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Analytical Studying of the Effect of Different Ignition Systems on the Engine Performance

Prof. Ibrahim L. Ahmed[1], Prof. Essam M. Allam[2], Prof. Ibrahim Saber Abdel-Rahman Qassem[3], Ibrahim S. Ibrahim[1] and Dr. M. Rabea[4]

[1]Automotive Technology Department, Faculty of Industrial Education, Helwan University, Cairo,Egypt.

[2] Automotive Engineering Department, Faculty of Engineering in Mataria, Helwan University, Cairo, Egypt.

[3] Curricula and Teaching Methods Department, Faculty of Education, Helwan University, Cairo, Egypt

[4] Automotive Engineering Department, Faculty of Engineering, Minia University, Minia, Egypt.

ABSTRACT

Laser ignition is considered to be one of the most promising future ignition concepts for internal combustion engines. This study focuses on the investigation of the different ignition systems which affect engine performance. Conventional (CIS), electronic (EIS) and laser ignition systems (LIS) were used during this studying. The major engine performances were predicted such as power, torque, and specific fuel consumption, in addition to cylinder temperature and pressure. The output of the engine performance using computational model was established in MATLAB/Simulink. The results show that, the Laser ignition system (LIS) causes improves of the internal combustion engine performance. Where the results showed increases the power by about 15%, torque is increasing up to 16%, improves the BSFC by about 18 %, while the cylinder pressure is increased to 11% and LIS gives higher combustion temperatures when compared to other systems.

Keywords: *Cylinder pressure, Engine performance, Power, Torque, Laser ignition, Specific consumption of fuel.*

1. INTRODUCTION

The ignition system in an internal combustion engine ignites the mixture of fuel and air in the cylinders. It's directs an electric current to each spark plug when it needs to fire. The ignition system is a critical part of engine operation. Slight issues with the ignition can have dramatic impacts on performance, emissions, and maintenance. For this reason, it is important to always make sure all parts of your ignition system are properly set up and maintained. The ignition system sends an extremely high voltage to the spark plug in each cylinder when the piston is at the top of its compression stroke. The tip of each spark plug contains a gap that the voltage must jump across in order to reach ground. That is where the spark occurs. The voltage that is available to the spark plug is somewhere between 20,000 volts and 50,000 volts or better. The job of the ignition system is to produce that high voltage from a 12 volt source and get it to each cylinder in a specific order, at exactly the right time [1]. The main idea behind engine modelling is to elucidate an engine phenomenon by establishing cause and effect dynamics relation between its main inputs and outputs. The dynamic relations used in modelling are differential equations obtained from conservation of mass and energy laws. The input variables in engine modelling are usually throttle angle, spark advance angle, exhaust gas recirculation and air-fuel ratio. The output variables are engine speed, torque, fuel consumption, exhaust emissions, and drivability .The challenge in engine modelling is to establish the relations between the engine input and output variables which best describe the model and predict the output variables in different working conditions of the engine [2].The ignition energy has a significant effect on the initial unsteady evolution of flame kernel, which will affect the performance and emissions of a spark-ignition engine and the uncertainty in determining laminar burning velocity and mark stein length due to the inappropriate selection of the lower limit of flame radius.

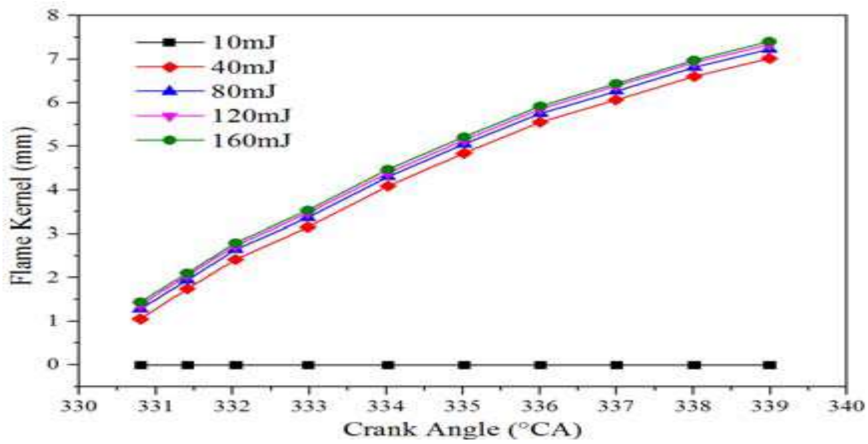

Figure- 1. Flame kernel radius at different ignition energy in biogas mixture [3]

From Figure 1, the initial flame kernel cannot be generated at 10mJ and the ignition is failed. It shows that there is minimum ignition energy to ignite biogas engine and the ignition will be failed below this level. Enhancing the ignition energy in certain range will improve the generation of initial flame kernel for the biogas engine.

