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THE EFFECT OF PARAMETRIC VOLUMETRIC EFFICIENCY ON DECK'S ENGINE EFFECTIVE POWER

Haitham Abd-Elrahman Mansoor Taha[1],
Osama Mohammed Elmardi Suleiman Khayal[2]

[1]Red Sea University, Faculty of Engineering, Mechanical Engineering Department
[2]Department of Mechanical Engineering, College of Engineering and Technology, Nile Valley University, Atbara, Sudan
e-mail: haitham01176@gmail.com, osamamm64@gmail.com

ABSTRACT: In this research, the air intake and exhaust systems in internal combustion deck's engine are investigated and the volumetric efficiency as a major impact on effective power of deck's engine is studied comprehensively and thoroughly. Some of the parameters affecting the volumetric efficiency were studied such as air pressure, air temperature, compression ratio, residual gas pressure, variation of temperature, compressor temperature and fuel air ratio individually. This was done through the aid of computer program using the MATLAB environment. The effects of those parameters were varying on the volumetric efficiency, where air pressure, air temperature and compressor temperature were having a proportional effect on the volumetric efficiency and effective power. On the other hand, the compression ratio, variation of temperature, residual gas pressure and fuel air ratio were having an inverse effect. As conclusion, the maximum value of volumetric efficiency (86%) and the corresponding effective power was attained due to the effect of compressor temperature. The minimum value of volumetric efficiency was (62%) due to the effect of increasing the fuel air ratio.

KEYWORDS: Volumetric Efficiency; Air Pressure; Air Temperature; Compression Ratio; Residual Gas Pressure

1 INTRODUCTION

There are many types and arrangements of internal reciprocating deck's engines, and some classification is necessary to describe a particular deck's engine adequately. Two main methods of classification are employed, the first is by the fuel used and the way in which the combustion is initiated, and the second is by the way in which the cycle of processes is arranged. When a deck's engine is selected to suit a particular application, the main consideration being its power/speed characteristics. Important additional factors are initial capital cost and running cost. In order that different types of engines or different engines of the same type may be compared, certain performance criteria must be defined. These are obtained by measurements of the quantities concerned during bench test, and calculation is done by standard procedures. The results are plotted graphically in the form of performance curves.

The testing of a particular deck's engine consists of running it at different loads and speeds and taking sufficient measurements for the performance criteria to be calculated. The intake systems and flow processes are of a major importance in the performance tests. They are influenced by so many factors; e.g. configuration of the intake system, which includes; valve lift, profile, design, and discharge coefficients; manifold dynamics and ram effect; inlet Mach number index; and volumetric efficiency which is governed by the factors; fuel type, phase, and amount; intake manifold temperature; compression ratio; inlet/exhaust pressure ratio; frictional losses. Study proposed will involve the influences of all the above-mentioned factors on the intake systems and flow processes in internal reciprocating deck's engines.

The effect of the volumetric efficiency on the deck's engine effective power is investigated in this work. The effective power is found to be influenced by the volumetric efficiency parameters in different ways, depending on the influencing parameters. Some parameters result in proportional relation while others result in an inverse relation, [1] – [13].

2 THE PARAMETERS AFFECTING VOLUMETRIC EFFICIENCY

2.1 Introduction

It is well known that volumetric efficiency is affected by the type of the fuel used, engine design and a combination of different operating parameters. In this chapter, the concentration is on the influence of the operating parameters on the volumetric efficiency. The influence of every parameter is investigated individually to see how it affects the efficiency. Formulating the effect of the parameter on the efficiency by a mathematical model is necessary to study this influence, and a computer program by MATLAB to analyze and apply the model within permissible range of values helps to choose the most sensitive parameter among those, which affects the efficiency. The volumetric efficiency against power will be investigated in the next chapter.

2.2 The Effect of the Air Pressure (p_a) on the Volumetric Efficiency

The volumetric efficiency is increasing by increasing atmospheric pressures (p_a)because higher atmospheric pressure increases the air density and therefor, augment the intake air charge to the engine. A higher intake charge improves the engine volumetric efficiency and / or power delivered, [14].

The mathematical method used to describe the effect of the air pressure on the volumetric efficiency is formulated as follow: [15].

$$\eta_v = T_c \times \frac{(c_r \times p_a - p_r)}{(T_a + \Delta T)} \times (c_r - 1) \times p_c \qquad (1)$$

Where:

$\eta_v = volumetric\ efficiency.$

$T_c\ =\ the\ compressor\ temperature.$

$T_a\ =\ the\ air\ temperature.$

$p_a\ =\ the\ air\ pressure.$

$p_r\ =\ residual\ gas\ pressure.$

$\Delta T\ =\ the\ heat\ transfer.$

$c_r\ =\ the\ compression\ ratio.$

$p_c\ =\ the\ compressor\ pressure.$

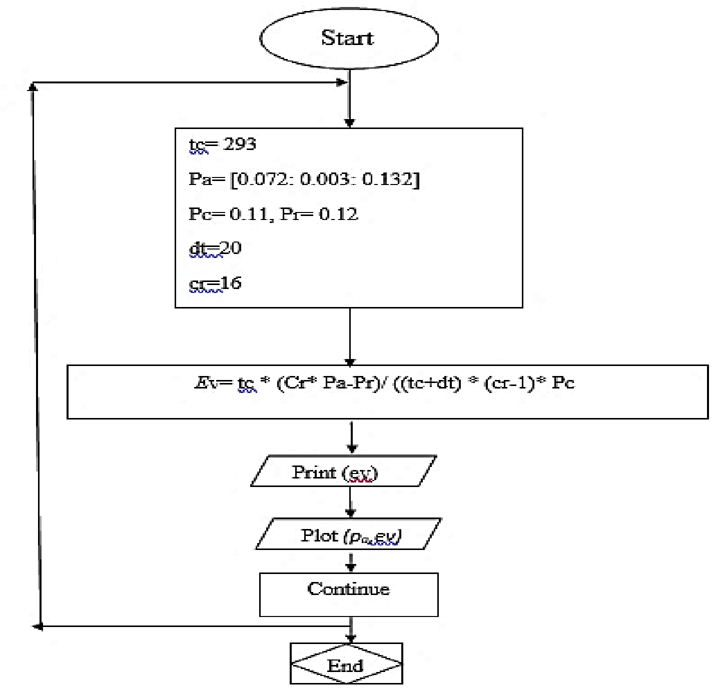

Figure 1. The Flow chart of the program

The application of the mathematical model above, which investigates the influence of the variable air pressure on volumetric efficiency, is written in MATLAB language environment. A flow chart (Figure 1) above illustrates the procedure of the program accompanied by Figure 2 which shows the relation between air pressure (p_a) and volumetric efficiency(η_v).

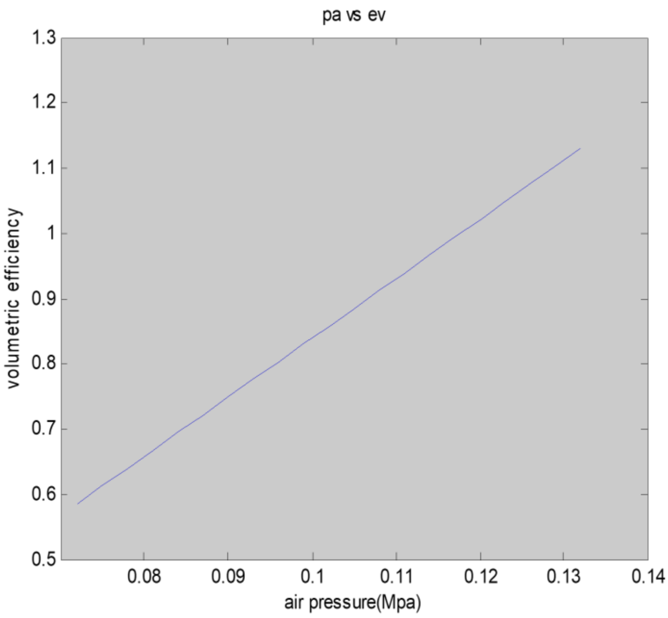

Figure 2. The changes of the volumetric efficiency with respect to the change of air pressure

2.3 The Effect of air temperature (t_a) on volumetric efficiency

The volumetric efficiency is increased by increasing air temperature because the increase of (t_a) will decrease the difference between combustion champers temperature and incoming air temperature and thus (ΔT) will decrease and leads to increasing volumetric efficiency [16]. A mathematical formula that describes the influence of the air temperature on the volumetric efficiency is given by Equation (2) below, [15]:

$$\eta_v = \left(\frac{M}{M_a}\right)\left(\frac{P_i}{P_{a,o}}\right)\left(\frac{T_a}{T_i}\right)\frac{1}{(1+F/A)}\left\{\frac{c_r}{c_r-1} - \frac{1}{\gamma(c_r-1)}\left[\frac{P_e}{P_i}+(\gamma-1)\right]\right\} \quad (2)$$

Where:

η_v $Volumetric\ efficiency.$
M $molecular\ weight.$
M_a $molecular\ weight\ of\ atmospheric\ condition.$
P_i $intake\ pressure.$
$P_{a,o}$ $intake\ mixture\ pressure\ at\ atmospheric\ condition.$
T_a $Atmospheric\ temperature\ (K).$
T_i $Intake\ mixture\ temperature\ (K).$
$\frac{F}{A}$ $fuel\ air\ ratio.$
P_e $exhaust\ pressure\ (MPa).$
γ $Specific\ heat\ ratio.$

c_r $compression\ ratio.$

The solution of the mathematical model mentioned above, taking into consideration various values of temperature within a permissible range, is written in MATLAB language. A flow chart displaying the program solution steps is depicted in Figure 3. The results of the solution are shown in Figure 4.

