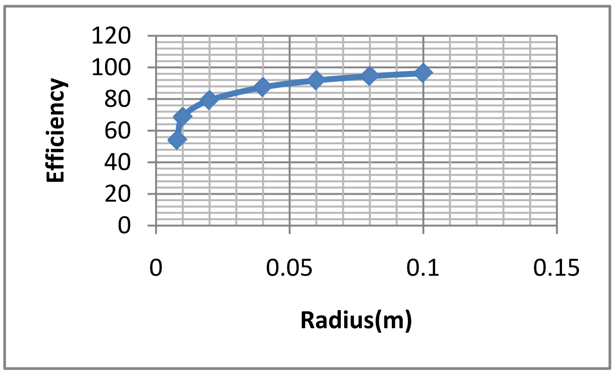

Fig. 17: Variation of Efficiency with variation of radius.(Copper)

c) *Variation of Effectiveness and Efficiency for Different Fin Dimension*

Table 4 : For Copper(k=400 w/m-k)

Radius (m)	Length (m)	Effectivencess	Efficiency(%)
.02	.2	19.76635	94.12550
.002	.03	29.323790	94.592873
.001	.02	38.379875	93.609459
.003	.04	26.2769	94.977020

From this table the optimum dimensions can be easily found. The one having the maximum effectiveness and maximum effciency. Though the 3rd result has minimum effciency but it has the maximum effectiveness. The daviation of efficiency is not very large so the 3rd result is selected as the optimum dimension.

IV. Conclusion

From the above information and comparison it's been observed that the optimum dimension for the conditions assumed is a fin having .02m of length and .001m of radius. This fin gave the maximum effectiveness and efficiency for the assumed condition. But the results can vary according to the change of condition, which were assumed to be constant for the purpose of the simplification of the whole process. Material having higher conductivity can be used to get more higher effectiveness and efficiency, but for simplification Copper is selected as the optimum material for the fin.

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Nomenclature

Symbol	Meaning	Unit
q_f	Heat transfer rate from the fin	(watt)
A_c	Cross-section area of fin	(sq-m)
K	Thermal conductivity	(W/m-°C)
T(i,j,k)	Temperature At a point	(°C)
r_i	Radius at i-th circle	(m)
Δr	Radius of small element	(m)
$\Delta\theta$	Angle of small element	(radian)
Δz	Length of small element	(m)
T_∞	Ambient Fluid Temperature	(°C)
r_l	Maximum radius	
		(m)
L	Maximum length of fin	
		(m)
ε_f	Fin effectiveness	
		Dimensionle
η_f	Fin efficiency	Dimensionle
		(sq-m)
A_{fin}	Fin Surface area	
		(watt)
q_{max}	Maximum heat transfer if th	
	Index along radial direction	
i		Dimensionle
	Index along angular directio	
	Index along length direction	Dimensionle
j		Dimensionle
	Fin perimeter (m)	
k		(m)
	Heat transfer from fin base	
p		(watt)
q_b		

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Optimization of Diesel Engine Parameters for Performance, Combustion and Emission Parameters using Taguchi and Grey Relational Analysis

By M, Shailaja & A V Sitarama Raju
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Abstract- Design and operating parameters of diesel engine were optimized in the present work with respect to performance, combustion and emission parameters. The goal is to reduce brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), ignition delay (ID), emissions (CO, NOx, HC) and to increase peak pressure (PP), brake thermal efficiency (BTHE), heat release (HR) simultaneously with least number of experimental runs. The objective was accomplished through experimental investigations, design of experiments, Taguchi method and Grey Relational Analysis. Four parameters viz. injection timing (IJT), injection pressure (IP), compression ratio (CR) and load were varied at four levels and the (nine) responses were recorded. Taguchi approach was applied to individual response and observed that optimal factor settings for various responses are different.

Keywords: diesel engine, performance parameters, combustion parameters, emission parameters, taguchi approach, signal to noise ratio, grey relational approach.

GJRE-A Classification : FOR Code: 290501p

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Strictly as per the compliance and regulations of:

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M, Shailaja [α] & A V Sitarama Raju [σ]

Abstract- Design and operating parameters of diesel engine were optimized in the present work with respect to performance, combustion and emission parameters. The goal is to reduce brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), ignition delay (ID), emissions (CO, NOx, HC) and to increase peak pressure (PP), brake thermal efficiency (BTHE), heat release (HR) simultaneously with least number of experimental runs. The objective was accomplished through experimental investigations, design of experiments, Taguchi method and Grey Relational Analysis. Four parameters viz. injection timing (IJT), injection pressure (IP), compression ratio (CR) and load were varied at four levels and the (nine) responses were recorded. Taguchi approach was applied to individual response and observed that optimal factor settings for various responses are different. Grey relational approach (by assigning weighting factor for each response) was applied to solve multi objective optimization problem. The optimal combination of factors was obtained as injection timing 28^0 bTDC, injection pressure 180 bar, compression ratio 19 and load 80% full load and load was observed to be most influential factor among the four with a contribution of 70.37%. The model developed was validated by confirmation test and found good agreement between predicted and experimental values of responses.

Keywords: diesel engine, performance parameters, combustion parameters, emission parameters, taguchi approach, signal to noise ratio, grey relational approach.

I. Introduction

There is a huge demand for diesel engines in industrial, agricultural and automotive sector. The advantages of diesel engines over gasoline engines are fuel economy, high thermal efficiency, low CO_2 emissions, ruggedness, flexibility to operate at higher compression ratio and so on. However, faster depletion of fossil fuels and environment pollution demand the engine designers to take control over fuel economy and emissions. Much research has been carried out to tackle these problems. Various investigators attempted to optimize engine design and/or operating parameters with respect to performance, combustion and emission parameters to control fuel economy or emissions. Diverse numerical and statistical techniques are available for optimization; however, some offer single objective optimization and some other multi objective. The benefit of multi objective or multivariate optimization over single objective optimization is that influence of factors on multiple responses can be assessed and studied.

a) Design of experiments

Most processes depend on some controllable factors. Similarly, performance, combustion process and emissions of a diesel engine , depends on design parameters like injection timing, injection pressure, compression ratio, engine size, type of combustion chamber and operating parameters such as load, intake temperature and pressure of air, speed, air-fuel ratio etc. To realize the effect of control factors on responses like; performance, combustion and emission parameters, a series of experiments are to be run. Experiments are to be well designed for generating more significant information within fewer runs to evaluate the important effects, rather than employing unplanned experiments. Design of Experiments (DOE) offer systematic investigation of the control factors that influence the responses. Common methods in DOE are hit and miss, one factor at a time, full factorial, fractional factorial etc. Fractional factorial method has advantage of less number of experiments without loss of much information and adopted in the present work. The four phases involved in DOE are planning, screening or process characterization, optimization and verification. Planning includes defining the problem and objective, followed by development of experimental plan which provides all significant information. Screening or process characterization comprises of selection of factors which are really important, or the vital few. Various methods are available for screening but most widely used is fractional factorial method. In fractional factorial method, only a selected subset or fraction of runs in the full factorial design is performed. Optimization is the phase where best or optimal values of control factors are determined by various techniques available. Verification is the phase in which optimal factor values after

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prediction are tested for confirmation of results. In planning phase, factors, levels and responses are chosen and orthogonal arrays are formed, which were originally developed by Sir R.A. Fisher and later added by Taguchi. Experiments are conducted based on orthogonal arrays and analysed based on Signal to Noise Ratio (SNR). Signal to Noise Ratio (SNR) measures the variation of response relative to nominal or target value. Two types of SNR used in the present work; smaller the better and larger the better.

