International Baccalaureate

Physics Extended Essay

May 2017

How does the increase in expansion/compression ratio of an internal combustion engine change its efficiency when compression ratio is kept constant?

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1. Abstract

The main purpose of this experiment is to investigate the effect of expansion/compression ratio on efficiency of an internal combustion engine. Efficiency of internal combustion engines are affected by compression ratio, expansion/ compression ratio, internal friction and many other factors. Compression ratio is the factor affecting on the fuel combustion process mainly affects the combustion pressure, as compression ratio increases, fuel solubility therefore released energy increases. Expansion is the process of converting pressure produced by heat, into kinetic energy. With enough expansion ratio pressure inside the combustion chamber can equalized to the pressure outside pressure. With optimization of these two ratios, useful energy produced from unit amount of fuel can be increased. To conserve fuel burning efficiency and increasing expansion ratio, first I determined what expansion/compression ratio to test and then calculated the volume need to be reduced in the combustion chamber to fix compression ratio at eight and increase expansion ratio. To reduce volume, metal pieces were bolted on the cylinder head, graduated cylinder was mounted on the fuel tank. To make results closer to real life usage, 2 kilos of cylindrical mass was bolted on the crankshaft. In each test same amount of fuel was used, RPM was kept constant in each run, times were recorded for each setup. Each configuration of expansion/compression ratio is tested for four times. Four different time data for each expansion/compression ratio configuration summed and divided by four to get average time. To calculate average percentage efficiency gain, average time of running for each expansion/compression ratio configuration was divided by the average time of configuration with expansion/compression ratio of 1 and 1 was subtracted and divided by 100. Graphs show that efficiency increases as expansion/compression ratio increases.

Word Count: 284

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2. Introduction

The aim of this study is to test the effect of cycle of internal combustion engine. Internal combustion engine was invented in late 18's by Karl Benz. With internal combustion engines invention, production of compact and efficient power plants has enabled. This mobility and wide range of usage is achieved by its small size, higher efficiency, low cost, being more environmental friendly and safe working capabilities compared to external combustion engine and other engines using other types of fuel.

During the working process of internal combustion engine, there are mechanical friction between moving parts and pressure applied on piston affecting engines efficiency. Heat loss to exhaust gases and environment is another issue affecting combustion process. This information indicates that besides mechanical design, the burning process is the key for efficiency. Cycle, compression ratio, expansion ratio, pressure and temperature are some of the main factors that have effect on fuel burning process. However, cycle is the only factor that can affect other properties that may change fuel burning characteristic of engine. Cycle is consecutive processes that continuously repeat themselves in a specific order, which take place in combustion chamber. Focus of this study is observing the difference between Atkinson and Otto Cycle and their effect on engines efficiency.

I have chosen this topic for my investigation because I have grown with Formula 1 cars and their screaming V10 engines at 22.000 RPM and rally car thanks to my dad and his friends who are also into motorsports. Even today, any high revving, high-pitched sounded engines still makes me smile. Ever since I could remember, I have always keen on them and I think Michael Schumacher has also a great influence on me. When I get old enough, I begun searching and learning what makes F1 and other race series cars super fast, so what makes a tiny engine produce so much power.

3. Background Information

3.1 Internal Combustion Engine

An internal combustion engine is a compact, cheap and portable power source with low maintenance cost. They are widely used in cars and transportation vehicles. Internal combustion engine produces mechanical energy by burning liquid and gas fuels in pressurized combustion chamber. Burning the fuel heats the air in the combustion chamber and results in increase of pressure as well as the gas molecules formed during the combustion event. This increased pressure of gas in the combustion chamber applies force on piston and pushes it down. This downward linear motion converted into rotational motion by a crankshaft.