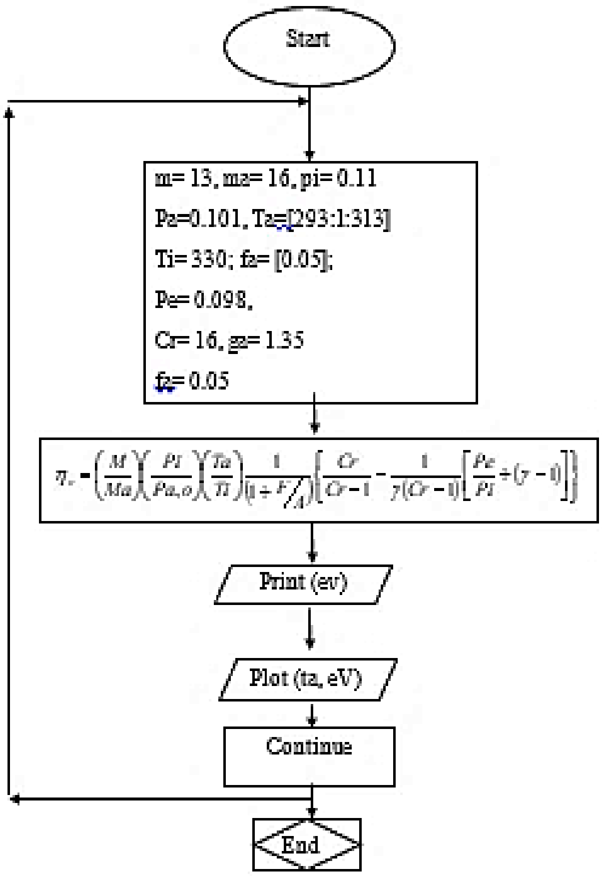

Figure 3. Flow diagram of the execution of the program

Figure 4 below shows clearly the changes of the volumetric efficiency with respect to the change of air temperature.

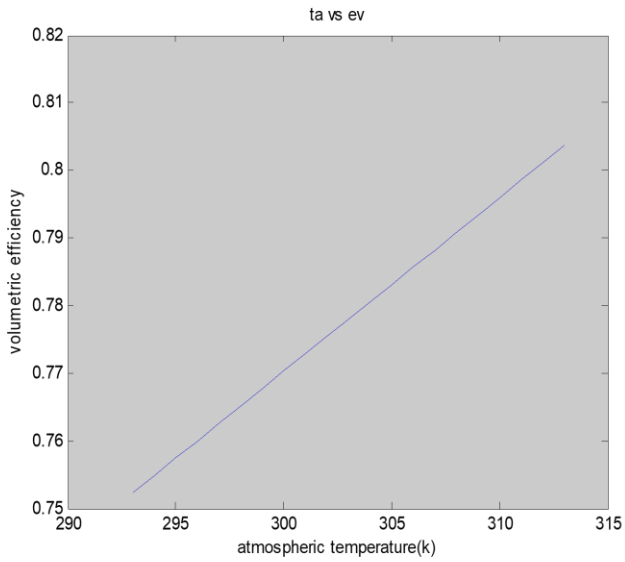

Figure 4. The changes of the volumetric efficiency with respect to the change of air temperature

2.4 The effect of compression ratio (c_r) on volumetric efficiency

As the pressure ratio (p_e/p_i) and the compression ratio (p_c) are varied, the fraction of the cylinder volume occupied by the residual gas at the intake pressure varies. As this volume increases volumetric efficiency decreases,[16].

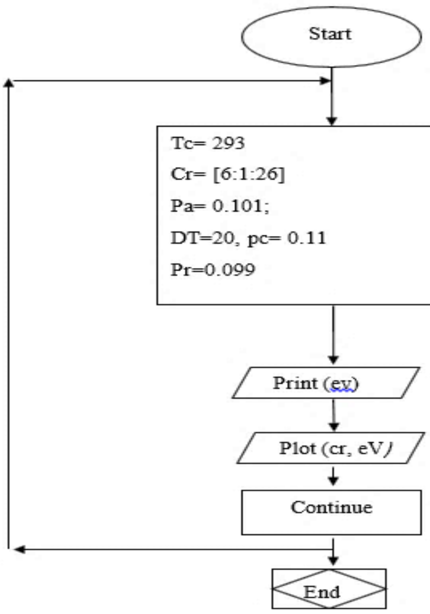

Figure 5. The procedure of program execution

The influence of the compression ratio on the volumetric efficiency can be mathematically formulated as Equation (1).

A computer program using MATLAB language (see Appendix (A)) is used to solve the mathematical model combining compression ratio and volumetric efficiency. The program processes different values of the compression ratio versus volumetric efficiency. The flow chart illustrated in Figure 5 is drawn to show the procedure of program execution and the results of the solution are shown in figure 6. Figure 6 below shows the changes of the volumetric efficiency with respect to change of compression ratio.

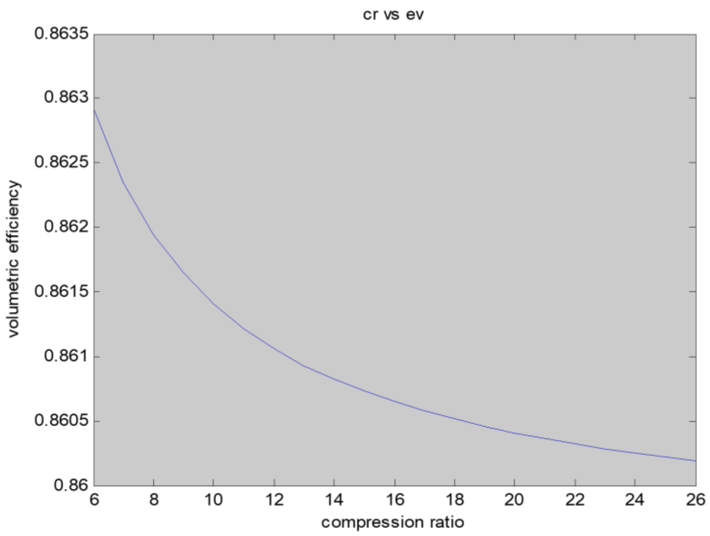

Figure 6. The changes of the volumetric efficiency with respect to the change of compression ratio

2.5 The effect of the residual gas pressure (p_r) on the volumetric efficiency

As the pressure ratio (p_e/p_i) is varied, the fraction of the cylinder volume occupied by the residual gas at the intake pressure varies. As this volume increase, volumetric efficiency decreases, [16].

Mathematically, the effect of the residual gas pressure on the volumetric efficiency is expressed using the Equation (1).

The MATLAB language programming capability is used to find a solution for the above equation by varying the values of the residual gas pressure within the possible interval and observe the resultant values of the volumetric efficiency. A flow chart that illustrated in Figure 7 is drawn for program processing procedure and Figure 8 illustrates the form of the solution of the equation.