When the response is to be minimized, 'smaller the better' SNR is appropriate and is computed using the Eq. 1 while 'larger the Better' SNR is apt for the maximizing response applying the Eq. 2.

$$SNR_S = -10\log\frac{1}{n}\left\{\sum_{i=1}^{n} y_i^2\right\} \quad (1)$$

$$SNR_L = -10\log\frac{1}{n}\left\{\sum_{i=1}^{n}\left(\frac{1}{y_i^2}\right)\right\} \quad (2)$$

Where y_i is the response from ith experiment and i=1, 2 ...n. After SNRs are evaluated, main effect plot for SNRs are drawn to find optimal values of the factors. ANOVA is performed to explore and model relationship between responses and factors and relative percentage contribution of factors on response.

Numerous studies have been carried out to study the effect of IJT, IP, CR and load of the engine on performance, combustion and emission parameters [1-5]. For better performance, the engine should be operated at a set of optimal design and operating parameters. Optimization with the help of orthogonal arrays was proposed by Taguchi [6] in which optimum set of factors is determined for each response with the help of (Signal to Noise Ratio) SNR. Taguchi method has been applied successfully for numerous problems in various fields of science and technology. Diesel engine parameters are not an exception for it. A brief review of research carried is following.

T. Ganapathy et al.[7] used Taguchi method to optimize ten operating and design variables of diesel engine for maximum brake thermal efficiency, peak pressure, temperature, IMEP, BMEP and reported improvement in above said parameters at optimal condition obtained by Taguchi approach. Horng-Wen Wu et al. [8] reported that Taguchi method is good to find optimal operating parameters for high brake thermal efficiency and low BSFC, NO_x and smoke. Kaliamoorthy.S et al.[9] employed Taguchi method to optimize power, static injection timing, fuel fraction and compression ratio for best values of brake power, fuel economy and emissions and reported that confirmation tests showed good agreement with predicted values of parameters. Karthikeyan. R et al. [10] from their work concluded that Taguchi method of optimization efficiently predicted optimum level of parameters and found satisfactory results at optimum setting. The inference from the work of Vincent H. Wilson et al.[11] confirmed that Taguchi method is efficient in predicting range of optimum settings of valve opening pressure, piston to head clearance volume, static injection timing, area of the spray nozzle hole and load for best values of NO_x emissions and brake specific fuel consumption.

Even though Taguchi method proved as one of the best methods for optimization, its major limitation is inability to tackle multi objective optimization. This drawback is trounced by application of grey relation analysis and Taguchi method collectively. Grey relational analysis, proposed by Deng in 1982, which is commonly used for assessing the degree of correlation between sequences by grey relational grade. In this analysis, responses are normalized (between zeros to one) which is known as grey relational generation. Grey relational coefficient is calculated using normalized data of responses. Grey relational coefficients of all the responses is averaged to get overall grey relational grade. The calculation of grey relational grade converts multi variant optimization problem into single response optimization, overall grey relational grade being objective function. By maximizing the overall grey relational grade the optimal parametric combination is evaluated. Some research work is also reported regarding use of grey relational analysis in conjunction with Taguchi method.

The results of research done by Ashish Karnwal et al.[12] emphasized that Taguchi method coupled with grey relational analysis can be used successfully for exploration of multiple-performance variables of diesel engine. In their work, biodiesel blend, compression ratio, opening pressure of nozzle and injection timing are optimized for best values of brake thermal efficiency, brake specific energy consumption and exhaust gas temperature of diesel engine. In a study carried out by Sumit Roy et al. [13] optimization of CNG energy share and fuel injection pressure for lowest values of BSFC, NO_x and HC done successfully.

Goutam Pohit et al.[14] reported effective optimization of biodiesel blend, compression ratio and load for better values of performance and emission parameters by grey relational analysis and supported by confirmatory experiments. Optimization of speed of the engine, load and type of fuel for better values of performance and emissions was prolifically done by M. I. Masood et al. [15] by means of grey Taguchi method and confirmatory test by artificial neural networks showed best validation. Taguchi method along with grey relational analysis and ANOVA was able to identify the order of significance/ contribution of each of the parameters (injector opening pressure, fuel injection timing and compression ratio) on BTHE, BSFC and emissions, further they reported that confirmation test

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results were in good agreement with predicted values [16]. Similar results were also reported by some other investigators [17, 18,].

b) Motivation and Objectives

As per available literature, most of the research work pertaining to diesel engine parameters was concentrated on either of performance or emission parameters or both. However, so far no work was reported on optimization for parameters of combustion like peak pressure, ignition delay, and heat release together with performance and emission parameters. Hence, objective of present work is to spot out optimal values of design and operating parameters of diesel engine, which would maximize brake thermal efficiency, peak pressure, and heat release and to minimize BSFC, exhaust gas temperature, ignition delay and emissions simultaneously.

In the present work Taguchi method and grey relational analysis are used for optimization. Taguchi analysis results shows order of factors influencing particular response in the form of ranks. Hence, ANOVA (Analysis of variance) is used to find the percentage contributions of IJT, IP, CR and load on response parameters.

II. Materials and Methods

a) Experimental setup

Experiments were carried out on a 4-s single-cylinder, water cooled direct injection, variable compression ratio diesel engine. The specifications of the engine are presented in Table1.and layout of engine in Fig. 1.

Table 1 : Specifications of Engine.

Engine Type	Kirloskar
Number of cylinders	Single(01)
Combustion	Direct injection
Bore	80 mm
Stroke	110 mm
Compression Ratio	Variable (15-20)
Rated Speed	1500 rpm
Power	5 hp
Type of cooling	Water cooling
Fuel injector opening pressure	200 bar
Fuel injection timing	22° before TDC
Type of loading	Electrical loading

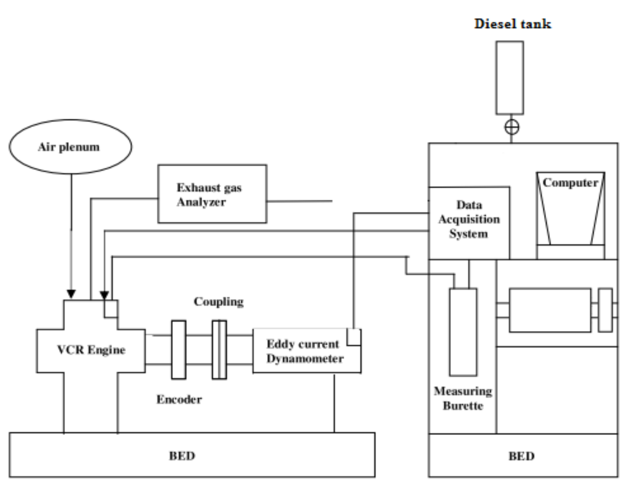

Fig. 1 : Engine setup

The engine is attached to an eddy current dynamometer with speed sensing unit incorporated. PCB (USA) make piezo - electric transducer is flush mounted in the cylinder head and used to measure cylinder pressure. An optical encoder is employed to capture the rpm of the crank shaft. Data acquisition system with high speed is used for acquisition and analysis of pressure crank angle data is done by software. To eliminate effect of cycle to cycle variation, pressure crank angle data for 100 consecutive cycles is recorded and averaged. Parameters are calculated using averaged data. Software calculates and displays performance and combustion parameters from the recorded observations. Each experiment was conducted four times and values are averaged to avoid errors. Emissions are measured by a gas analyzer; specifications are presented in Table 2.