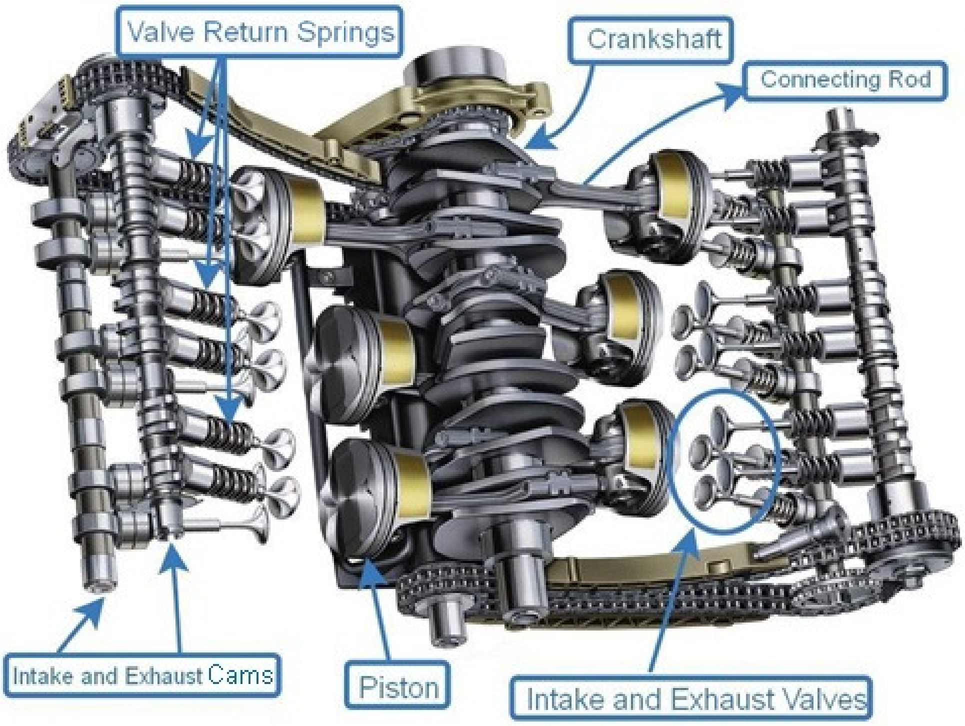


Figure 1: General components of an internal combustion engine

3.2 Properties of Valves

Gas exchange of combustion chamber is provided by valves. Valves are controlled by eccentric shaft, which is rotating at half of the speed of crankshaft. Cam lobes on the camshaft push the valves and let gases to transfer. There are three properties of valves: valve duration, valve lift (distance that valve pushed from the cylinder head) and timing (timing enables valves to vary their opening and closing times but not duration).

3.2.1 Valve Duration

Cam duration determines for how long valves held open, letting gas exchange, in terms of crankshaft degree angle. It is determined by angle of the arc that is under the nose. It can provide more time for gas exchange on low RPM range and less time on high RPM range.

3.2.2 Valve Lift

Valve lift is how much further valve is pushed away from the cylinder head to allow gas transfer in combustion chamber. Valve lift can affect the turbulence formed in the combustion chamber and the amount of air entering the cylinder. It is determined by the distance between the nose (vertex) of the cam and base circles closest point to nose.

3.2.3 Valve Timing

With the help of the valve timing, amount of the air sucked into cylinder can vary. This is related to effective combustion volume. If an intake valve advances to open, it also advances to close, this reduce the amount of air sucked into cylinder besides fuel, creating a smaller volume engine. Because valve duration is controlled by solid metal camshafts and can not be changed while engine is running, valve timing provides some ability to control gas exchange properties.

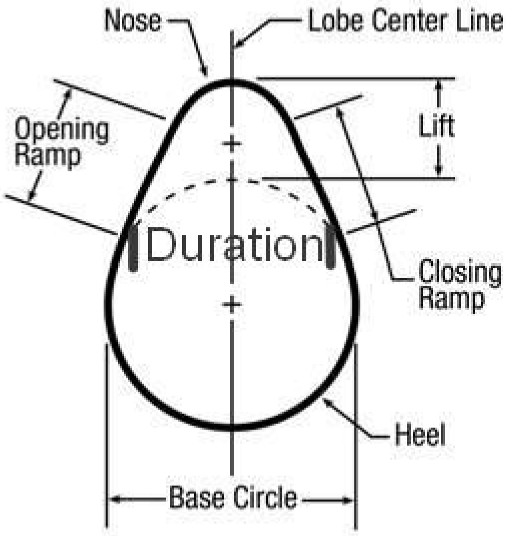


Figure 2: Profile of a cam lobe and the cam lobe's block analysis.

3.3 Compression Ratio

Compression ratio is volume of the combustion chamber just after the intake valve closed (V_1+V_2) divided by the volume of the combustion chamber when piston is at the top dead center (TDC), formulized as $(V_1+V_2)/V_1$. To start a combustion reaction, energy must be given to ignite the fuel but this energy is not enough for a complete combustion. There are other factors effecting combustion process such as solubility and temperature. Compression stroke enables higher efficiency because increasing pressure of air increases solubility of fuel particles. Increased solubility of fuel enables more carbon-hydrogen and carbon-carbon bonds to break therefore releasing more heat to air in the combustion chamber. Temperature has effect on ignition process, if temperature is hot enough, fuel can ignite itself with the energy it absorbed from the combustion chamber and this is directly related to the compression ratio, because if a gas compressed quickly, it heats up.

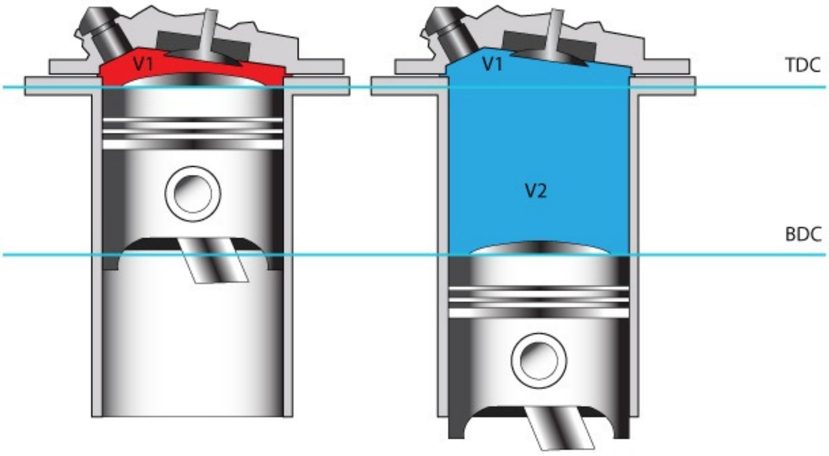


Figure 3: Diagram of the volumes when piston is at the bottom dead center and top dead center, which shows the compression ratio.