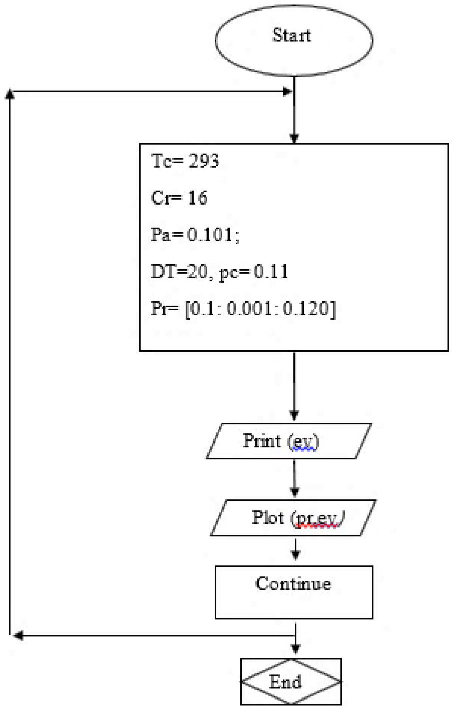

Figure 7. Program processing procedure

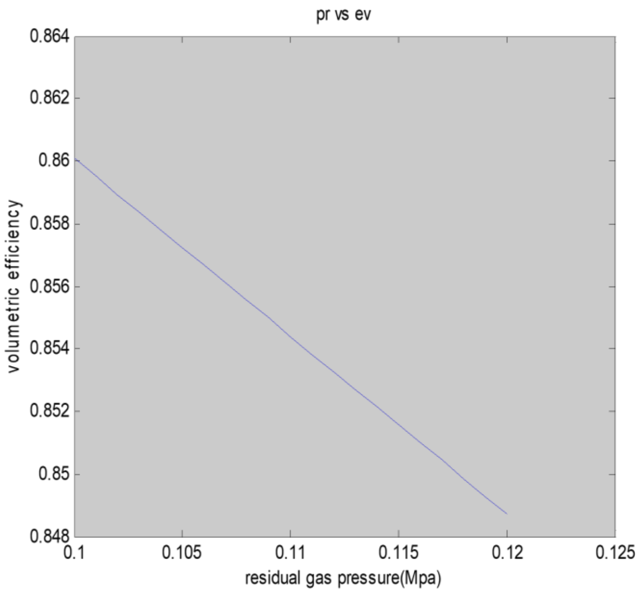

Figure 8. The residual gas pressure (p_r) versus the volumetric efficiency (η_v)

Figure 8 above, shows the residual gas pressure (p_r) versus the volumetric efficiency (η_v).

2.6 The effect of the (ΔT) on the volumetric efficiency

The effect of increase of the heat transfer will decrease the volumetric efficiency. When the gas temperature in the cylinder is higher than that in the inlet manifold, volumetric efficiency will decrease. This is because the density of the gas in the combustion chamber will decrease. Therefore, the mass of the gas in combustion chamber will decrease, [17].

The mathematical formula, which describes the effect of ΔT on volumetric as in Equation (1).

To investigate the influence of varying of this parameter a program was written in MATIAB language. The flow chart in Figure 9 of the program is shown below and the result of the investigation is plotted on Figure 10.

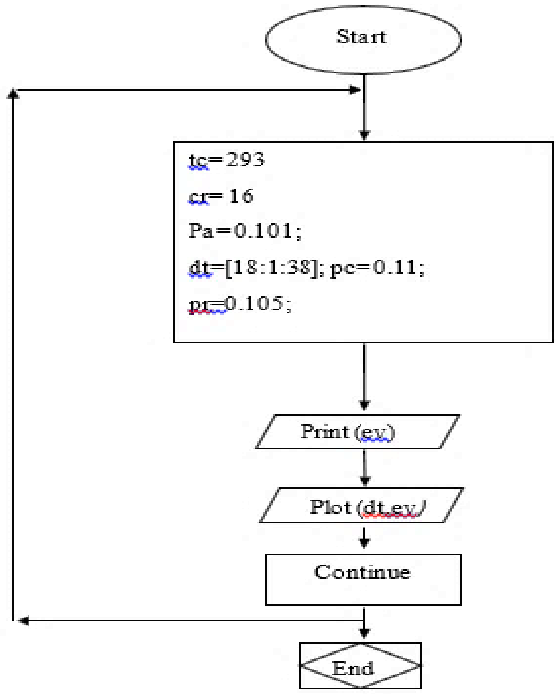

Figure 9. The flow chart of the program

Figure 10 below shows the change of the volumetric efficiency with respect to the change of (ΔT).

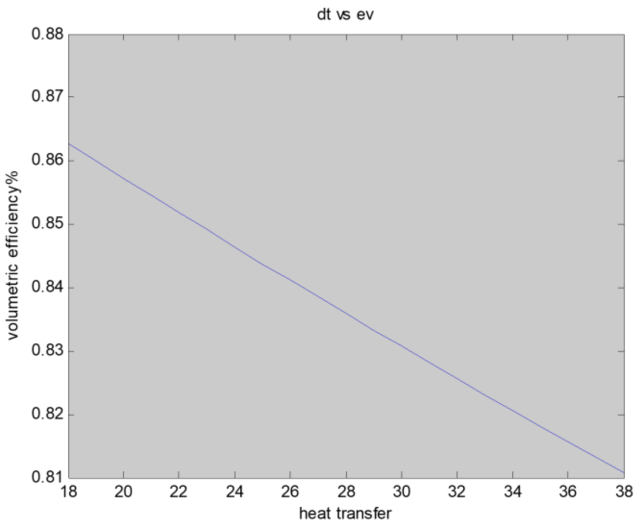

Figure 10. The change of the volumetric efficiency with respect to the change of (ΔT)

2.7 The effect of the compressor temperature (t_c) on the volumetric efficiency

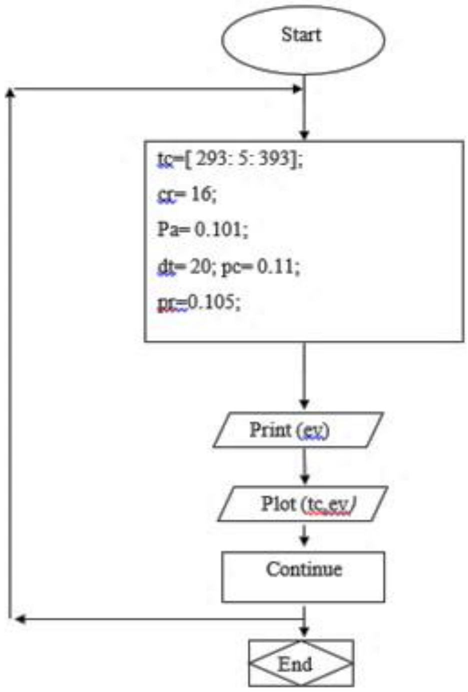

Figure 11. The flow chart, which describes the flow of the program

The volumetric efficiency is increased with increasing compressor temperature because a turbo charger has two separate components that affect the mass flow through the engine.

The compressor pumps the fresh mixture into the inlet manifold and thus increases the density of the air, [18].

A mathematical formula that describes the influence of the compressor temperature on volumetric efficiency is given as in Equation (1). The solution of the model with respect to the change of compressor temperature in the possible interval is written in MATLAB program language and the flow chart which describes the flow of the program is shown in Figure 11 and the results of the solution is shown on Figure 12.

Figure 12 below shows the compressor temperature (t_c) versus the volumetric efficiency (η_v).

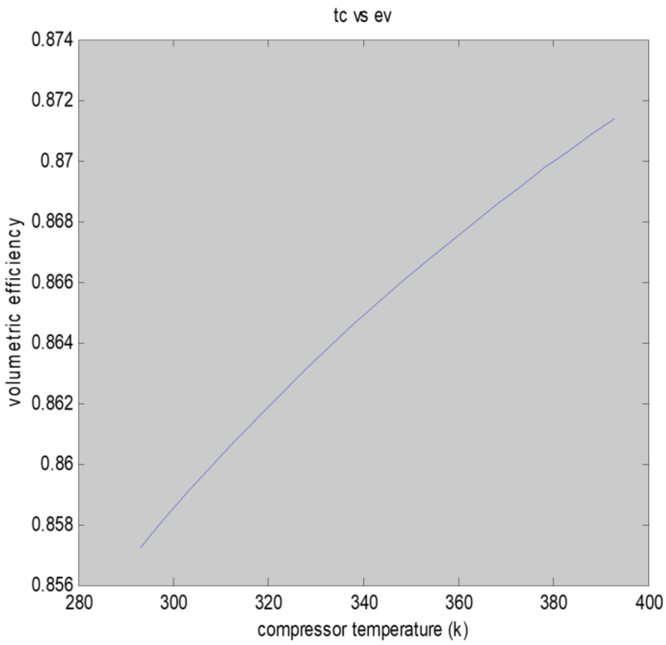

Figure 12. The compressor temperature (t_c) versus the volumetric efficiency (η_v)

2.8 The effect of the (F/A) fuel air ratio on the volumetric efficiency

Volumetric efficiency tends to decrease with increasing fuel /air ratio, which in case of diesel engine, increases the operating range of both combustion temperature and residual gas temperature which, in their turn, raise the value of heat transfer through increasing surface temperature, [16].

$$\eta_v = \left(\frac{M}{M_a}\right)\left(\frac{P_i}{P_{a,o}}\right)\left(\frac{T_a}{T_i}\right)\frac{1}{(1+F/A)}\left\{\frac{c_r}{c_r-1} - \frac{1}{\gamma(c_r-1)}\left[\frac{P_e}{P_i} + (\gamma-1)\right]\right\} \quad (2)$$

A computer program using MATLAB language (see Appendix (A)) is used to solve the mathematical model combining fuel air ratio and volumetric efficiency.