This work is concerned with a theoretical investigation into the effect of the modern electronic ignition systems on the performance of the vehicle. It is based on study the various performance factors at the vehicle such as measuring horse power, torque, fuel consumption, cylindrical pressure and combustion temperature.

2. Basic equations in the system:

The equations of volume and area that relate to crank angle are described as following equation [4]

$$V(\theta)=\frac{V_d}{\mathcal{E}-1}+\frac{V_d}{2}\left[\frac{1}{a}+1-\cos\theta-\left(\left(\frac{1}{a}\right)^2-\sin^2\theta\right)^{\frac{1}{2}}\right]\ldots\ldots\ldots(1)$$

$$A(\theta)=\frac{V_d}{\mathcal{E}-1}+\frac{V_d}{2}\left[\frac{1}{a}+1-\cos\theta+\left(\left(\frac{1}{a}\right)^2-\sin^2\theta\right)^{\frac{1}{2}}\right]\ldots\ldots\ldots(2)$$

Overall heat input can be determined by using heating value of fuel and amount of mass which is drawn into cylinder [4]

$$Q_{in}=\frac{HV\int_{IVO}^{IVC}m(\theta)d\theta}{1+m_{air,stoich}}\ldots\ldots\ldots(3)$$

The Wiebe function curve has a characteristic S-shaped curve and is commonly used to characterize the combustion process. The mass fraction burned profile grows from zero, where zero mass fraction burn indicates the start of combustion, and then tends exponentially to one indicating the end of combustion. The difference between those two ends is known as the duration of combustion. Although the Wiebe function simple and robust in specifying the combustion process,

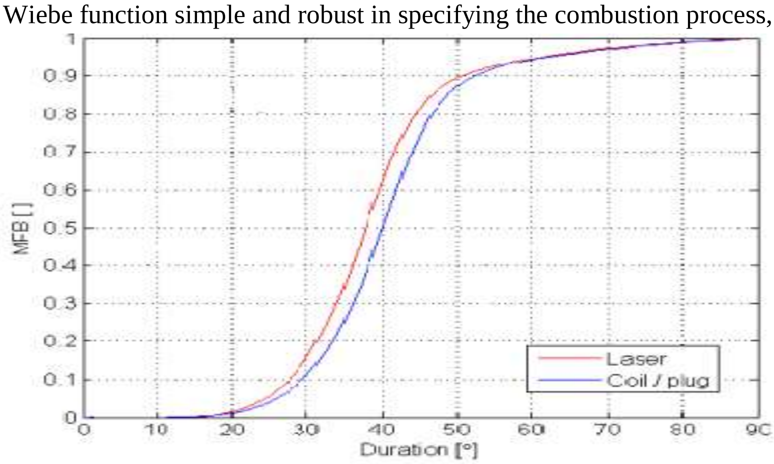

Figure-2 ,Mass fraction burn curves for LIS and EIS at 1500 rpm, 2.62 bar BMEP, λ = 1, with the ignition timing for LI and SI at 36° BTDC [6]

$$X_B=\left(1-exp\left(-a\left(\frac{\theta-\theta_0}{\Delta\theta}\right)^{m+1}\right)\right)\ldots\ldots\ldots(\mathbf{4})$$

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Where, (x_B) mass fraction burn (θ) the crank angle , (θ_0) spark angle, (Δθ) Total Burning angle, (a) Coefficient efficiency, (m) form factor [7]
Method of calculating factors (a & m) for combustion curve

$$\boldsymbol{m} = \frac{\ln\left(\frac{\ln(1-x_A)}{\ln(1-x_B)}\right)}{\ln\left(\frac{\alpha_A}{\alpha_B}\right)} - 1 \; \ldots\ldots\ldots (5)$$

$$\boldsymbol{a} = \frac{\ln\left(\frac{1}{1-x_A}\right)}{\left(\frac{\alpha_A}{\alpha_C}\right)^{m+1}} \; \ldots\ldots\ldots (6)$$