3.4 Expansion Ratio

Expansion ratio can be defined as how much the compressed air fuel mixture in the cylinder is expanded after the ignition. This ratio is visualized in the Figure 3 as V_3/ V_1, where V_1 is volume of the cylinder when piston is at top dead center (TDC) and V_3 is the volume of the cylinder before exhaust valve opens. To build an efficient engine, pressure inside the cylinder, which is provided by the heat released from the fuel, has to be as close as possible to the pressure value outside the piston. This means the pressure inside the cylinder when piston reaches bottom dead center (BDC) after the combustion should be neither more nor less than the pressure outside the piston. If the pressure in the cylinder is greater than the outside pressure before exhaust valve opens, it means air did not expand enough to equalize pressure and give its all energy to piston as force applied by pressure. If the pressure in the cylinder is less than the outside pressure before exhaust valve opens, backpressure is applied on piston, which slows the piston. Based on this information, optimizing compression/expansion ratio enables engine to get maximum out of fuel.

3.5 Cycle of an Internal Combustion Engine

Internal combustion engine has to perform basic strokes in an order to get maximum energy from the fuel and continuity keeps engine running. Cycle is a simple algorithm for internal combustion engine. There are four basic strokes: intake, compression, power and exhaust. These strokes are commonly took place in different cycles, such as six stroke water injected cycle. However due to the practicality of application of water injection it is not common. Most of the production engines are engineered to run Diesel, Otto and Atkinson, dependent on the application. Although these three cycles are based on same four strokes, they are different from each other by factors such as ignition method, compression/expansion ratio.

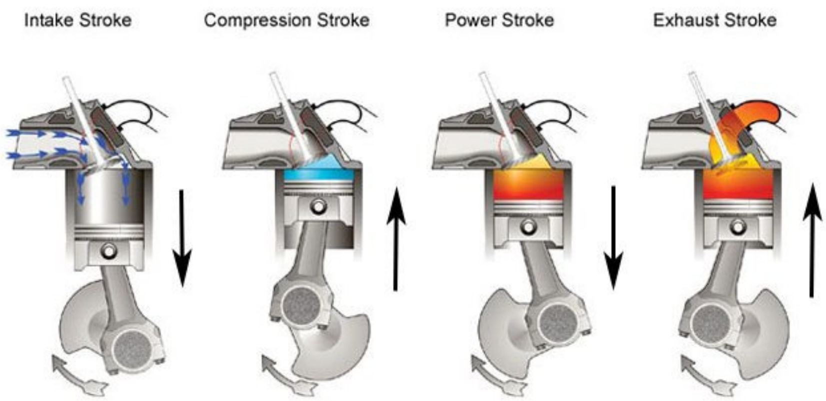


Figure 4: Basic four strokes of an internal combustion engine

3.5.1 Otto Cycle

Otto cycle is the most used cycle for gasoline engines. It has four strokes: Intake, compression, power and exhaust. Otto cycle has spark plug ignition system. Otto cycles compression ratio is equal to its expansion ratio. Therefore, there is some excessive pressure left in the cylinder before exhaust valve opens, which can be used to push piston further down for maximum possible efficiency. General theoretical efficiency equation for the Otto cycle engines is

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

where r is compression ratio and k is specific heat ratio of air but this formula does not include factors such as friction and temperature, which have impact on efficiency. Another term might be useful for this experiment about internal combustion engines is mean effective pressure

$$MEP = \frac{W_{net}}{V_{max} - V_{min}}$$

where V_{max} is maximum, V_{min} is minimum volume of combustion when piston is at bottom dead center and top dead center respectively and W_{net} is net work done by piston.

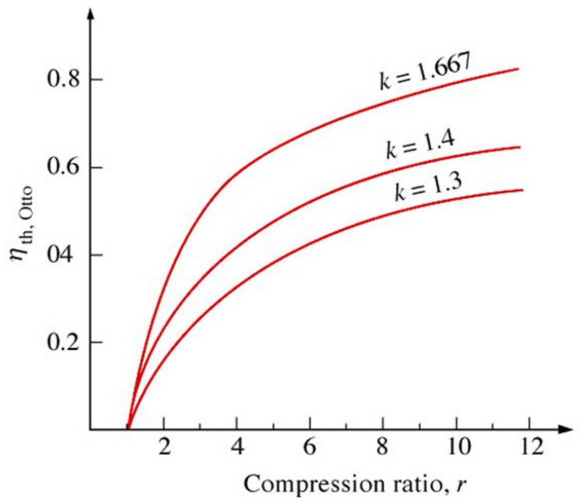


Figure 5: Otto cycle efficiency curve with variables compression ratio and specific heat ratio

3.5.2 Atkinson Cycle

Atkinson cycle was invented to make internal combustion engines more efficient. Its main aim is to increase efficiency by fully using the pressure produced by heat of burning fuel. This is achieved by expanding the air in the combustion chamber more than it compressed provided by the expansion/compression ratio higher than one. Atkinson cycle engines are not common for production engines because of their lower power output compared to Otto cycle engines. They mostly used in hybrid vehicles for range extending applications. Atkinson cycle engines are more efficient than Otto cycle engines due to its greater expansion /compression ratio.