The program processes different values of the fuel air ratio versus volumetric efficiency. A flow chart illustrated in Figure 13 is drawn to show the steps of program execution. The results of the solution are shown in Figure 14.

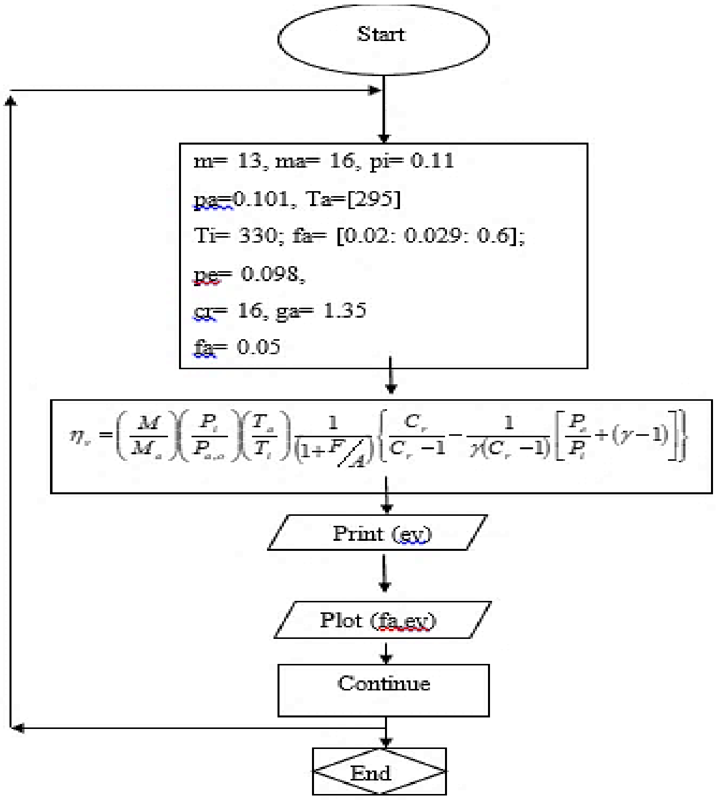

Figure 13. A flow chart showing the steps of program execution

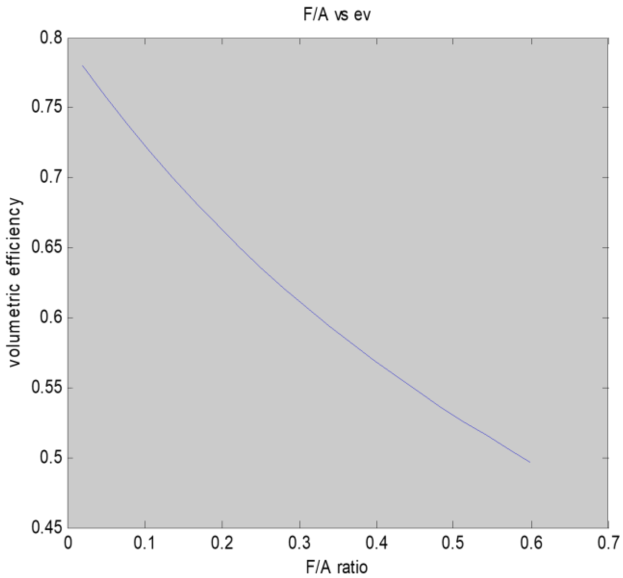

Figure 14. The variations of $\left(\frac{F}{A}\right)$ versus volumetric efficiency (η_v)

3 VOLUMETRIC EFFICIENCY AFFECTING EFFECTIVE POWER

3.1 Introduction

It is well known that the engine is the source of the energy that puts the car in motion. The engine transforms the fuel energy (input) into revolution torque (output). The power is known to be the resultant of multiplying torque by the speed of revolution in the engine. Regarding the slow speeds, the speed of the piston is slow and disintegration inside cylinders and the intake manifold is lower thus the quantity of the mixture entering to the cylinders will be consequently low leading to reduced volumetric efficiency. As the speed increases, the quantity of the fuel directed to the cylinders will be increased which will increase the volumetric efficiency coincident with speed increase.

However, as the speed of the engine increases, the flow of the mixture passing through the valves will lead to the reduction of the quantity of fuel to the cylinders causing throttling and inability of engine to breathe. Hence, at higher speeds the volumetric efficiency decreases.

Relationship between the Volumetric Efficiency and Engine Torque:

As the degree of filling (air and fuel) increases the engine torque increases, consequently the torque curve relative to the engine revolution speed is similar to the volumetric efficiency curve. At the slow revolution speeds, the volumetric efficiency is low and hence the torque. As the speed increases the volumetric efficiency increases and hence the torque at the speed with the maximum volumetric efficiency then the torque is maximum. As speed increases beyond that, the degree of filling decreases due to the throttling of the entering mixture followed by torque reduction. In addition, the effective power of engine increases with torque increasing and vice versa.

In the previous chapter the volumetric efficiency was subjected to the effect of different parameters like air pressure (p_a), air temperature (t_a), change of heat (ΔT), residual gas pressure (P_r), compression ratio (c_r), (F/A) fuel air ratio, and compressor temperature (t_c). The resultant volumetric efficiency is introduced into the equation of the effective power (Equation (3)), [19] – [22].

$$n_e = \frac{v_h \times i \times n}{30 \times \tau} \times \frac{h_u}{\alpha \times l_o} \times \rho_k \times \eta_v \times \eta_i \times \eta_m \qquad (3)$$

Where:

n_e $effective\ power\ (W).$
v_h $swept\ volume.$
i $Number\ of\ cylinders.$
n $Engine\ speed\ (rpm).$
h_u $fuel\ heating\ value.$
$\propto$ $real\ quantity\ of\ air\ for\ complete\ combustion\ of\ unit\ fuel.$
l_o $theoretical\ quantity\ of\ air\ for\ complete\ combustion\ of\ unit\ fuel.$
ρ_k $Density\ of\ air\ \left(\frac{kg}{m^3}\right).$
η_v $Volumetric\ efficiency.$
η_i $Indicated\ efficiency.$
η_m $Mechanical\ efficiency.$
τ $Stroke.$

The new form of the effective power equation after introduction of this new volumetric efficiency will be discussed and analyzed in this chapter.

The study of volumetric efficiency resulting from the effect of the above – mentioned parameters on the effective power would be explained as will be described follows:

3.2 The effect of atmospheric pressure (p_a) – Subjected volumetric efficiency on the effective power

Figures 15, 16, and 17 show the result of the air pressure and subjected volumetric efficiency on the effective power. The maximum value of the effective power obtained (4.1489×10^4 W) under the influence of volumetric efficiency of value (85.84%) subjected to an air pressure of (0.1020) MPa.

Taking that into consideration, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of (4.1489×10^4 W), and then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