Table 2 : Specifications of 5-gas analyzer Indus make.

Exhaust gas	Measurement Range	Resolution	Accuracy	Measuring Method
CO	0-15.0% vol	0.01% vol	+ 0.06% vol	NDIR
HC	0-30000 ppm (Propane) 0-15000 ppm (Hexane)	1 ppm vol	+ 12ppm	NDIR
NO_x	0-5000 ppm	1 ppm vol	+ 50% vol	Electrochemical

III. Methodology

The factors considered in the present work are injection timing, injection pressure, compression ratio and load. Each factor is varied at 4-levels as presented in Table 3.

Table 3 : Factors and their levels

Factors	Level 1	Level 2	Level 3	Level 4
Injection Timing (°bTDC)	20	22	24	26
Injection Pressure (bar)	180	200	220	240
Compression Ratio	15	16.5	18	19
% of Full Load	22	40	60	80

The Taguchi method employs orthogonal arrays from theory of DOE to learn the effect of huge number of controllable factors on responses inside a small experimental matrix. Use of orthogonal arrays notably reduce the number of experiments in view of the fact that it provides the shortest possible matrix in which all factors are varied over working range. Furthermore, the conclusions from this shortest number of experiments are valid over entire range. L_{16} orthogonal array is prepared from Taguchi's design with four factors and four levels as presented in Table 4.

Table 4 : Orthogonal array for experimental data

S.No	Injection Timing(°bTDC)	Injection Pressure (bar)	Compression Ratio	% Full Load
1.	22	180	15	20
2.	22	200	16.5	40
3.	22	220	18	60
4.	22	240	19	80
5.	24	180	16.5	60
6.	24	200	15	80
7.	24	220	19	20
8.	24	240	18	40
9.	26	180	18	80
10.	26	200	19	60
11.	26	220	15	40
12.	26	240	16.5	20
13.	28	180	19	40
14.	28	200	18	20
15.	28	220	16.5	80
16.	28	240	15	60

Interaction among the factors was neglected because all are independent. Motivation for selection of response variables is, to make the present work significant to the existing studies of focussing all-pervading performance, combustion and emission parameters that confront the contemporary diesel engine design.

Experiments were conducted as per L_{16} orthogonal array presented in Table 4. Compression ratio was varied with the help of a lever attached to the cylinder head. Number of shims was adjusted under the seat of the mounting flange of fuel pump to alter static injection timing. It was noted that, addition of shims retards fuel injection timing and vice versa. Injection pressure was measured and adjusted using an injector opening pressure test rig. It comprises of a pipe to connect to the injector and a fuel reservoir. Spring tension of the nozzle is varied by adjusting screw on the injector to vary the pressure.

Various performance parameters considered in the present work are brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE) and exhaust gas temperature (EGT). Low values of BSFC and EGT are preferable whereas high value of BTHE is preferable. BSFC and BTHE were calculated and EGT was recorded from display.

Combustion parameters studied in the present work are ignition delay (ID), peak pressure (PP) and Heat release (HR).The time interval between start of injection (CAD at which fuel injection starts) and start of combustion (CAD at which combustion starts) in diesel engines is called ignition delay period [19] . It may be expressed in terms of CAD (crank angle degrees) or milliseconds. From p-θ data, CAD is noted, where positive values of heat release (start of combustion) is observed and ignition delay was calculated as difference between CAD of start of combustion and start of injection.

Peak pressure is the maximum cylinder pressure attained during combustion process very near to and after TDC and is taken from p- θ data. Heat release is the amount of heat released during combustion process. According to Heywood [19], combustion continues well into the expansion stroke up to 31°. HR is taken as the sum total of HR per CAD from start of combustion to significant positive values of HR per CAD.

NO_x, CO and HC are the emissions considered in this work for analysis and are measured using exhaust gas analyser (details are presented in Table.2)

a) Taguchi Method

Taguchi approach employs the parameter SNR (Signal to Noise Ratio) for optimization. Largest value SNR is preferred as it indicates minimized effects of noise factors. SNRs are calculated by formulae mentioned in section 1.2 based on criteria smaller the better or larger the better. Larger the better criteria is used for brake thermal efficiency, peak pressure, and heat release whereas smaller the better criteria is used for BSFC, exhaust gas temperature, ignition delay, CO, NO_X and HC. In the present work Minitab software is used for Taguchi design, SNR calculations, main effects plots and performing ANOVA. After computation of SNRs, main effect plots for SN Ratios are plotted by taking data means. The SNRs for different responses were calculated at each factor level. The average effects were calculated by taking sum total of each factor level and then dividing by number of data points.

In view of the fact that Taguchi approach results in different optimal conditions for various responses, overall optimal condition cannot be figured out. Hence in the present work grey relational analysis is also carried out for multi objective optimization.

b) Grey Relational Analysis

The degree of approximation among the sequences is measured using a parameter called grey relational grade in grey relational analysis. In grey relational analysis, the responses are normalized between zero and 1. This process is known as grey relational generation. Normalized data for lower the better criteria can be calculated by Eq.3 and for higher the better by Eq. 4.

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (3)$$

$$x_i(k) = \frac{y_i(k) - \max y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (4)$$

Where $y_i(k)$ is the original sequence (response from experiments) , $x_i(k)$is the sequence

for comparison (normalized value of response) and i=1,2,....,m and k= 1,2,....,n; m is total number of experiments and n is total number of responses. min $y_i(k)$and max $y_i(k)$are lowest and highest values of $y_i(k)$respectively.

Next, deviational sequences Δ_{oi} for responses are calculated from Eq.5.

$$\Delta_{oi} = | x_0(k) - x_i(k) | \quad (5)$$

where $x_0(k)$ was an ideal sequence.

GRC (Grey relational coefficient) $\xi_i(k)$ for each response is calculated to represent the correlation between the desired responses and actual experimental data using Eq. 6 .

$$\xi_i(k) = \frac{\Delta_{\min} + \psi \Delta_{\max}}{\Delta_{oi}(k) + \psi \Delta_{\max}} \quad (6)$$

Δ_{min} and Δ_{max} are the minimum and maximum values of the absolute differences of all comparing sequences. ψ is the distinguishing coefficient and it lies in the range $0 \leq \psi \leq 1$. Value of distinguishing coefficient is taken as 0.5 for all responses [20, 21].

Subsequent to calculation of grey relational coefficients grey relational grade γ_k is calculated for each response by assigning appropriate weighting factor β_i. Weighting factor is assigned to a particular response, based on their relative significance, and the sum of weighting factors must be equal to unity [22]. In the present work weighting factor 0.2 is assigned for brake thermal efficiency and 0.1 for all other responses.

A grey relational grade is a weighted sum of the grey relational coefficients, and is calculated using Eq. 7.

$$\gamma_k = \sum_{k=1}^{n} \xi_i(k)\beta_i \tag{7}$$

For k^{th} response variable, where γ_k is grey relational grade, $\xi_i(k)$ is distinguishing coefficient, β_i is weighting factor. Closeness of particular response with optimal value is given by higher value of grey relational grade.