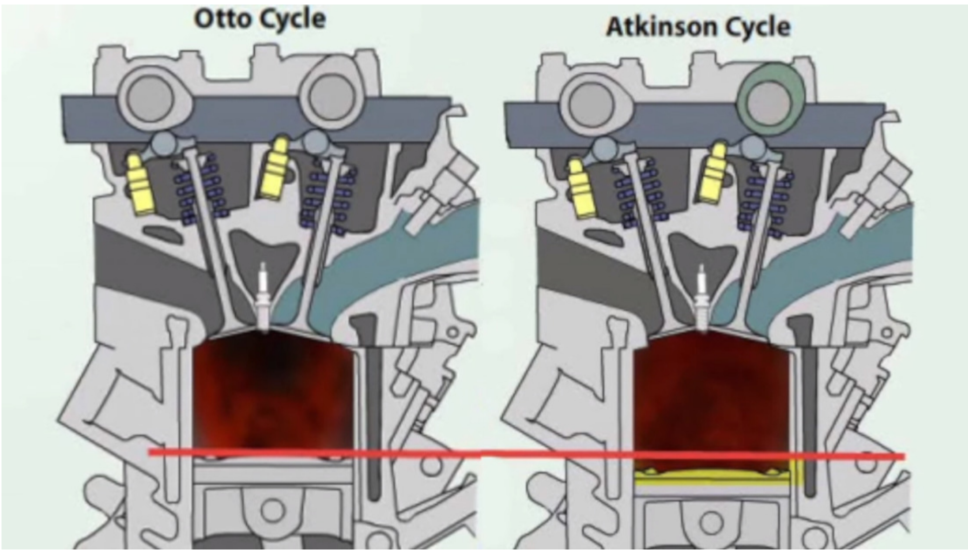


Figure 6: The figure showing the difference between the Otto and Atkinson cycles' intake cam lobes

3.6 Torque

Torque is vector quantity of force applied on a pivoting object around a center, performing circular motion. Its formula is $\tau = \vec{F} \times r$ where r is distance from pivoting center where $\vec{F}$ is applied vertically on rotating arm. If force applied in an angular direction, force is multiplied by sinus of angle between the direction of force and the rotating arm.

$$\tau = \vec{F} \times r \times \sin\theta$$

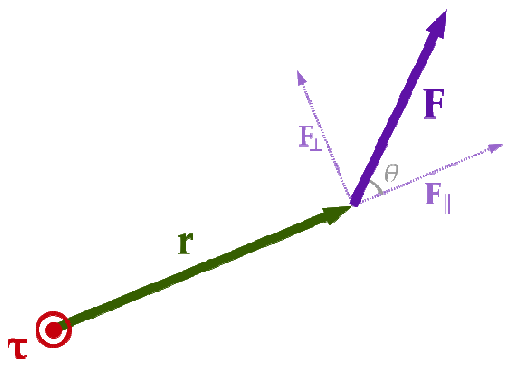


Figure 7: Diagram of torque

3.7 Ideal Gas Law

Ideal gas law is an equation that is used to determine pressure, volume, mole amount and temperature of a gas in different conditions. Its formula is $P \times V = n \times R \times T$. P stands for pressure in Pascal, V for volume in cubic meter, T for temperature in Kelvin unit, n is Avogadro's number and R is gas constant. It is used to calculate the pressure when temperature, mole of gases and volume is constant.

4. Design

4.1 Research Question

How does the increase in expansion/compression ratio of an internal combustion engine change its efficiency when compression ratio is kept constant?

4.2 Hypothesis

Every internal combustion engine runs dependent on the cycle. Cycle is the key for engines characteristics because it controls some important features of engine; these features are compression, expansion ratio and cam timing for this experiment. In every internal combustion engine, there is little pressure left inside the combustion chamber after the ignition when piston is at the top dead center due to insufficient expansion ratio and this pressure on the cylinder is directly transmitted to the crankcase, rather than being converted into useful torque because of crankshafts angle with connecting rod. Anything that is not converted into useful torque is inefficiency in internal combustion engine. Thus, Atkinson cycle is aiming to reduce the pressure left in the combustion chamber without creating negative pressure on piston by making expansion/compression ratio higher than 1. In other words, making the pressure in the combustion chamber closer to the pressure outside the piston will make the more efficient.