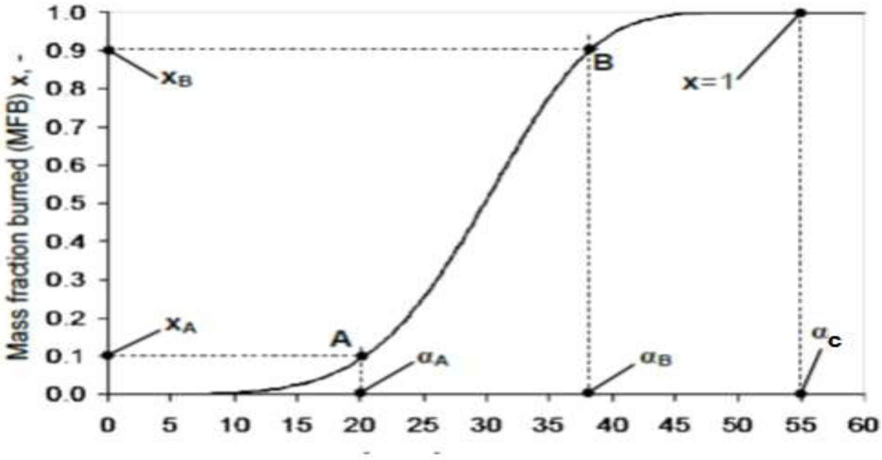

Fig- 3. Characteristic periods of MFB function [8]

From the Fig- 3, the mass fraction burn depends on the ignition energy of where if the ignition energy increases, the mass fraction burn will increase .In this research will use an experimental engine so When applying one of the types of ignition systems will get a special combustion curve and then Will be calculated the factors of it (a & m) , Then Will be calculated the burned mass through the equation (1) The measurements of power , torque ,SFC and peak pressure depend on the amount of mass fraction burn in the engine. The conditions for simulation are summarized in appendix (A).
The heat release (dQ) over the crank angle change (Δθ) is :

$$\frac{\partial Q}{d\theta} = Q_{in}\frac{df}{d\theta} \ldots\ldots\ldots (7)$$

In spark ignition engines, the primary heat transfer mechanism from the cylinder gases to the wall is convection, with only 5% from radiation. Using a Newtonian model, the heat loss to the wall is given by

$$Q_{loss} = hA(T_g - T_w) \quad \ldots\ldots\ldots (8)$$

The Hohenberg correlation for calculating co-efficient of heat transfer which is used in calculating heat loss trough cylinder[9]

$$h = 130V^{-0.06}\, P^{0.8}T_g^{-.04}(C_m + 1.4)^{0.8} \quad \ldots\ldots\ldots (9)$$

Pressure equation for engine cylinder is derived from the first law of thermodynamics. The pressure is derived as a function of crank angle also [10]

$$\frac{dP}{d\theta} = \frac{K-1}{V}\left[Q_m\frac{df}{d\theta} - \frac{hA}{6N}(T_g - T_w)\right] - k\frac{P}{V}\frac{dV}{d\theta} \ldots\ldots\ldots (10)$$

The intake system (air filter, carburetor, and throttle plate, intake manifold, intake port, intake valve) controls the amount of air which an engine of given displacement can breathe. The parameter used to measure the effectiveness of an engine's breathing is the volumetric efficiency (ηv).Volumetric efficiency is only used with four-stroke engines which have distinct induction process. It is defined as the volume of air which is drawn into the intake system divided by the volume which is displaced by the piston.

$$\eta_v = \frac{m_a}{P_a V_d} \ldots\ldots\ldots (11)$$

Valve lift design uses polynomial function as described by Hermann, McCartan and Blair (HMB) technique [11] uses up to 11th order polynomial functions. The alternative approach is the G. P. Blair (GPB) method which considers jerk characteristic of valve motion. The method is employed depends on how smooth the lift and acceleration diagrams are otherwise the forces and impacts on the cam follower mechanism will be considered.

$$L_v(\theta) = \frac{L_{v,max}(1 + \cos\varphi)}{2}$$

$$and\ \varphi = \frac{\pi(IVO-IVC+2\theta+540)}{IVO+IVC+180} \dots\dots\dots (12)\ .$$