This study uses L_{16} orthogonal array of Taguchi method mentioned in Table 4 to find out best Injection timing, injection pressure, compression ratio and load setting for diesel engine. At four levels of each factor, the responses viz. BSFC, brake thermal efficiency, peak pressure, and heat release, exhaust gas temperature, ignition delay, CO, NO_X and HC are determined.

IV. Taguchi Results Analysis and Confirmation Experiments

SNR curves are graphical representations of variation in responses with variation in factor levels. From these curves two observations are noted. First one is most influential parameters and second is their optimum levels. After taking average of SNRs at four levels of particular factor, plots are drawn for means of SNRs Vs factor level. Fig. 2 (a) to 2(i) show such plots for all 9 response variables. Level with highest value of mean SNR is considered as optimal value.

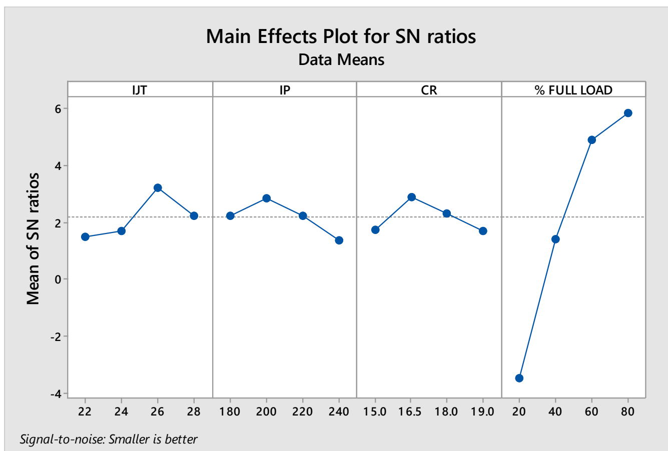

Fig. 2 (a) : Main effects plot for SNR of BSFC

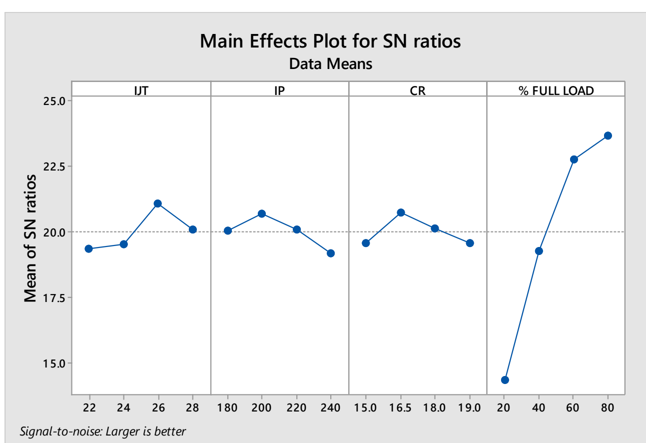

Fig. 2 (b) : Main effects plot for SNR of BTHE.