4.3 Variables for Experiment

Independent Variable: Expansion/compression ratio (Intake valve duration dependent on the intake cam's lobe profile)

Dependent Variable: Time of working with same amount of fuel (Efficiency)

Controlled Variables:

1. Intake Air Temperature

Intake air temperature should be controlled since it affects its density and pressure, which determines the amount of air sucked into the cylinder. Higher temperatures make air less dense, which decreases the amount of oxygen molecules sucked into the combustion chamber. To maximize the consistency of the experiment, there must be always same mole of air in the combustion chamber. Using the formula $PV = nRT$ mole amount of air stabilized, where n, R and T are constant and P is inversely proportional to the V.Since the air pressure in the intake manifold is variable for every value independent variable, intake air temperature should be kept constant at 25° Celsius (298.5° Kelvin).

2. Fuel Type

Every fuel has its own characteristic properties, varied in air/fuel mixture ratio (ratio that specifies the amount (mass) of air needed to burn unit amount of fuel, stoichiometric ratio), auto ignition temperature, energy density (amount of heat released by burning unit amount of fuel) and all these factors play a crucial role on thermodynamics of the engine. Every cylinder in engines has a specific amount of air it can suck, so the amount of fuel injected varies by its type. For example, air/fuel mixture ratio of gasoline is 14.7, ethanol is nine, and because they have different specific energy densities, heat released after the combustion is different.

3. Lubrication Oil Viscosity

Some parts of the internal combustion engines, like crankshaft and piston, needs to be lubricated to reduce friction on moving metal parts. This also reduces wear on parts but viscosity of oil might increase pumping loss. This effect is actually caused by difference of the thickness of the oil layer on metal parts.

4. Rotating Mass

In this experiment, to get closer results to real life usage of internal combustion engines, 2 kilos of mass should be fitted on crankshaft to measure and calculate the fuel usage and efficiency. To compare the fuel usage between two cycles, weights on the crankshaft will be kept same.

5. Combustion Chamber Volume

Because Atkinson cycle is provided by the valve timing, effective compression ratio is affected by the valve timing. If not balanced by volume of combustion chamber at top dead center, piston compresses air fuel mixture less than the original compression ratio, causing less pressure at compression stroke, which also causes experiment to be inconsistent since the aim of the study is to investigate the effect of the cycle. Decreases in pressure at the compression stroke also decreases solubility of the fuel, which make the experiment incoherent again. To prevent this fatal mistake, pressure is calculated for each setup based on the compression ratio and the amount of volume need to be reduced in the combustion chamber volume is calculated.

6. Pressure Inside the Intake Manifold and Outside the Piston

Pressure can change the mole amount of gas in unit volume, in this sense difference in pressure, can change the amount of oxygen molecules in the combustion chamber therefore fuel burning capacity of the setup and the expansion/compression ratio and energy produced. Pressure outside and inside the piston can create pressure difference, which causes a force piston in any direction, affecting the net force transmitted to the crankshaft. For these reasons, pressure inside the intake manifold and outside the piston must be equal to each other and same for every expansion/compression ratio configuration.

4.4 General Description of Equipment

Essential equipment used in this experiment is listed and described below.

1. An internal combustion engine with 10 camshafts with different durations and same lifts
2. Gasoline fuel for engine (Unleaded 98 octane gasoline)
3. Tachometer (revolutions per minute)
4. Solid weight (2 kg)
5. Lubrication oil (10W-40)
6. Pressure controlled chamber with temperature controlling function

7. Graduated Cylinder (ml)
8. Metal pieces to reduce volume in combustion chamber

4.5 Experiment Description

1. Set the temperature to 25 degree Celsius (298.15° Kelvin) by temperature controlling chamber.
2. By using pressure controller, stabilize pressure around the engine for each intake camshaft setup.
3. Mount the internal combustion engine in the chamber placed on the bench above the ground.
4. Fit the 2 kilos of cylindrical mass on the crankshaft.
5. Apply the reflective mark on the cylindrical masses.
6. Glue the graduated cylinder on top of the fuel tank inlet.
7. Reduce volume of the combustion chamber by bolting metal pieces on to the cylinder head, place the engine in pressure-controlled chamber and set the pressure to the 100 kPa for each camshaft.
8. Fill the lubrication oil in the engine.
9. Connect an iron pipe to the exhaust for transferring the exhaust gases.
10. Full the tank and fill the graduated cylinder add 20 milliliters more when fuel level reaches the 96.56 ml, adjust fuel flow controller.
11. Start the engine and set the throttle for 1800 RPM.
12. Let the engine run until fuel level on graduated cylinder reaches 96.56 and start chronometer and recording the data on digital tachometer.
13. Let the engine cool for 30 minutes than repeat the experiment 3 more times.

14. Repeat the steps 7 to 13 for all 10 different intake camshafts and their specific pressure rates, which are defined and listed below in Table 1.

	Theoretical Compression Ratio	Theoretical Expansion Ratio
1	8.00:1	8.00:1
2	7.66:1	8.00:1
3	7.33:1	8.00:1
4	7.00:1	8.00:1
5	6.66:1	8.00:1
6	6.33:1	8.00:1
7	6.00:1	8.00:1
8	5.66:1	8.00:1
9	5.33:1	8.00:1
10	5.00:1	8.00:1

Table 1: Expansion and compression ratios.