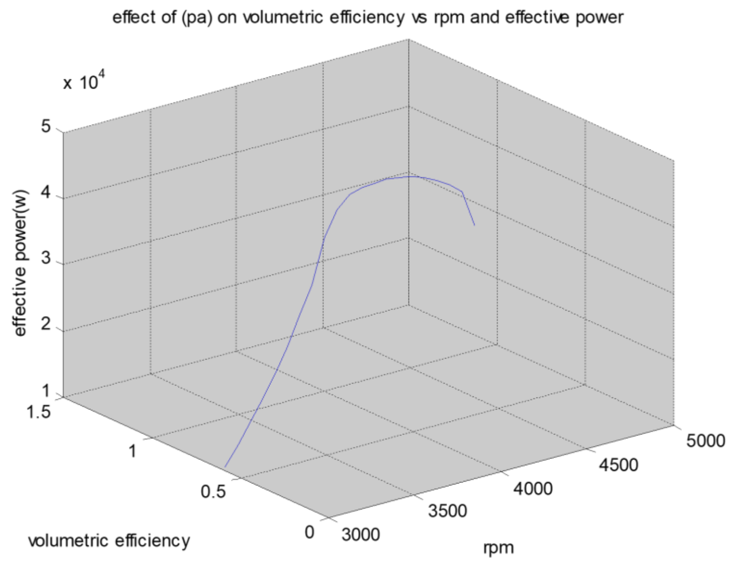

Figure 15. The effect of subjected volumetric efficiency on the effective power

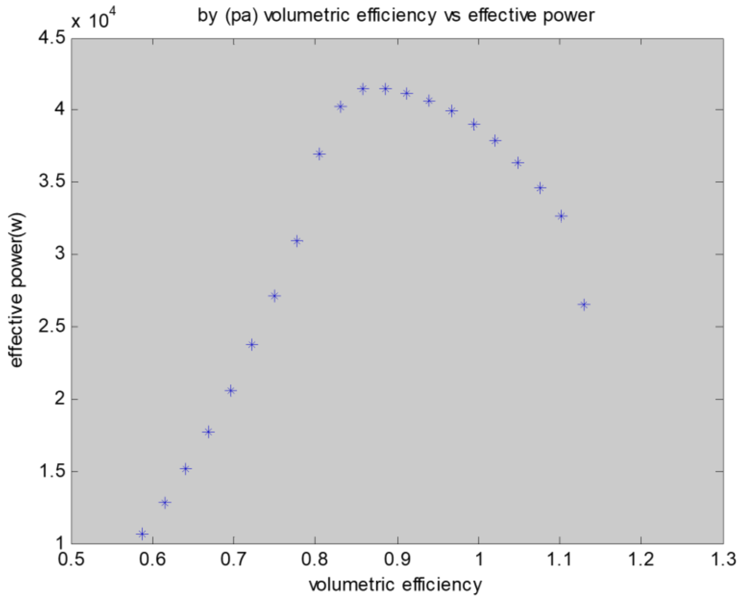

Figure 16. The effect of subjected volumetric efficiency on the effective power

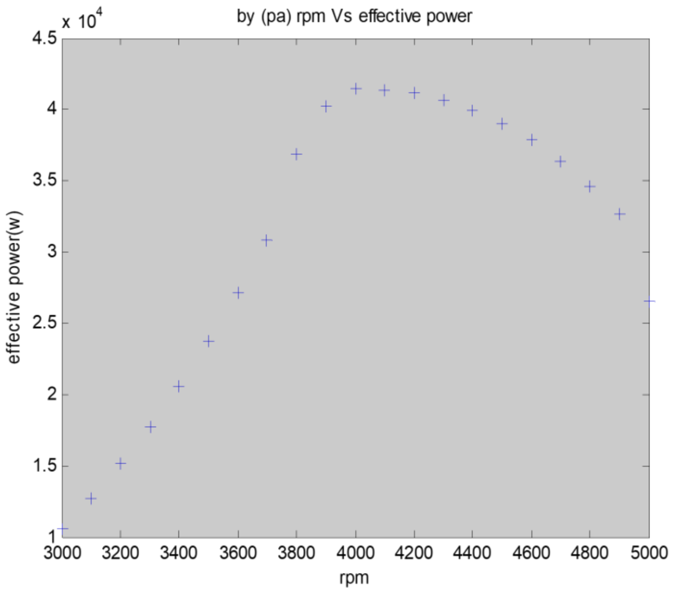

Figure 17. The effect of subjected engine speed on the effective power

3.3 The Effect of air temperature (t_a) – Subjected volumetric efficiency on the effective power

Figures 18, 19 and 20 show the impact of air temperature–subjected volumetric efficiency on the effective power. The maximum value of the effective power obtained is equal to (3.7600×10^4W) under the influence of volumetric efficiency of value (77.80%) subjected to an air temperature of (303K).

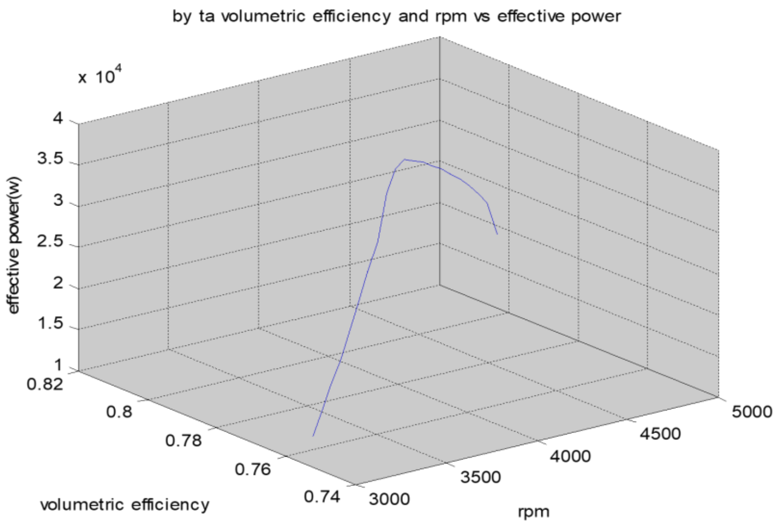

Figure 18. The effect of subjected volumetric efficiency on the effective power

Considering those, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of (3.7600×10^4W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

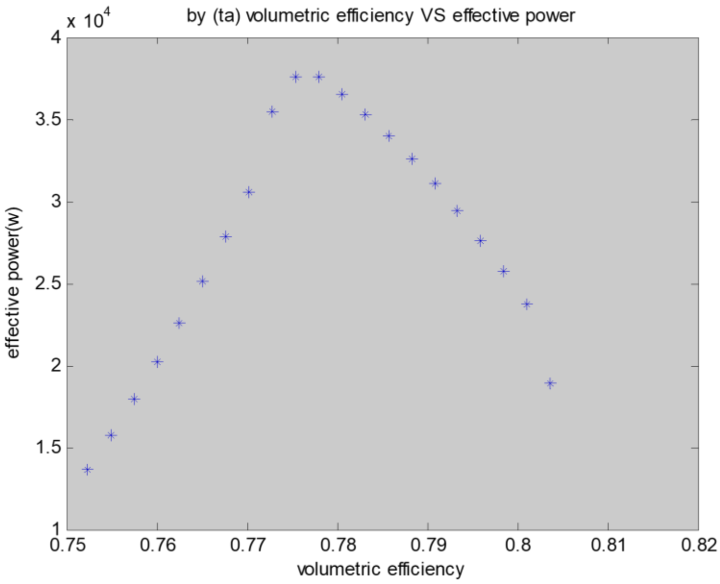

Figure 19. The effect of subjected volumetric efficiency on the effective power

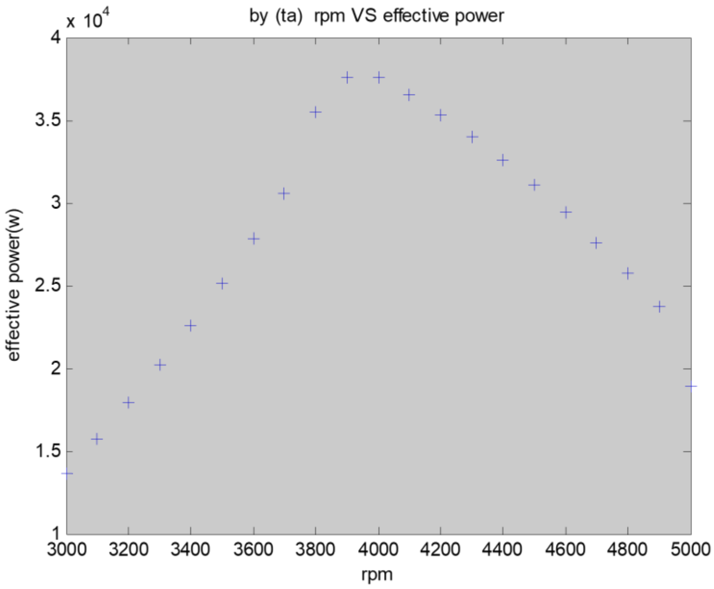

Figure 20. The effect of subjected engine speed on the effective power

3.4 The effect of compression ratio (c_r) – Subjected volumetric efficiency on the effective power

Figures 21, 22, and 23 show the effect of the compression ratio (c_r) – subjected volumetric efficiency on the effective power.