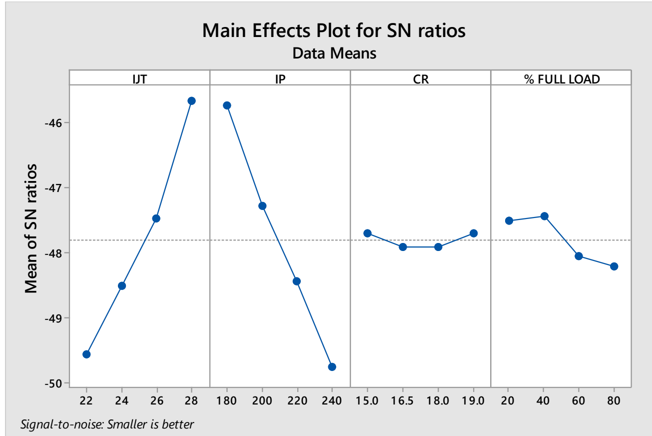

Fig. 2 (c) : Main effects plot for SNR of EGT

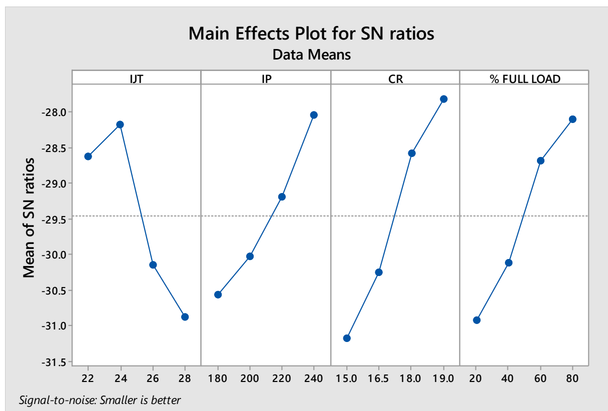

Fig. 2(d) : Main effects plot for SNR of Ignition Delay

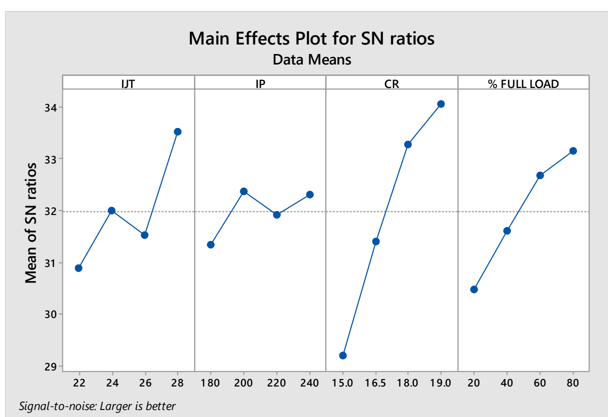

Fig. 2(e) : Main effects plot for SNR of Peak Pressure

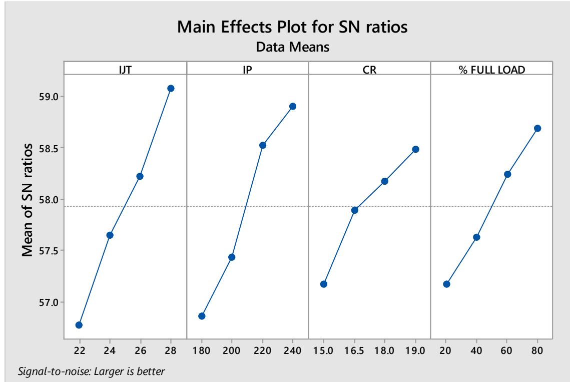

Fig. 2 (f) : Main effects plot for SNR of Heat Release

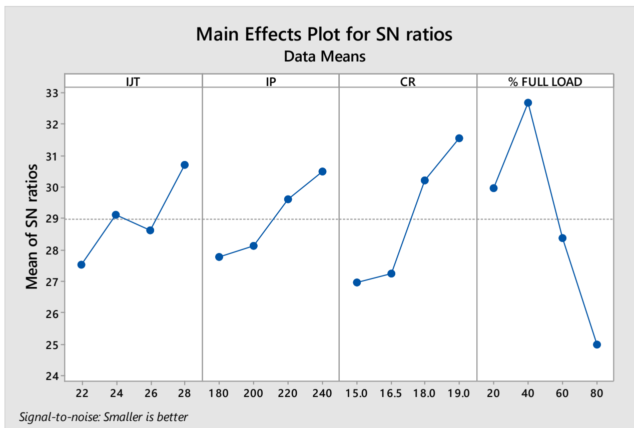

Fig. 2 (g) : Main effects plot for SNR of CO

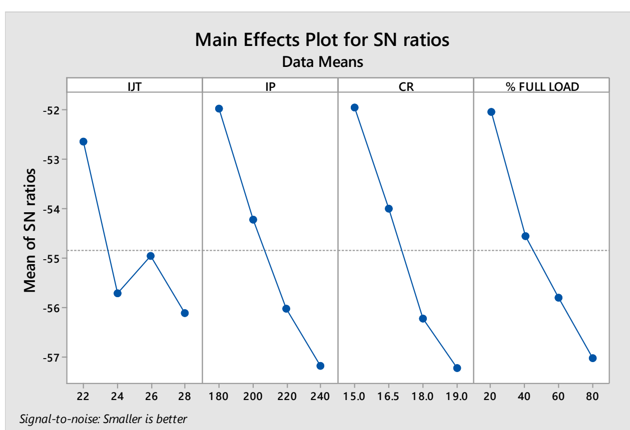

Fig. 2 (h) : Main effects plot for SNR of NOx

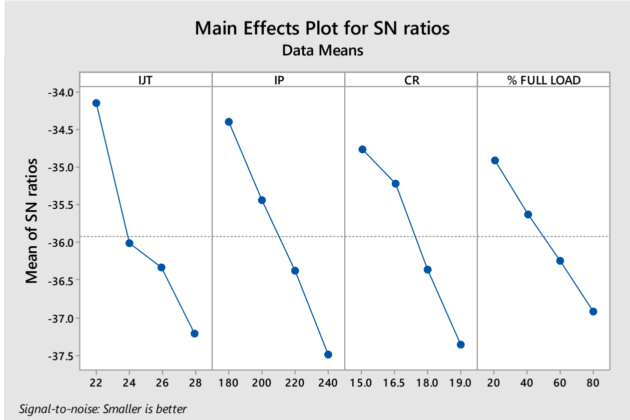

Fig. 2 (i) : Main effects plot for SNR of HC

Table 5 presents optimal settings of factors for various responses. It is evident from Table 5 that different set of factor values lead to optimal values of different responses.

Table 5 : Optimum factor settings from SNR analysis

Controlled Factors	BSFC (kg/kW-hr)	BTHE (%)	EGT (^{0}C)	PP (bar)	ID (CAD)	HR (J)	CO (% by vol)	NOx (ppm)	HC (ppm)
IJT (degrees BTDC)	26	26	28	28	24	28	28	22	22
IP (bar)	200	200	180	240	240	240	240	180	180
CR	16.5	16.5	19	19	19	19	19	15	15
% of Full Load	80	80	40	80	80	80	40	20	20

Experiments were conducted at optimal set of conditions as mentioned in Table 4 and corresponding responses were recorded. The values of responses at optimal settings from Taguchi analysis are compared with that of baseline engine and presented in Table 6.

Table 6 : Comparison of base line engine experiments with optimized engine experiments

	BSFC (kg/kW-hr)	BTHE (%)	EGT (^{0}C)	PP (bar)	ID (CAD)	HR (J)	CO (% by vol)	NOx (ppm)	HC (ppm)
Baseline Engine	0.41	18.95	253	40.9	20	817.74	0.0632	651	62
Optimized Engine	0.37	21.63	139	69.4	14	1185.68	0.0101	153	32

It is observed from Table 6 that the parameters BSFC, EGT, ID, CO, NOx and HC shown significant decrease for optimized engine compared to baseline engine and is represented in Fig. 3(a), whereas the parameters BTHE, PP and HR shown significant increase for optimized engine compared to baseline engine and is represented in Fig. 3(b).

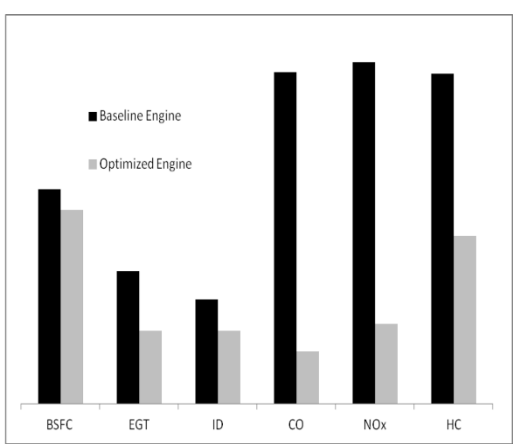

Fig. 3(a) : Comparison of parameters (to be minimized) between baseline engine and optimized engine

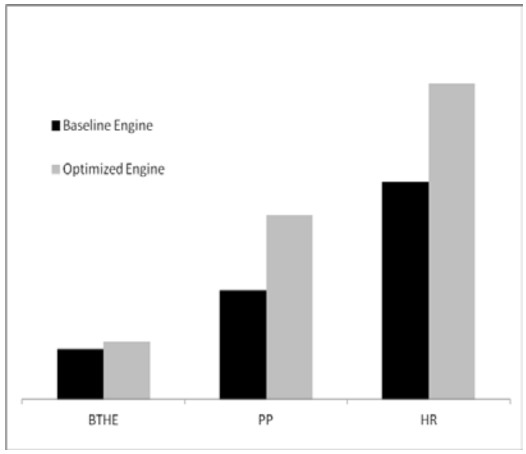

Fig. 3 (b) : Comparison of parameters (to be maximized) between baseline engine and optimized engine

To validate Taguchi model, SNR and response value for a set of factors can be predicted and experiments are conducted at the same factor settings to get response value and compared. Confirmation tests are conducted at different sets of factor settings for each response variable and values are recorded. A comparison between predicted values and experimental values of responses is presented in Table 7 and good agreement between Taguchi prediction and confirmation tests is observed.

Table 7 : Comparison between Taguchi prediction and confirmation test values.

S.No	Response Variable	Taguchi Prediction value	Confirmation test value	% Difference between prediction and confirmation test
1	BSFC (kg/kW-hr)	0.455688	0.42	-8.49714
2	BTHE (%)	15.26	16.2	5.802469
3	EGT (^{0} C)	229.75	228	0.7617
4	PP (bar)	45.5812	44.4	-2.66036
5	ID (CAD)	23.43	22.3	-5.06726
6	HR (J)	606.519	623.6	2.739096
7	CO (% by vol)	0.05948	0.0622	4.37299
8	NO_X (ppm)	653.875	596	-9.71057
9	HC(ppm)	58.875	55	-7.04545

a) Grey Relational Analysis Results

Taguchi approach, even though resulted in optimal values of responses, factors are optimized one at a time (single objective optimization) and for various responses different factor settings were obtained. To overcome this problem with Taguchi approach, grey relational analysis with Taguchi approach was carried out for multi objective optimization.

Initially responses were normalized based on higher the better or smaller the better criteria and deviation sequences were calculated. Grey relational coefficients are calculated using Eq. 6 and grey relational grades for responses were calculated using Eq. 7 by assigning appropriate weights and are presented in Table 8.