5. Data Collection and Processing

5.1 Raw Data

Effective Expansion/Compression Ratio	Trials	Amount of Used Fuel (ml) (±0.01)	Average RPM (revolutions per minute) (±1)	Time (seconds) (±0.01)	Average Time (seconds) (±0.04)
1.000	1	96.56	1800	59.64	60.24
	2	96.56	1800	60.20	
	3	96.56	1800	60.54	
	4	96.56	1800	60.65	
1.044	1	96.56	1800	60.18	60.56
	2	96.56	1800	60.29	
	3	96.56	1800	60.87	
	4	96.56	1800	60.90	
1.092	1	96.56	1800	60.55	60.87
	2	96.56	1800	60.74	
	3	96.56	1800	60.96	
	4	96.56	1800	61.22	
1.146	1	96.56	1800	60.88	61.16
	2	96.56	1800	61.17	
	3	96.56	1800	61.31	
	4	96.56	1800	61.28	
1.206	1	96.56	1800	61.76	61.41
	2	96.56	1800	61.13	
	3	96.56	1800	61.58	
	4	96.56	1800	61.15	
1.273	1	96.56	1800	61.69	61.69
	2	96.56	1800	61.64	
	3	96.56	1800	61.47	
	4	96.56	1800	61.94	
1.350	1	96.56	1800	62.46	62.26
	2	96.56	1800	62.49	
	3	96.56	1800	62.39	
	4	96.56	1800	61.71	
1.438	1	96.56	1800	61.67	62.78
	2	96.56	1800	62.99	
	3	96.56	1800	63.40	
	4	96.56	1800	63.06	
1.538	1	96.56	1800	63.11	63.06
	2	96.56	1800	63.16	
	3	96.56	1800	63.09	

	4	96.56	1800	62.88	
1.656	1	96.56	1800	63.40	63.12
	2	96.56	1800	62.74	
	3	96.56	1800	63.30	
	4	96.56	1800	63.04	

Table 2: Expansion/compression ratios of experiment configurations and their work produced from same amount of fuel.

5.2 Data Processing

A= Original volume of combustion chamber (ml)

B= Theoretical compression volume (ml)

C= Volume need to be reduced in combustion chamber (ml)

D= Effective expansion ratio

E= Theoretical expansion/compression ratio

F= Effective compression ratio

G= Volume of combustion chamber at the top dead center after size reduction (ml)

H= Volume of combustion chamber after size reduction (ml)

I= Effective expansion/compression ratio

J= Effective compression volume (ml)

K= Effective expansion volume (ml)

- Uncertainty of *A*

= Smallest division on micropipette is 0.01ml

=0.01ml

- $B = {}^{A}/_{E}$

$$B = {}^{198}/_{1.091}$$

$$B = 181.49\text{ml}$$

- Uncertainty of *B*

= Uncertainty of *A*

= 0.01ml

- $C = {}^{A - B}/_{(F - 1)}$

$$C = {}^{198 - 181.500}/_{8 - 1}$$

$$C = 2.36\text{ml}$$

- Uncertainty of *C*

= Uncertainty of *A*+ Uncertainty of *B*

= 0.01 + 0.01

= 0.02ml

- $D = {}^{A - C}/_{\frac{A}{F} - C}$

$$D = {}^{198 - 2.36}/_{24.750 - 2.36}$$

$$D = 8.737 \sim 8.74$$

- Uncertainty of *D*

= Uncertainty of *A* + Uncertainty of *C* + Uncertainty of *C*

= 0.01 + 0.02 +0.02

= 0.05

- $G = {}^{A}/_{F} - C$

$$G = {}^{198}/_{8} - 2.36$$

$$G = 22.39\text{ml}$$

- Uncertainty of *G*

= Uncertainty of *A* + Uncertainty *C*

= 0.01 + 0.02

= 0.03ml

- $H = K = A - C$

$$H = 198 - 2.36$$

$$H = 195.64\text{ml}$$

- Uncertainty of *H*

= Uncertainty of *A* + Uncertainty *C*

= 0.01 + 0.02

= 0.03ml

- $I = {}^{D}/_{F}$

$$I = {}^{8.74}/_{8}$$

$$I = 1.092$$

- Uncertainty of *I*

= Uncertainty of *D*

= 0.05

- $J = B - C$

$$J = 181.485 - 2.36$$

$$J = 179.13\text{ml}$$

- Uncertainty of *J*

= Uncertainty of *B* + Uncertainty *C*

= 0.01 + 0.02

= 0.03ml

- Efficiency gain

= Time required for finishing fuel / Time required for finishing fuel of base model with expansion/compression ratio 1.000

$${}^{60.87}/_{60.24} - {}^{1}/_{100} = 1\%$$

- Uncertainty of efficiency gain

= Uncertainty of time required for finishing fuel + Uncertainty of time required for finishing fuel of base model with expansion/compression ratio 1.000.