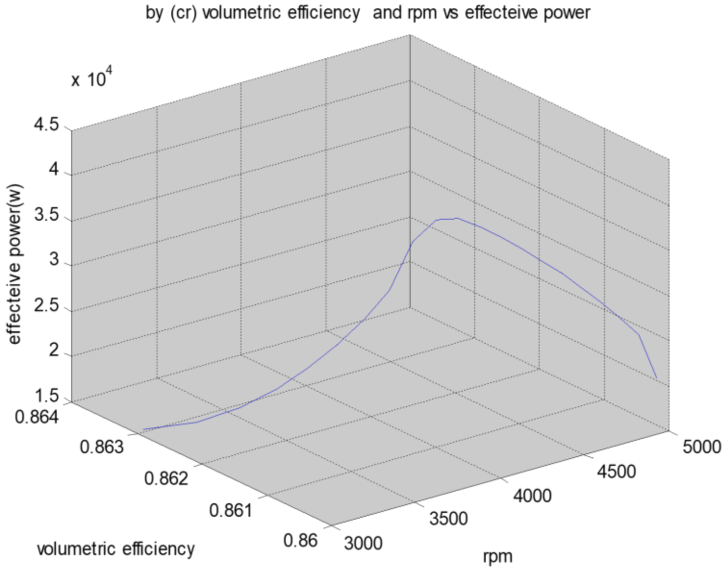

Figure 21. The effect of subjected volumetric efficiency on the effective power

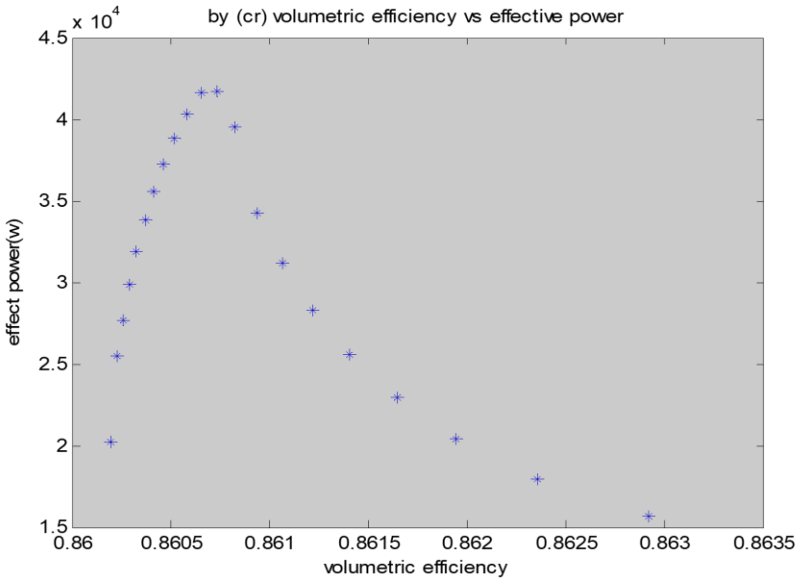

Figure 22. The effect of subjected volumetric efficiency on the effective power

The maximum value of the effective power obtained is equal to ($4.1686{\times}10^4$W) under the influence of volumetric efficiency of value (86.07%) subjected to compression ratio of (15).

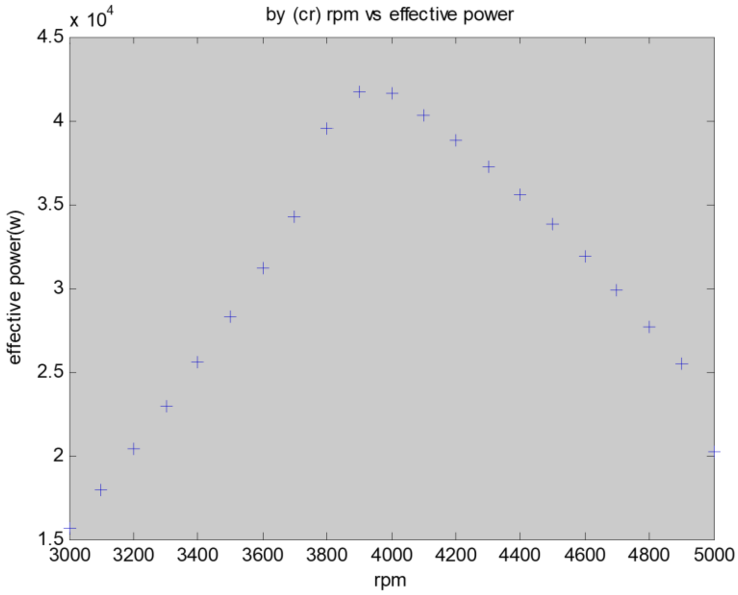

Figure 23. The effect of subjected engine speed on the effective power

Considering those, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of ($4.1686{\times}10^4$ W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

3.5 The Effect of residual gas pressure (p_r) – Subjected volumetric efficiency on the effective power

Figures 24, 25 and 26 show the effect of the residual gas pressure (p_r) – subjected volumetric efficiency on the effective power.

The maximum value of the effective power obtained is equal to ($4.1407{\times}10^4$W) under the influence of volumetric efficiency of value (85.50%) subjected to residual gas pressure of (0.1090 MPa).

Considering the above results, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of ($4.1407{\times}10^4$W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

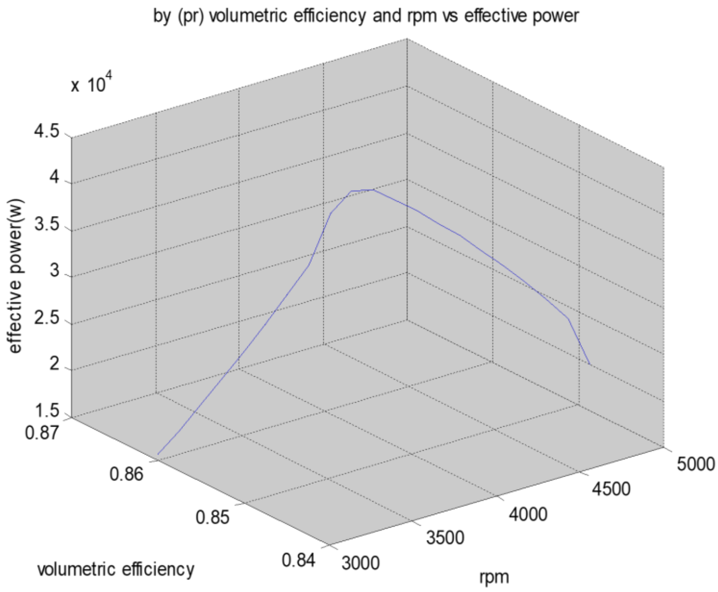

Figure 24. The effect of subjected volumetric efficiency on the effective power

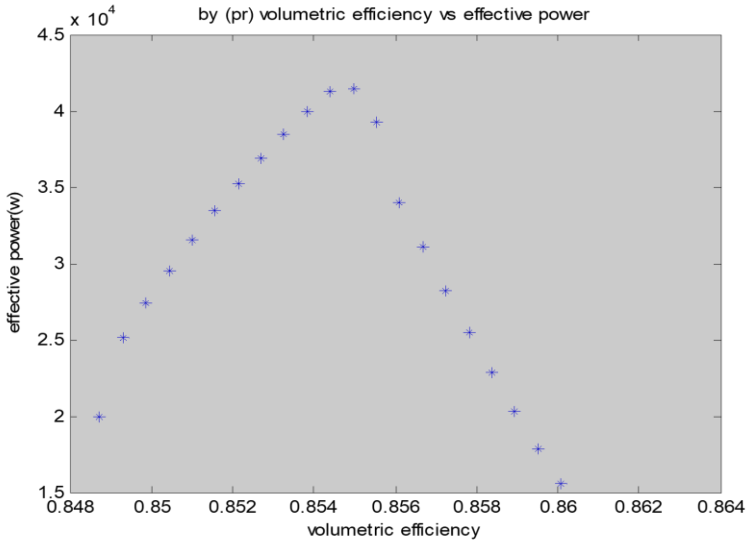

Figure 25. The effect of subjected volumetric efficiency on the effective power

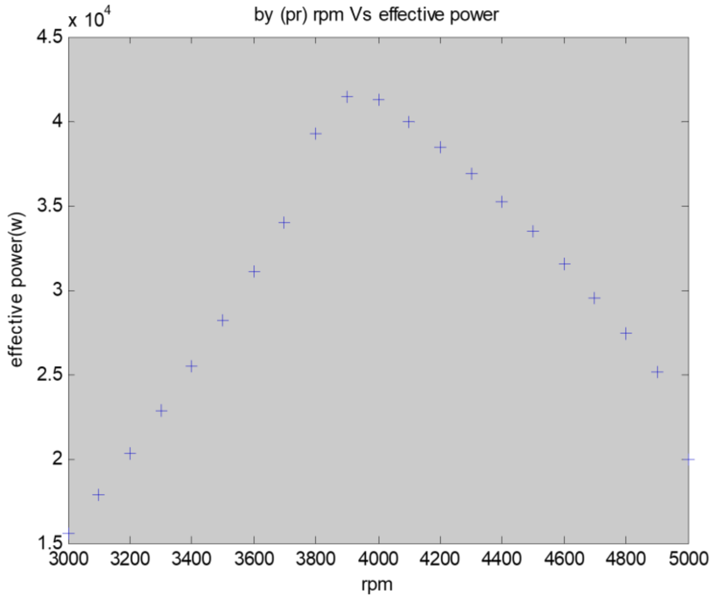

Figure 26. The effect of subjected engine speed on the effective power

3.6 The effect of variation change of temperature (ΔT) – Subjected volumetric efficiency on the effective power

Figures 27, 28 and 29 show the effect of the(dt) – subjected volumetric efficiency on the effective power.