The mass flow rate through a poppet valve is usually described by the equation for compressible flow through a flow restriction. The equation is derived from a one-dimensional isentropic flow analysis, and real gas flow effects are included by means of an experimentally determined discharge coefficient.

$$m = \frac{C_D A_R P_O}{RT_O}\left[\frac{P_T}{P_O}\right]^{\frac{1}{K}}\left\{\frac{2k}{k-1}\left[1-\left[\frac{P_T}{P_O}\right]^{\frac{K-1}{K}}\right]\right\}^{\frac{1}{2}} \dots\dots\dots (13)$$

should be converted into a function of crank angle also by dividing with 6N

$$\frac{dm}{d\theta} = \frac{C_D A_R P_O}{6NRT_O}\left[\frac{P_T}{P_O}\right]^{\frac{1}{K}}\left\{\frac{2k}{k-1}\left[1-\left[\frac{P_T}{P_O}\right]^{\frac{K-1}{K}}\right]\right\}^{\frac{1}{2}} \dots\dots\dots (14)$$

steady flow discharge coefficient results can be used to predict dynamic performance with reasonable precision [12].

$$C_D = 190\left[\frac{L_v}{D_{IV}}\right]^4 - 143.13\left[\frac{L_v}{D_{IV}}\right]^3 + 31.248\left[\frac{L_v}{D_{IV}}\right]^2 - 2.5999\left[\frac{L_v}{D_{IV}}\right] + 0.6913 \dots\dots\dots (15)$$

the parameters which are used to calculate the pressure losses still unknown,But the equation is used to calculate frictional losses [13].

$$P_F = 0.05\left(\frac{N}{1000}\right)^2 + 0.15\left(\frac{N}{1000}\right) + 0.97 \quad For\ 1000 \le N \le 6000 \ \dots\dots\dots (16)$$

To determine the overall performance, indicated mean effective pressure is used. The indicated mean effective pressure represents the work per combustion cycle normalized by the displacement volume also called specific work. This value indicates amount of maximum available power that can generate from single cylinder**,** finally, torque and power can be determined by following relation.

$$P_e = \frac{\pi NT}{30} \dots\dots\dots (17)$$

the Specific fuel consumption of vehicles by g/kwH- can be determined by following relation.

$$\text{Brake Specific } Fuel\ consumption = \frac{\text{Fuel Consumption}}{\text{out put Power}} \dots\dots\dots (18)$$

3. RESULTS AND DISCUSSION

This section present the effect of different ignition systems on the engine performance in term of engine power, engine torque, brake specific fuel consumption, cylinder pressure and cylinder temperature.

Figure (4) demonstrates the effect of the three ignition systems on the engine power at different engine speed. From the results shown in figure (4) it can be seen that the uses of both laser ignition system and electronic ignition system increases the engine's power for different engine speeds. The engine power increases by about 15% (1.2 KW) when the conventional ignition system is replacement by laser ignition system at 1000 rpm of engine speed, this percentage increases to 7% (4.8 KW) with increase engine speed to 6000 rpm. This difference between the two values maybe due to the weak response of the conventional ignition system at the higher speeds which effect on the ignition timing. Also, the engine power increases by about 6%(0.5 KW) when the conventional ignition system is replacement by electronic ignition system at 1000 rpm of engine speed, this percentage increases to 5% (3.5 KW) with increase engine speed to 6000 rpm. The LIS is the best when compared to the other two systems because the ignition energy reaches more than 150 mJ [15] (ignition energy of EIS up to 90 mJ and CIS up to 60 mJ [14]), It doesn't give a single spark, but gives ignition energy in the form of several successive pulses, which increases the efficiency of the combustion process and improves performance factors.