= 0.01+ 0.01

= 0.02s

- Average time of working

= (trial1 + trial2 + trial3 + trial4)/4

= (60.55 + 60.74 + 60.96 + 61.22)/4

= 243.48/4

= 60.87s

- Uncertainty of time

= Uncertainty of trial1+ Uncertainty of trial2+ Uncertainty of trial3+ Uncertainty of trial4

= 0.01 +0.01 +0.01 +0.01

=0.04s

5.3 Processed Data with Graphs

	Theoretical Compression Ratio	Theoretical Expansion Ratio	Theoretical Compression Volume (ml) ±(0.01)	Theoretical Expansion Volume (ml) ±(0.01)	Theoretical Expansion/Compression Ratio
1	8.00:1	8.00:1	198.00	198.000	1.000
2	7.66:1	8.00:1	189.66	198.000	1.044
3	7.33:1	8.00:1	181.49	198.000	1.091
4	7.00:1	8.00:1	173.23	198.000	1.143
5	6.66:1	8.00:1	165.00	198.000	1.200
6	6.33:1	8.00:1	156.77	198.000	1.263
7	6.00:1	8.00:1	148.54	198.000	1.333
8	5.66:1	8.00:1	140.23	198.000	1.412
9	5.33:1	8.00:1	132.00	198.000	1.500
10	5.00:1	8.00:1	123.75	198.000	1.600

Table 3: Volume need to be reduced in combustion chamber to keep pressure at top dead center constant.

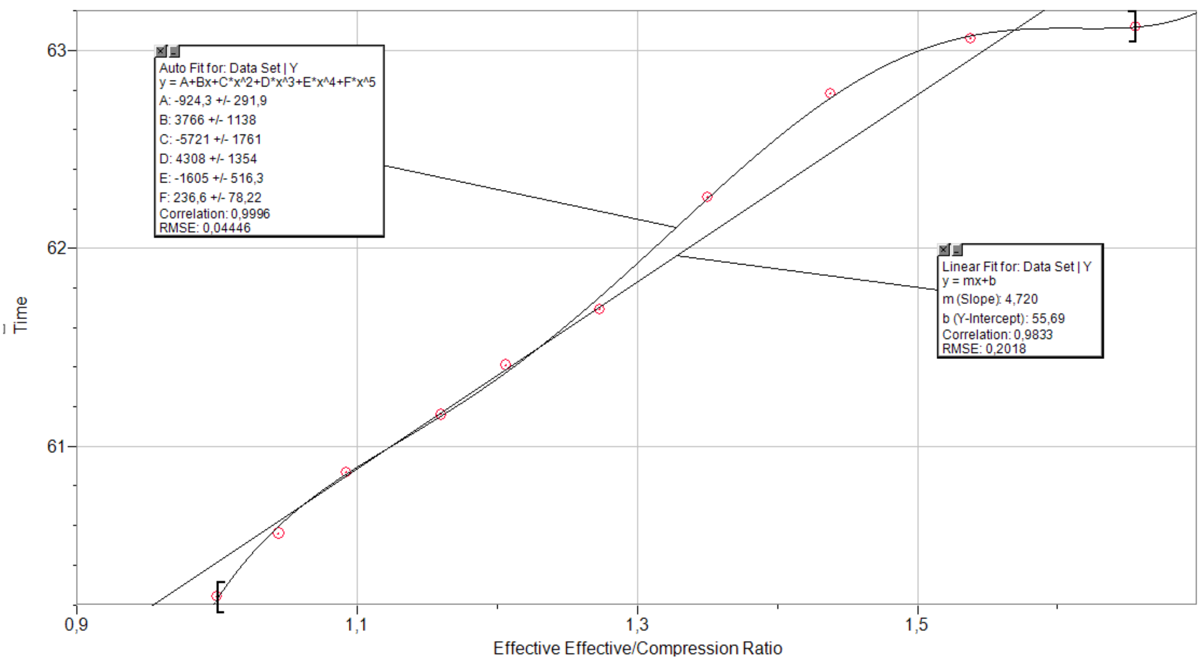
	Effective Compression Ratio	Effective Expansion Ratio	Effective Compression Volume (ml) ±(0.01)	Effective Expansion Volume (ml) ±(0.01)	Effective Expansion/Compression Ratio	Volume Need to be Reduced (ml) ±(0.01)	Volume of Combustion Chamber at Top Dead Center (ml) ±(0.01)
1	8.00:1	8.00:1	198.00	198.00	1.000	0	24.75
2	8.00:1	8.35:1	188.47	196.81	1.044	1.19	23.56
3	8.00:1	8.74:1	179.13	195.64	1.092	2.36	22.39
4	8.00:1	9.17:1	169.69	194.46	1.146	3.54	21.21
5	8.00:1	9.65:1	160.29	193.29	1.206	4.71	20.04
6	8.00:1	10.19:1	150.88	192.11	1.273	5.89	18.86
7	8.00:1	10.80:1	141.47	190.93	1.350	7.07	17.68
8	8.00:1	11.50:1	131.98	189.75	1.438	8.25	16.50
9	8.00:1	12.31:1	122.57	188.57	1.538	9.43	15.32
10	8.00:1	13.25:1	113.14	187.39	1.656	10.61	14.14