Table 8 : Grey relational coefficients and grey relational grades

Weights	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
S.No	BSFC	BTHE	EGT	PP	ID	HR	CO	NOX	HC	GRG
1	0.3349	0.3335	0.5812	0.3333	0.3333	0.33333	0.3862	1	1	0.496937
2	0.6266	0.4428	0.4583	0.4667	0.4366	0.39108	0.5544	0.6316	0.6986	0.514963
3	0.9098	0.7494	0.3952	0.5965	0.6889	0.49505	0.6005	0.4142	0.4857	0.608461
4	0.8868	0.7146	0.3333	0.905	1	0.63613	0.4766	0.3333	0.3333	0.633373
5	0.986	0.9701	0.616	0.5022	0.5636	0.43081	0.3951	0.5825	0.5604	0.657692
6	1	1	0.52	0.4555	0.5254	0.44138	0.3333	0.4816	0.4857	0.624302
7	0.3333	0.3333	0.4617	0.6387	0.6078	0.52241	0.7994	0.4029	0.4016	0.483446
8	0.5402	0.4008	0.3965	0.6765	0.6889	0.57478	0.8957	0.3389	0.3778	0.529082
9	0.9591	0.8628	0.6552	0.7708	0.5254	0.53367	0.3868	0.4307	0.4359	0.642322
10	0.9098	0.7559	0.5812	1	0.5636	0.57663	0.5753	0.3863	0.3835	0.6488
11	0.7622	0.5481	0.5576	0.3773	0.4026	0.49044	0.6336	0.5825	0.4766	0.537909
12	0.4879	0.3803	0.4634	0.4148	0.4247	0.53775	0.6322	0.5119	0.4359	0.466896
13	0.6812	0.479	1	0.8956	0.4247	0.52378	1	0.4448	0.4016	0.632967
14	0.4983	0.3841	0.7792	0.7377	0.4133	0.51787	0.6927	0.5342	0.4286	0.536988
15	0.945	0.8381	0.601	0.8147	0.4627	1	0.398	0.3549	0.3669	0.661939
16	0.7231	0.5095	0.52	0.5651	0.4493	0.75654	0.6005	0.3998	0.3517	0.538499

The average of grey relational grade for each level of factor is calculated and tabulated in Table 9.

Table 9 : Average values of GRG

LEVELS	IJT	IP	CR	% FULL LOAD
1	0.563433	**0.607479**	0.549412	0.496066
2	0.57363	0.581263	0.575372	0.55373
3	0.573982	0.572939	0.579213	0.613363
4	**0.592598**	0.541962	**0.599646**	**0.640484**
Delta	0.029165	0.065517	0.050235	0.144418
Rank	4	2	3	1

The grey relational grade signifies the correlation between the reference sequence and comparability sequence, higher value of grey relational coefficient indicates stronger correlation. From Table 9. it is concluded that optimal factor setting is 4th level of IJT i.e. 28^{o} bTDC, 1st level of IP (180 bar), 4th level of both CR and % full load i.e. 19 and 80% full load respectively.

To validate the model developed for optimize factor settings for maximum value of GRG prediction was carried at IJT 24^{0} bTDC, IP 200 bar, CR 16.5 and at 40% full load. GRG for prediction was 0.556263 where as confirmation test by experimentation at the above factor settings was 0.551443. Further, from Table 9. it is reported that most influencing factor is % full load whereas least one is injection timing. However, relative importance of factors on responses quantitatively must be known for accurate determination of optimal factor setting, which can be accomplished by ANOVA.

b) Analysis of Variance

The objective of Analysis of Variance (ANOVA) is to explore most influential parameter (factor) that effect response, quantitatively. ANOVA is carried out using MINITAB software and results are presented in Table 10.

Table 10 : ANOVA results grey relational grade

Factor	Degrees of Freedom	Adjusted Sum Square	Mean sum Square	F-Value	P-Value	Contribution
IJT	3	0.001772	0.000591	0.33	0.805	2.51%
IP	3	0.008746	0.002915	1.64	0.347	12.37%
CR	3	0.005107	0.001702	0.96	0.513	7.22%
% FULL LOAD	3	0.049758	0.016586	9.34	0.050	70.37%
Error	3	0.005325	0.0017775			7.53%
Total	15					100.00%

From ANOVA results it is reported that load is the most influential parameter (70.37%) where as injection pressure, compression ratio and injection timing influence in the order is 12.37%, 7.22% and 2.51%.

V. Conclusions

In this paper, optimal engine design and operating parameters viz. injection timing, injection pressure, compression ratio and % full load were determined for (nine) multiple response parameters (brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, peak pressure, ignition delay, heat release, CO, NOx and HC) by using Taguchi and grey relational analysis. 16 experiments were conducted as per L_{16} orthogonal array.

As Taguchi approach can handle single objective optimization problem optimal factor settings for each of nine parameters was explored separately, however it was observed that for various response parameters optimal factor settings were different. Hence authors attempted multi objective/variant optimization by using grey relational approach coupled with Taguchi approach. The grey relational analysis by assigning weighting factors, converts optimization of multi response problem into optimization of single objective i.e. grey relational grade. By using grey relational analysis coupled with Taguchi approach optimal factor settings reported were 28^0 bTDC injection timing, 180 bar injection pressure, 19 compression ratio and 80% of the full load and load was observed to be most influential parameter. To validate the model developed for multi objective optimization confirmation test were conducted and compared with prediction and the results were satisfactory. Further ANOVA was carried out to explore relative influence of factors on responses and relative contribution of load was reported as 70.37%. Thus the relationship between the diesel engine design and operating parameters with performance, combustion and emission parameters could be better understood using Taguchi and grey relational method.

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The Design and Construction of a Step Grate Incinerator

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Abstract- This paper presents the design and fabrication of an incinerator meant to thermally treat (i.e. combust) domestic waste for the purpose of reducing its volume and destroying hazardous substances or pathogens present in the waste. A step grate package incinerator with a capacity of 100 kg/day was designed and constructed to combust domestic solid waste which otherwise cannot be economically recycled. The mass balance of the equipment was done to determine the amount of combustion air needed to completely burn the waste; likewise the heat balance was done to determine if an auxiliary burner would be needed. The performance test carried out on the waste – plastic, paper, rubber, leather, textile, wood and garbage – reveal a percentage decrease in volume between 78% – 95%.

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THEDESIGNANDCONSTRUCTIONOFASTEPGRATEINCINERATOR

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Olisa, Y. P. [α], Amos, A. E. [σ] & Kotingo, K. [ρ]

Abstact- This paper presents the design and fabrication of an incinerator meant to thermally treat (i.e. combust) domestic waste for the purpose of reducing its volume and destroying hazardous substances or pathogens present in the waste. A step grate package incinerator with a capacity of 100 *kg/day* was designed and constructed to combust domestic solid waste which otherwise cannot be economically recycled. The mass balance of the equipment was done to determine the amount of combustion air needed to completely burn the waste; likewise the heat balance was done to determine if an auxiliary burner would be needed. The performance test carried out on the waste – plastic, paper, rubber, leather, textile, wood and garbage – reveal a percentage decrease in volume between 78% – 95%.

Keywords: combustion, waste management, incineration, solid waste, mass and heat balance.

I. Introduction

The efficient management of solid waste is very important to public health and well-being of urban residents(Ernst, 2008). In most cities in the developing world, several tons of municipal solid waste is left uncollected on the streets each day, interfering with the free flow of drainage, creating feeding ground for pests that spread diseases and creating an enormous health and infrastructural problems. Municipal solid waste management is an important part of the urban infrastructure that ensures the protection of environment and human health (Sandna, 1982).