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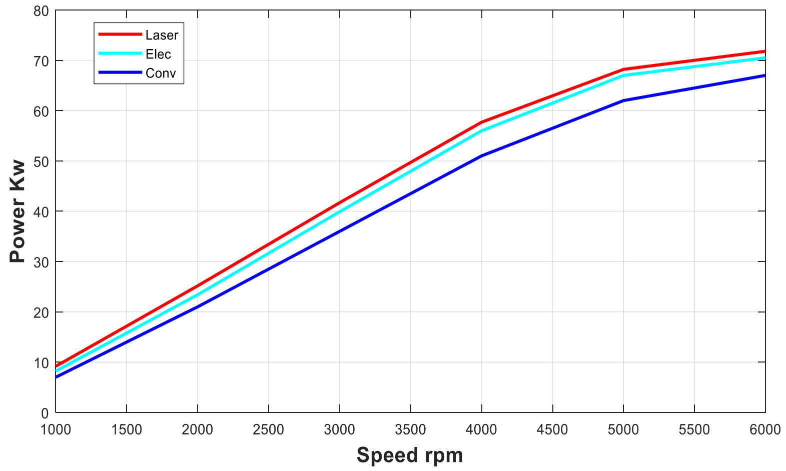

Figure 4. Power Curve

Figure- 5 shows the demonstrations the effect of the three ignition systems on the engine torque at different engine speed. From the results shown in figure (5) it can be seen that the uses of both laser ignition system and electronic ignition system increases the engine's torque for different engine speeds. The engine torque increases by about 16% (12 Nm) when the conventional ignition system is replacement by laser ignition system at 1000 rpm of engine speed, this percentage increases to 8% (7 Nm) with increase engine speed to 6000 rpm. . Also, the engine torque increases by about 8% (6 Nm) when the conventional ignition system is replacement by electronic ignition system at 1000 rpm of engine speed, this percentage increases to 6% (5 Nm) with increase engine speed to 6000 rpm. the laser and electronic curves are almost identical, because of the low opening time of the intake valve ,The figure shows that the maximum torque is at 4000 rpm Where the laser ignition system increases by 10% , while the electronic ignition system increases by 7%.

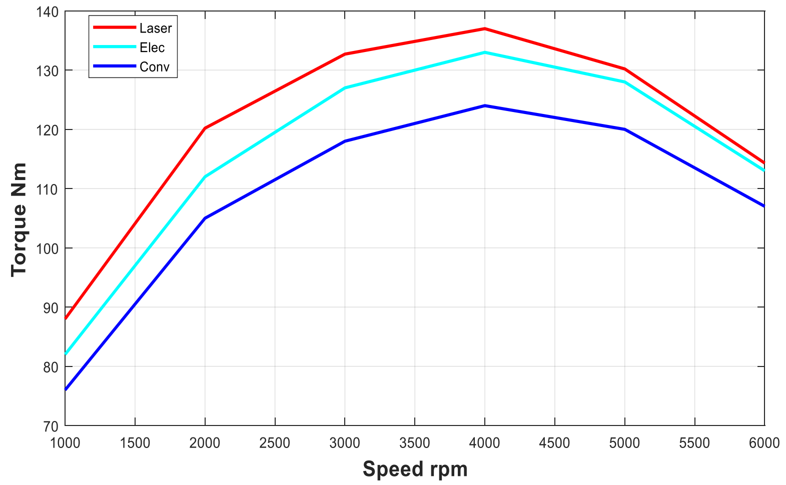

Figure-5. Torque curve

Figure (6) demonstrates the effect of the three ignition systems on BSFC of engine at different engine speed. From the results shown in figure (6) it can be seen that the uses of both laser ignition system and electronic ignition system decreases the BSFC of engine for different engine speeds. The engine BSFC of LIS decreases by about 18% (62 g/kwh)while the engine BSFC of EIS decreases by about 5% (43g/kwh) when replacing any of the two systems with conventional ignition system at 1000 rpm of engine speed. At maximum speeds, the LIS and EIS curves of engine BSFC are almost identical, because of the low opening time of the intake valve.