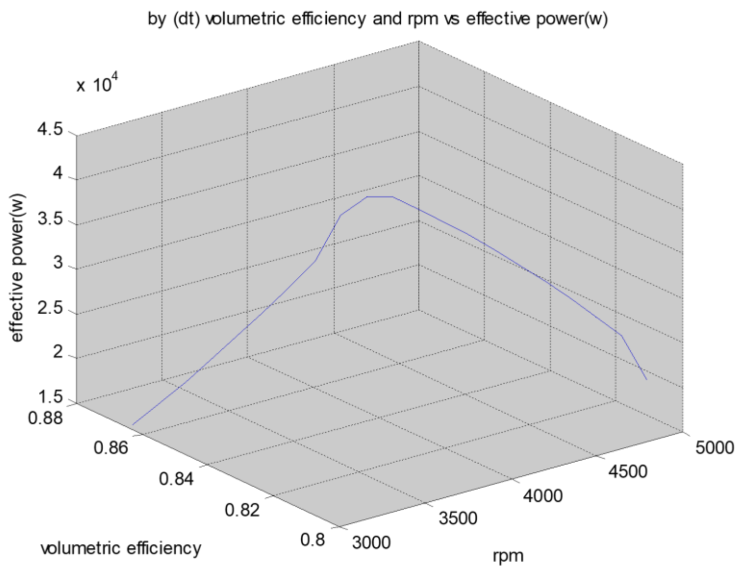

Figure 27. The effect of subjected volumetric efficiency on the effective power

The maximum value of the effective power obtained (4.0609×10^4W) under the influence of volumetric efficiency of value (83.85%) subjected to variation of temperature (27).

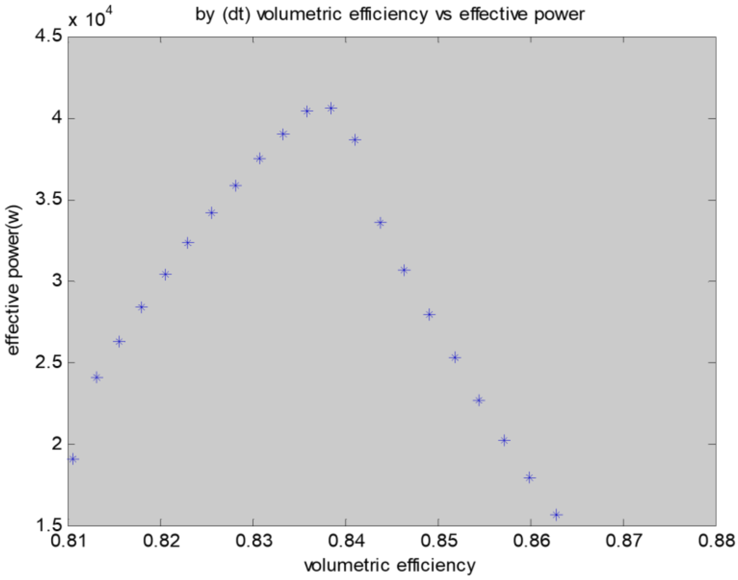

Figure 28. The effect of subjected volumetric efficiency on the effective power

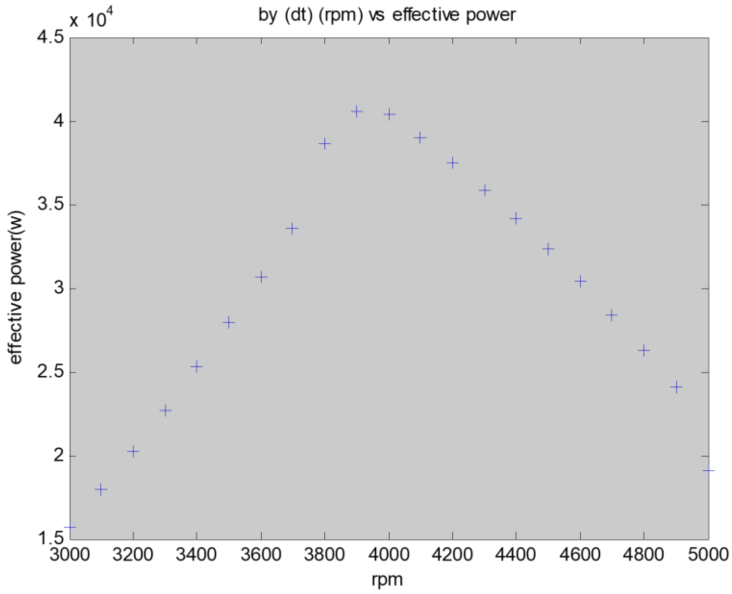

Figure 29. The Effect of Subjected Engine Speed on the Effective Power

Considering those, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of (4.0609×10^4W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

3.7 The effect of compressor temperature (t_c) – Subjected volumetric efficiency on the effective power

Figures 30, 31, and 32 show the effect of the (t_c) – subjected volumetric efficiency on the effective power. The maximum value of the effective power obtained is equal to (4.1874×10^4 W) under the influence of volumetric efficiency of value (86.46%) subjected to temperature (338 K).

Considering those, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of (4.1874×10^4 W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