The degradation of the environment caused by inefficient disposal of waste can be expressed by the contamination of soil, surface and ground water through leachate; the spreading of diseases by different vectors like birds, insects and rodents. There is also the uncontrolled release of methane by anaerobic decomposition of waste and air pollution by open burning of waste. The sustainability of the land filling system has become a global challenge due to increased environmental concerns. Growing public opposition together with unavailability of land is one of the reasons why obtaining sites for new landfill is becoming increasingly difficult. Locating a landfill far away from the urban area or far away from the source of waste generation increases transfer costs and additional investments for the infrastructure of roads, hence intensifying the financial problems of the responsible authorities. Common problems for Municipal Solid Waste (MSW) management in the cities include institutional deficiencies, inadequate legislation and resource constraints (Magrinho*et al*, 2006). Long and short term plans are inadequate due to capital and human resource limitations. There is a need to practice integrated solid waste management approach such as: Incorporation of more environmental and economic friendly concepts of source separation; recovery of waste; legitimization of the informal systems; partial privatization and public participation (Kreith, 1994). Although some governments have formulated policies for environmental protection, they were only implemented in the national capital cities. In rural areas, open dumping is still considered the most popular method of solid waste disposal (Oyelola*et al*, 2011).

The challenges of urban solid waste management can be addressed by building an incinerator to thermally treat the solid waste as a part of the integrated waste management method. The incineration of solid waste reduces the waste to about 10% to 15% of its original volume, destroys all the harmful substances contained in the waste, and so it is very ideal in big cities where the availability of land is very scarce(Knox,2005). The equipment can also be incorporated with a heat recovery device to produce steam for process industries and power plants. The process of incineration involves taking into consideration the temperature the combusting gases reach, the length of time the gases remain at elevated temperatures, how well the air and the gases are mixed and whether there is adequate oxygen to permit complete combustion (Niessen, 2014). The incineration of solid waste is imperative in a situation whereby the waste is so degraded to such extent that recycling is no longer cost effective. The aim of this work is to design and construct a step grate incineration for burning MSW especially those with high moisture content like garbage (70%) and pathological waste (85%).

II. Methodology

The detail design of the incinerator was done to calculate the mass and heat balance of the system, these were used to determine the size of the blower and also determine if an auxiliary burner is needed. The construction of the equipment was done with mild steel and refractory bricks.

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a) Selection of the Force Draft Fan (blower)

The selection of the draft fan was done based on the calculation of the mass balance to determine the size of the blower needed to introduce combustion air into the system. Table 1 shows the combustion equation of the various waste types and the stoichiometric airrequirement to completely burn the waste.

b) Selection of the Auxiliary burner

The heat balance was done to determine if an auxiliary burner will be needed to sustain the combustion process at a temperature of 600^{o}C.The heat balance in the combustion chamber of the incinerator is shown in the diagram of Figure 1while Table 2 shows the heat balance for the incinerator.

c) Performance Test

The performance test of the incinerator was carriedout to estimate the combustion efficiency of the equipment given by the formula in equation 1. The test was done using different types of waste and taking into consideration the amount of combustion air required and the volume reduction of the waste after the incineration process as shown in Table 3.

$$\eta = \frac{CO_2}{CO_2 + C_O} \times 100\% \qquad (1)$$

III. Results and Discussions

Table 1 shows the combustion equation of the various solid wastes and the amount of stoichiometric air needed to completely burn the waste. However, in the course of introducing air into the combustion chamber, a considerable amount of the air passes through without reacting with the waste, either because of the high speed with which it is introduced or the compactness of the waste which impede the proper diffusion of air into the waste. Therefore, an excess amount of air (30%) was supplied to compensate for the fugitive air that passes through the system without reacting with the waste. The calculation of the heat balance in Table 2 shows that 61,541*kJ/h* of heat energy (contained in the flue gas) exits the incinerator into the atmosphere. This heat energy can be used to dry a high moisture waste like pathological waste (85% moisture content) or garbage (70%) placed in the drying grate of the incinerator. The performance test in Table 3 reveals volume reduction of waste between the ranges of 78% - 95%. The ash produced after the combustion process can be safely land filled or used as construction material in the civil engineering industry. The combustion efficiency of the system is 86.5%, this is slightly higher than the 85.2% efficiency result obtained by Cyril et al (2016) from the design and development of a portable

IV. Conclusion

The thermal method of solid waste management (incineration) is one of the best methods of treating or disposing of waste as long as the emission produced is not harmful and within the range permissible by federal and state regulations. In order to avoid black smoke coming out of the chimney which is a sign of incomplete combustion or inadequate supply of air, it is important that an appropriate excess air ratio be used to ensure effective burnout of the combustibles in the chamber, suppressing the formation and emission of pollutants. Furthermore, the heat produced from the process can be captured by a heat recovery device (boiler) to produce steam for process industries or thermal power station. Also the incineration of solid waste reduces harmful substances to ash which can be safely landfilled or used as construction material.

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Tables

Table 1 : The combustion equation and the stoichiometric air requirement

Waste (1.0 *kg*)	Combustion equation	Stoichiometric air requirement (*perkg waste*)
Paper	$C_6H_{10}O_5 + 6O_2 \longrightarrow 6CO_2 + 5H_2O$	5.16
Rubber	$C_5H_8 + 7O_2 \longrightarrow 5CO_2 + 4H_2O$	14.32
Plastic	$C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$	14.9
Wood	$4C_{10}H_{15}O_7 + 41O_2 \longrightarrow 40CO_2 + 30H_2O$	5.74
Leather	$C_5H_8O_{0.75}N_{0.71}S_{0.013} + [4.64O_2 + 4.64(79/21)N_2] \longrightarrow 5CO_2 + 4H_2O + 0.013SO_2 + 17.8N_2$	7.05
Textile	$C_{4.6}H_{6.6}O_2N_{2.9}S_{0.0047} + [5.25O_2 + 5.25(79/21)N_2] \longrightarrow 4.6CO_2 + 3.3H_2O + 0.0047SO_2 + 21.2N_2$	7.76
Garbage	$C_6H_{9.6}O_{3.5}N_{0.28}S_{0.2} + [6.4O_2 + 6.4(79/21)N_2] \longrightarrow 6CO_2 + 4.8H_2O + 0.2SO_2 + 24.22N_2$	3.29
$Total\ air\ required$ (at 30% excess air) $= (\%\ excess\ air \times stoich.air) + stoich.air$ $m_{air} = (0.3 \times 58.22) + 58.22$ $= 75.69\ kg$		

Table 2 : Heat balance for the incinerator

Heat input (*kJ/kg*)		Heat output (*kJ/h*)	
Paper	14,085	Radiation loss = 5% of total heat available= 5% × 132,100	6,605
Plastic	33,712	Heat to ash $= mC_P(T_g - T_C)$ $= 0.35 \times 0.831 \times (600 - 25)$	167.23
Rubber	22,197	Heat to dry combustion product $= mC_PdT$ $= 98.6 \times 1.086 \times (600 - 25)$	61,541
Textile	17,476	Heat to moisture $= (mC_PdT) + (mH_V)$ $= [7.92 \times 2.347 \times (600 - 25)] + [7.92 \times 2460]$	30,173
Wood	16,580		
Leather	19,050		
Garbage	9,000		
Total	132,100		94,486.23

Net Balance $= Q_0 - Q_1$

$= 132{,}100 - 94{,}486$

$= 33{,}613.8$ *kJ/h* (heat required to maintain the incinerator at 600°C)