Table 4: Volume for each value of expansion/compression ratio in order

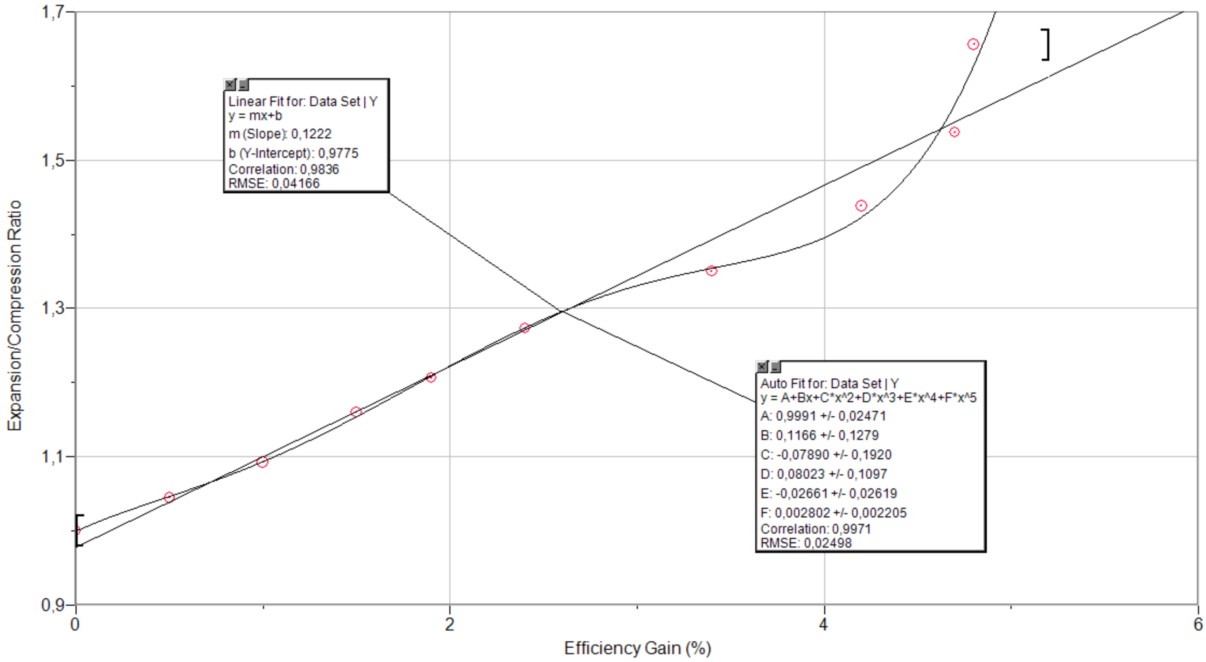
to keep the pressure at top dead center of air in the combustion chamber constant.

	Effective Expansion/Compression Ratio	Average Efficiency Gain (%)
1	1.000	0.0
2	1.044	0.5
3	1.092	1
4	1.146	1.5
5	1.206	1.9
6	1.273	2.4
7	1.350	3.4
8	1.438	4.2
9	1.538	4.7
10	1.656	4.8

Table 5: Average efficiency gain on each effective expansion/compression ratio.



Graph 1: Effective expansion/compression ratio vs. time of working.



Graph 2: Effective expansion/compression ratio vs. efficiency gain compared to base model with expansion/compression ratio of 1.000.

6. Conclusion and Evaluation

In this study, the aim was to examine the how would the engine cycle affect the efficiency of spark ignited internal combustion engine. In the hypothesis suggested idea is, to maximize the converted energy of heat to kinetic energy, the pressure and temperature inside the combustion chamber must be minimized and as close as possible to the outside pressure and temperature. From the Graph 2, it can be understood that as expansion/compression ratio increases, amount of heat energy converted into kinetic energy also increases. The experiment is appropriate and the hypothesis is confirmed to be true. Result of the experiment is slightly disappointing; efficiency gain of setup with expansion/compression ratio of 1.656 is predicted to be higher. Due to the small combustion chamber size of the engine, injected fuel into the combustion chamber in one cycle dropped by nearly 43%, which means less power, is produced. This reduction in power also comes with greater percentage of friction loss and moving parts of the engine, which could affected efficiency gain of specific setup. This situation can be observed by the working time data, as the expansion/compression ratio increases, standard deviation increases due to power loss. However, this might not be the only reasons for that, timing could be reasons for that because I was using the stopwatch during the experiment and all humans have different respond time. This delay between my eye and hand might caused these errors. Other factor that led experiment to be less reliable is relatively high uncertainty of chronometer.

To achieve results that are more reliable with this subject, each expansion/compression ratio could be tested for 10 times instead of four with bigger combustion chamber volume, which has low internal friction and moving mass. In addition, pressure of the chamber which engine is located could be increased to burn more fuel in the combustion chamber. Another issue with this experiment is, as volume of the combustion chamber decreased to provide equal compression ratio to solve equal density of fuel in the combustion chamber, maximum capacity of fuel burning is reduced because of the decreased amount of air causing less energy input on high expansion/compression ratio. To prevent this error, different internal combustion engine with different expansion ratio, same compression ratio and volume.

7. References

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