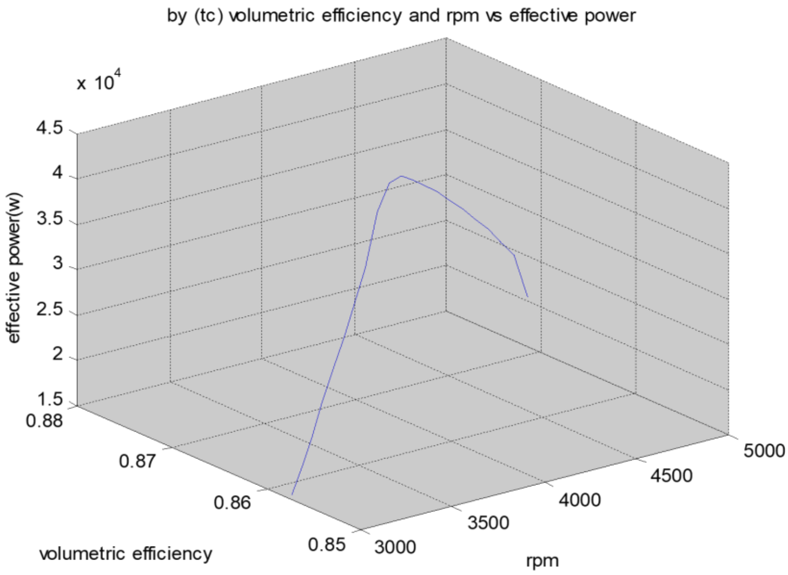

Figure 30. The effect of subjected volumetric efficiency on the effective power

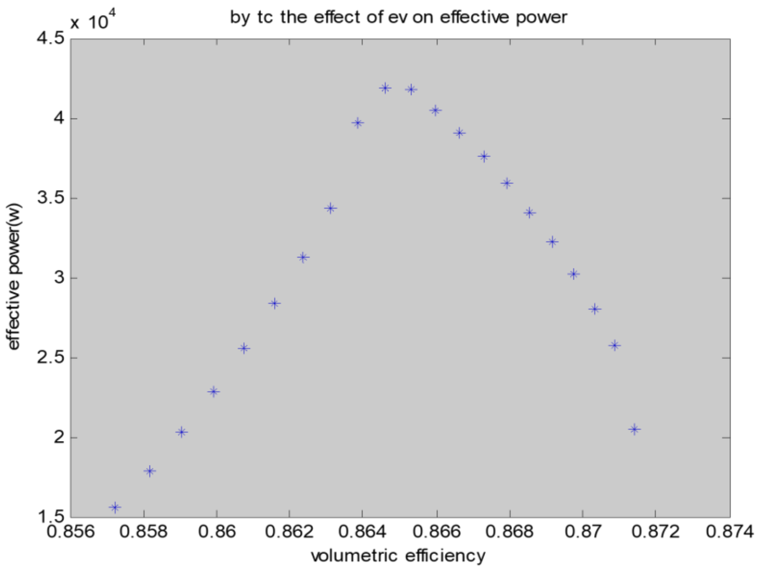

Figure 31. The effect of subjected volumetric efficiency on the effective power

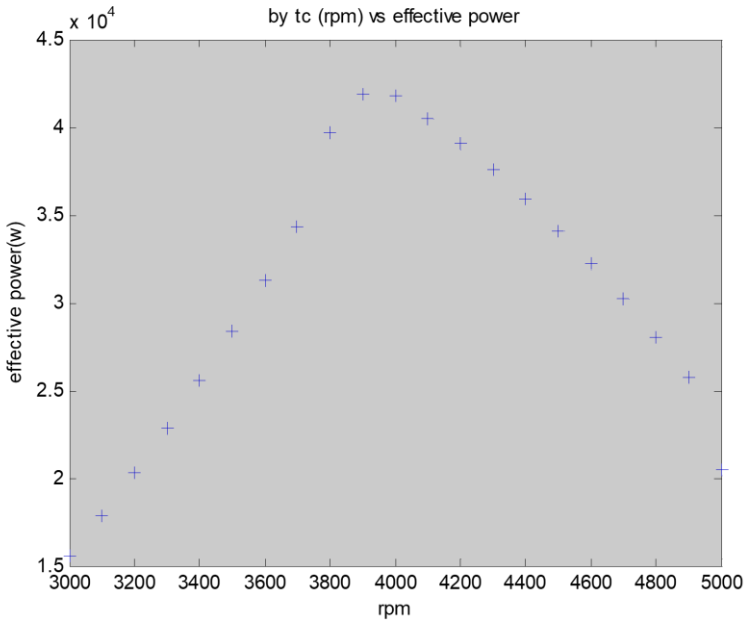

Figure 32. The effect of subjected engine speed on the effective power

5.8 The effect of (F/A) fuel air ratio – Subjected volumetric efficiency on the effective power

Figures 33, 34 and 35 show the effect of the (F/A) – subjected volumetric efficiency on the effective power. The maximum value of the effective power obtained is equal to (3.0069×10^4 W) under the influence of volumetric efficiency of value (62.09%).

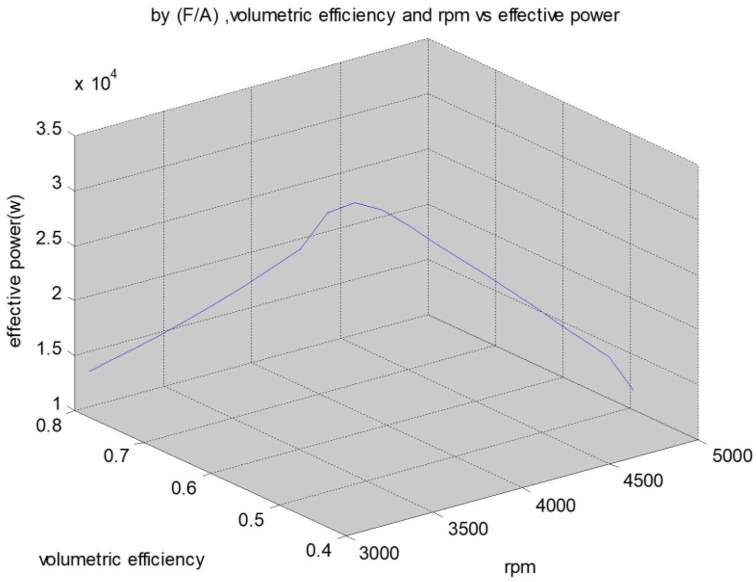

Figure 33. The effect of subjected volumetric efficiency on the effective power

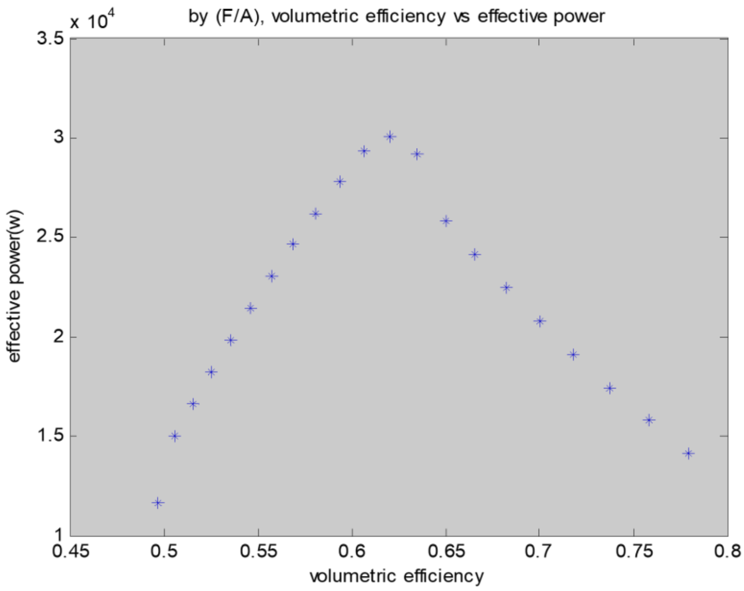

Figure 34. The effect of subjected volumetric efficiency on the effective power

Considering those, the effective power starts to increase with volumetric efficiency increase until arriving to the maximum value of (3.0069×10^4 W) then it starts to decrease regardless of the increase in the volumetric efficiency due to the throttling caused by high speeds.

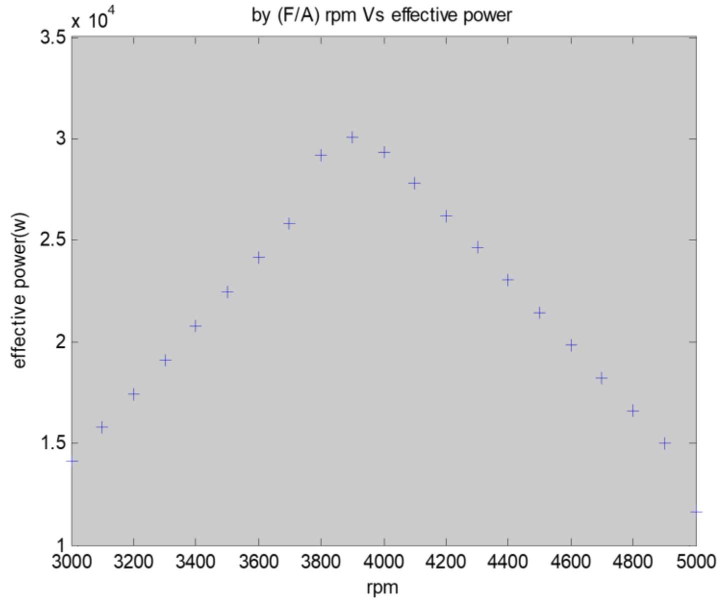

Figure 35. The effect of subjected engine speed on the effective power

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The impact of variation of volumetric efficiency on the effective power of deck's engine has been assessed by introducing the varied values of the former equation of the effective power. This has been done by subjecting volumetric efficiency to various mechanical operating parameters namely air temperature (T_a), air pressure (P_a) compressor temperature (T_c), compression ratio (C_r), fuel/air ratio (F/A), residual gas pressure (P_r) and variation of temperature (ΔT). Equations relating each of the above parameters with volumetric efficiency were written in MATLAB language and the resultant values were introduced into effective power equation. The following general remarks could be made about the outcomes of this study:

1. Air temperature (T_a), air pressure (P_a) and compressor temperature (T_c) are directly proportional to volumetric efficiency.
2. Compression ratio (C_r), fuel/ air ratio (F/A), residual gas pressure (P_r) and variation of temperature (ΔT), are inversely proportional to volumetric efficiency.

3. Of all parameters studied, It was found that compressor temperature (T_c) have the greatest effect on volumetric efficiency and hence the higher effective power.
4. Various values of residual gas pressure (P_r) were tried. The value (0.109Mpa) was found to give the maximum volumetric efficiency with particular parameter.
5. Various values of air temperature (T_a) were tried. The value (303 K) was found to give the maximum volumetric efficiency with particular parameter.
6. Atmospheric temperature showed some normality in that, it is directly proportional to volumetric efficiency and inversely proportion to effective power.
7. Compression ratio (C_r) was tried by feeding various value of it into equation (5.1). The value of (15) was found to give the heights volumetric efficiency and maximum effective power.
8. The lowest effect is given by (*F/A*) Ratio which is inversely proportional to volumetric efficiency and thus effective power. Low value of this parameter will give improved volumetric efficiency and effective power.

4.2 Recommendations

From the results of the research, the following points are recommended:

1. Experimental verification is essential to verify the output of this research since the poor and ill-acquired research facilities proved to be inefficient hindering.
2. The air temperature (T_c) requires extensive study due to its robust proportionate effect on the volumetric efficiency and hence on the output power.
3. The (*F/A*) ratio is also in need of more detailed study, since it has inverse effect on the volumetric efficiency and in turn the output power.

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