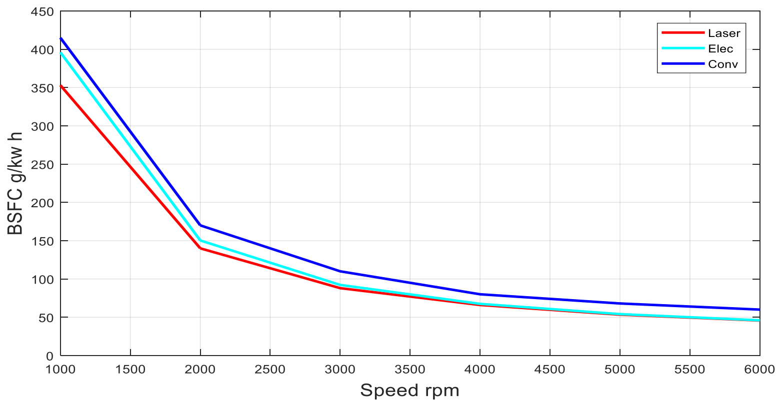

Figure- 6.BSFC curve

Figure-7 shows variation of cylinder pressure with crank angle of three ignition systems. From the results shown in figure (7) it can be seen that the uses of both laser ignition system and electronic ignition system increases the peak pressure of cylinder with crank angle. The cylinder pressure of LIS increases by about 11% while the cylinder pressure of EIS increases by about 7% When replacing of any two systems with conventional ignition system and that's because of improve of combustion efficiency.

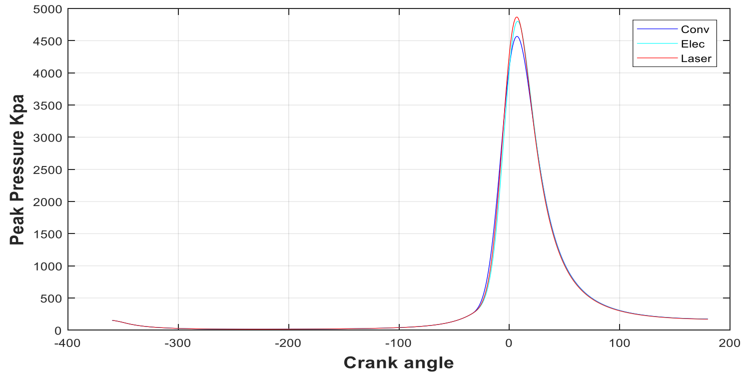

Figure 7. Variation of cylinder pressure with crank angle

Figure- 8 shows variation of cylinder pressure of the three ignition systems at different engine speed. From the results shown in figure (8) it can be seen that the uses of both laser ignition system and electronic ignition system increases the engine's pressure for different engine speeds.

The engine pressure increases by about 10% (16 Kpa) when the conventional ignition system is replacement by laser ignition system at 1000 rpm of engine speed, this percentage increases to 8%(28Kpa) with increase engine speed to 6000 rpm .also, the engine pressure increases by about 7%(6Kpa) when the conventional ignition system is replacement by electronic ignition system at 1000 rpm of engine speed, this percentage increases to 4%(9Kpa) with increase engine speed to 6000 rpm.

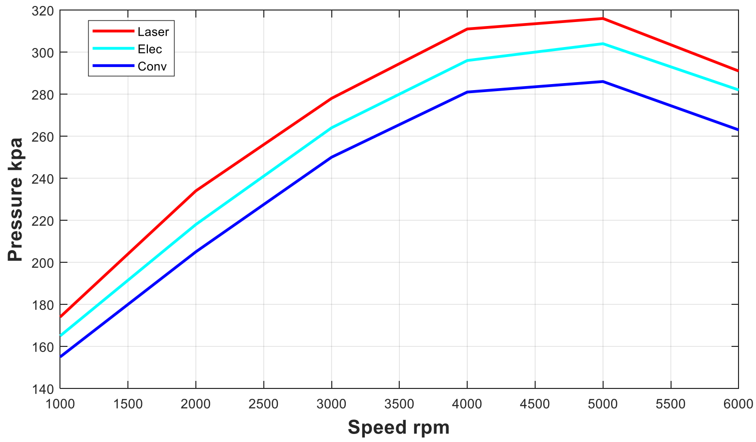

Figure-8. Variation of cylinder pressure with speed curve

Figure-9 shows variation of cylinder temperature with crank angle of three ignition systems.

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From the results shown in figure (9) it can be seen that the uses of both laser ignition system and electronic ignition system increases the peak temperature of cylinder with crank angle. The cylinder temperature of LIS increases by about 7% while the cylinder temperature of EIS increases by about 5% When replacing of any two systems with conventional ignition system and that's because of improve of combustion efficiency. while, From the results shown in figure (10) shows variation of cylinder temperature of the three ignition systems at different engine speed .it can be seen that the uses of both laser ignition system and electronic ignition system increases the engine's temperature for different engine speeds. The engine temperature increases by about 11% (67 k) when the conventional ignition system is replacement by laser ignition system at 1000 rpm of engine speed, this percentage increases to 8% (92 k) with increase engine speed to 6000 rpm. . Also, the engine temperature increases by about 7% (36 k) when the conventional ignition system is replacement by electronic ignition system at 1000 rpm of engine speed, this percentage increases to 4% (50 k) with increase engine speed to 6000 rpm.