Table 3 : Performance test of the incinerator

Type of waste (10 *kg*)	Stoichiometric air requirement (*perkg waste*)	Volume reduction (%)
Paper	51.6	95
Textile	77.6	92
Wood	57.4	96
Rubber	143.2	80
Leather	70.5	81
Plastic	149.0	78
Garbage	32.9	85

FIGURES

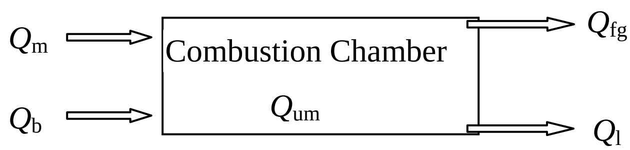

Figure 1 : Heat balance of the incinerator

Q_m: Heat energy of the waste material
Q_{um}: Heat energy retained in the unburned waste
Q_{fg}: Heat energy of the flue gas
Q_l: Heat loss to the surrounding
Q_b: Heat supplied by the auxiliary burner

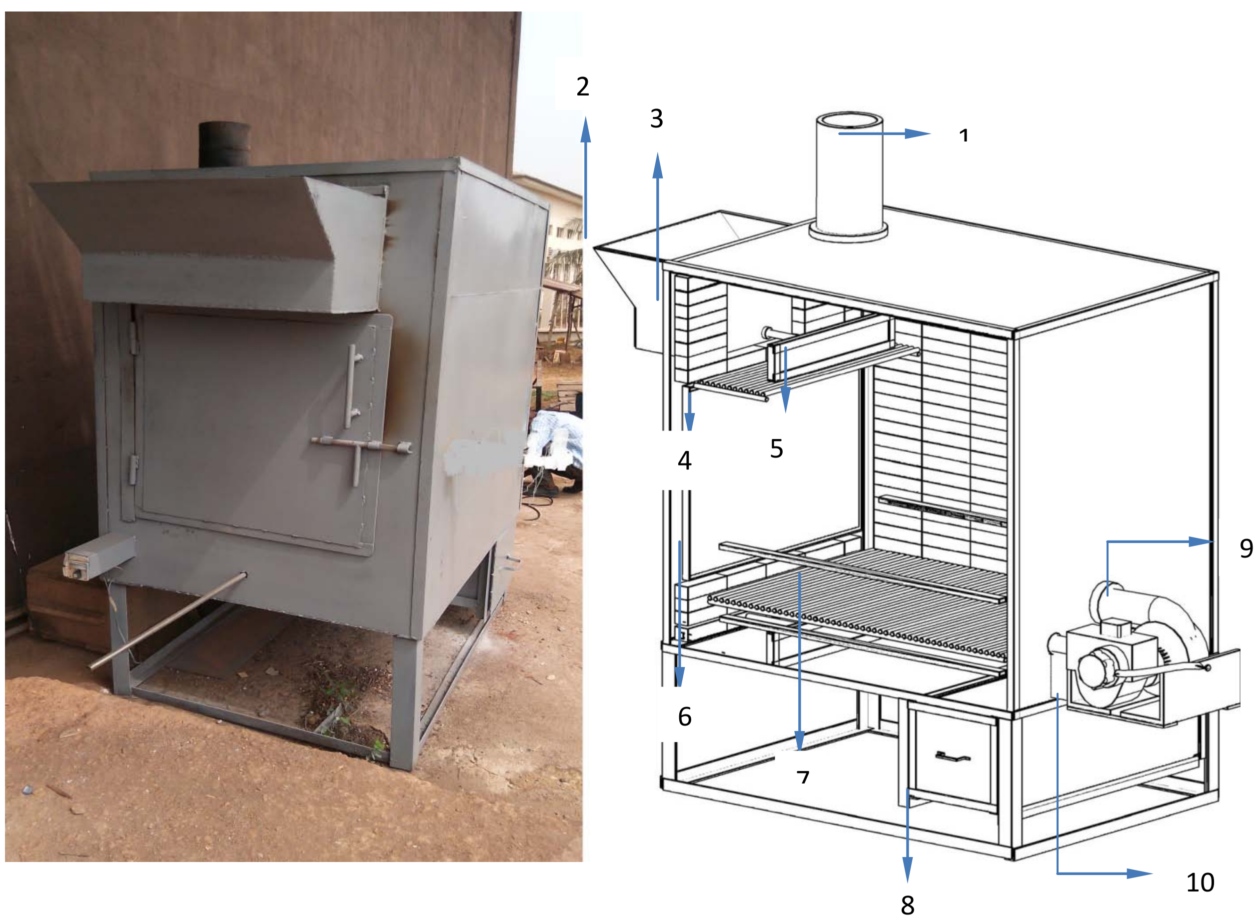

Figure 2 : The pictorial and isometric view of the incinerator

1. Chimney
2. Hopper
3. Refractory bricks
4. Drying grate
5. Feed ram
6. Combustion air piping
7. Combustion grate

8. Ash tray
9. Blower
10. Burner

Nomenclature

m	Mass, *kg*
C_p	Specific heat capacity, *kJ/kg°C*
T_g	Temperature of flue gas, °*C*
T_c	AmbientTemperature, °*C*
d_t	Temperaturedifference, °*C*
H_v	Latent heat of vapourization,*kJ/kg*
Q_o	Heat input, *kJ*
Q_1	exit heat, *kJ*
η	Combustion efficiency, %

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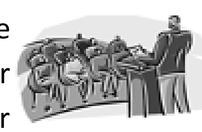

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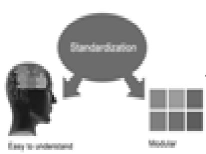

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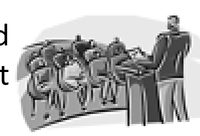

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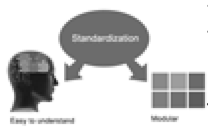

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Before submitting your research paper, one is advised to go through the details as mentioned in following heads. It will be beneficial, while peer reviewer justify your paper for publication.

Scope

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Complete support for both authors and co-author is provided.

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Based on potential and nature, the manuscript can be categorized under the following heads:

Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

5.STRUCTURE AND FORMAT OF MANUSCRIPT

The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

Papers: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

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It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

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Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

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Abstract, used in Original Papers and Reviews:

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Key Words

A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

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Figures: Figures are supposed to be submitted as separate files. Always take in a citation in the text for each figure using Arabic numbers, e.g. Fig. 4. Artwork must be submitted online in electronic form by e-mailing them.

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Even though low quality images are sufficient for review purposes, print publication requires high quality images to prevent the final product being blurred or fuzzy. Submit (or e-mail) EPS (line art) or TIFF (halftone/photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Do not use pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings) in relation to the imitation size. Please give the data for figures in black and white or submit a Color Work Agreement Form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Acrobat Reader will be required in order to read this file. This software can be downloaded

(Free of charge) from the following website:

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Proofs must be returned to the dean at dean@globaljournals.org within three days of receipt.

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TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

1. Choosing the topic: In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

2. Evaluators are human: First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

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4. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

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7. Use right software: Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

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15. Use of direct quotes: When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

16. Use proper verb tense: Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

17. Never use online paper: If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

18. Pick a good study spot: To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

19. Know what you know: Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

20. Use good quality grammar: Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

21. Arrangement of information: Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

22. Never start in last minute: Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

23. Multitasking in research is not good: Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

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32. Never oversimplify everything: To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

34. After conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

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Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

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The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

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This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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