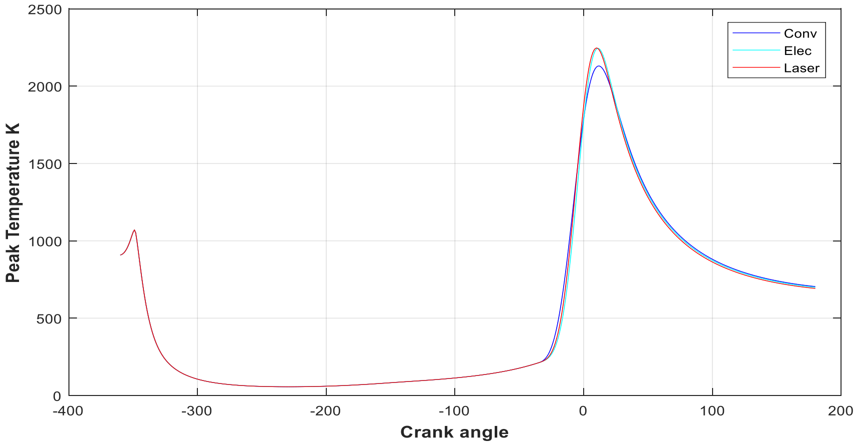

Figure 9. Variation of cylinder temperature with crank angle

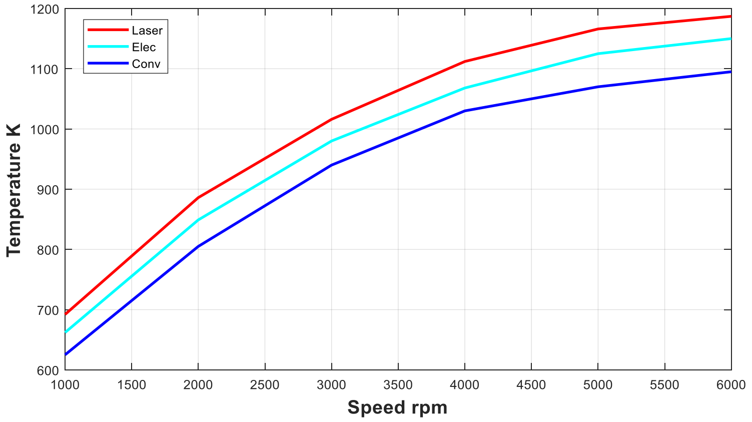

Figure10. Variation of cylinder temperature with engine speed

4. CONCLUSIONS

The effect of ignition systems on engine performance were discussed through various performance factors, such as the power, torque and specific consumption of fuel, cylinder pressure and temperature, the results showed improve of the laser ignition system for all performance factors due to high ignition energy, that's increases the radius of flame which improves combustion efficiency, Laser ignition (LIS) has as an efficient ignition technique for delivering superior engine efficiency with lower BSFC at all speeds, This gives preference to Circulate the use of the laser ignition system although its high costs

5. Appendix (A)

The conditions for simulation are summarized in Table 1 and 2.

Table 1. Simulation Results

Parameters	Value
Ambient Pressure	1 atm
Ambient Temperature	298 K
Mean cylinder wall temperature	400K
Specific heat ratio (k)	1.3
Air molecular weight	28.97 g/mol
Air density	1.2 kg/m³
Gasoline molecular weight	114 g/mol
Gasoline heating value	44000kJ/kg
Gasoline air/fuel ratio	14.6:1

Table 2. Engine specifications which are used for simulation in this thesis

No. of Cylinders	4
No. of Valves per Cylinder	2
Displacement (cc.)	1600
Bore × Stroke (mm.)	81 × 77.6
Compression Ratio	10 : 1
Intake Valve Open before TDC (degree)	11°
Intake Valve Close after BDC (degree)	47°
Maximum Valve Lift (mm.)	8
Inlet Valve Diameter (mm.)	41.2
Spark Angle	-36

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