California State University, Long Beach

College of Engineering
Department of Mechanical Engineering

EXPERIMENT 3: The Analysis of a Spark Ignition (SI) and a Compression Ignition (CI) Engine

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Course: MAE 337-Thermal Engineering Lab

Section 9

Group 5
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Abstract:
The purpose of this thermodynamic lab is to investigate the performance of a Chevy engine under 0.25 throttles, half throttle, and full throttle. After that, we can determine the P-v and T-s diagram of a Spark Ignition and Compression Ignition engine. The experiment is conducted using mainly a Chevy engine running on diesel, a dynamometer load cell, and a stroboscope. The engine was tested on diesel to test its performance. Dynamometer is used to measure the load of water disposed of. In addition, a stroboscope was used to capture the Chevy engine's speed. Furthermore, water temperatures were measured and the time for each run was recorded for further calculation. The results will show the engine will perform better on different loads as well as different engine speeds. In general, the calculated engine power output will vary within different throttles, dynamometer load, and engine speed. Therefore, we can optimize which load and speed combination will be ideal for any combustion engine or the Chevy diesel engine in general.

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Objective

To determine the P-v and T-s diagrams of a SI (Spark Ignition) and a CI (Compression Ignition or Diesel) engine, idealized to the air standard Otto cycle, and the operating characteristics of each engine.

Introduction

Thermodynamics plays a crucial role in power generation, typically achieved through systems operating on thermodynamic cycles. These power-producing systems are often referred to as engines, and the thermodynamic cycles they operate on are known as power cycles. The substance circulating through the cyclic device is referred to as the working fluid. When the working fluid remains in a gaseous phase throughout the entire cycle, the cycle is called a gas cycle, as seen in a car engine. On the other hand, a vapor cycle refers to a cycle in which the working fluid exists in both vapor and liquid phases during different parts of the cycle. A steam power plant is an example of a vapor cycle. The internal combustion engine is a heat engine where fuel combustion happens in a confined space known as a combustion chamber. The exothermic reaction between fuel and an oxidizer produces gasses of high temperature and pressure that expand. An internal combustion engine performs useful work by utilizing the expanding hot gasses to cause movement which push the piston walls which are connected to a shaft. This is different from external combustion engines like steam engines or stirling engines that utilize the combustion process to generate heat and convert it to work. A piston-cylinder device is the primary component of a reciprocating internal combustion engine. The four stroke cycle is the most commonly used cycle for internal combustion engines. It is practically impossible to do an exact analysis on these engines due to irreversibility such as friction and heat lost to the surroundings so assumptions are made to make the analysis doable and they are known as the air standard assumptions and they are the following:

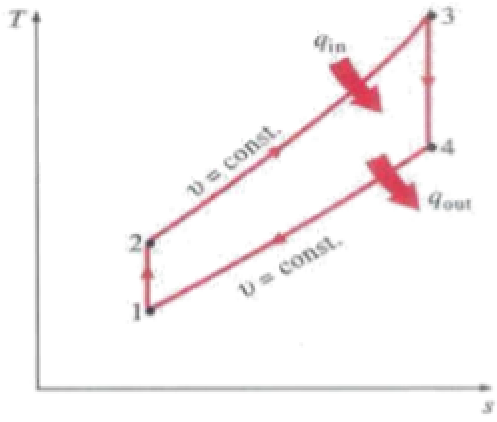
1. The working fluid is air that is continuously recirculated and behaves as an ideal gas
2. All processes that make up the cycle are internally reversible
3. The combustion process is replaced by a heat addition from an external source.
4. The exhaust process is replaced by a heat rejection process to an external sink and restores the air to its initial state

Another assumption that is often made is that the air has a constant specific heat at room temperature $25^{\circ}C$ and is referred to as the cold air standard assumption when used. When making calculations using these assumptions the results obtained are quite a bit off from actual experimental data but they will serve as a baseline for the ideal values for efficiency, compression ratio and size of the system. When dealing with internal combustion engines there are two cycles that are used, the otto cycle which is used for spark ignition engines and the diesel cycle which is used for compression ignition cycles. In a diesel engine, the diesel fuel is injected into the combustion chamber of the engine and ignited by the high temperatures achieved when the gas is compressed by the engine piston. These engines have more torque and are usually used alot in in trucks and other big machinery. In this experiment a gasoline spark ignition engine will be used and works very similarly, fuel is injected into the combustion chamber and combined with air then the air and fuel mixture is ignited by a spark from the spark plug. The ideal Otto cycle is consists of four ideal process:

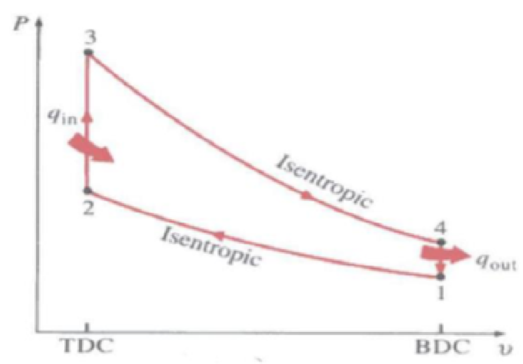
1. 1-2 isentropic compression process
2. 2-3 Constant volume heat addition process

3. 3-4 Isentropic expansion process
4. 4-1 Constant volume heat rejection

The pressure vs volume and temperature vs entropy diagrams are shown below.



T-s diagram for the ideal Otto cycle



To calculate the ideal efficiencies the following equations are used:

$$Thermal\ Efficiency\ (\eta_{th}) = \frac{w_{output}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}}$$

$$\eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_v(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(\frac{T_4}{T_1} - 1)}{kT_2(\frac{T_3}{T_2} - 1)}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - (\frac{V_2}{V_1})^{k-1} = 1 - [1/(\frac{V_1}{V_2})^{k-1}]$$

$$k = \frac{C_p}{C_v}$$

$$\eta_{th} = 1 - (\frac{V_1}{V_2})^{1-k} = 1 - (CR)^{1-k}$$

$$CR = \frac{v_1}{v_2}$$

Where CR is the compression ratio which is the ratio of the maximum to minimum volume in the cylinder of an internal combustion engine. The purpose of this experiment is to create actual P-V and T-S diagrams for the 4-stroke gasoline Chevy engine that operates on the following cycles:

1. Intake cycle: The piston moves downward in the cylinder, drawing air into the cylinder through the open intake valve.
2. Compression cycle: The intake valve closes and piston rises in the cylinder, compressing the air.
3. Power cycle: s the top of the compression stroke, the Air/Fuel mixture is ignited by the spark plugs. As the fuel burns, It creates a very high pressure In the cylinder and forces the piston down. This force is used to overcome the engine operating friction forces and to provide output power.
4. Exhaust cycle: The exhaust valve opens and the piston rises, pushing the exhaust gasses out of the cylinder into the exhaust system.

The engine that will be studied is mounted on a stand and connected to a dynamometer which is a device used for simultaneously measuring the torque and rotational speed of an engine, or other rotating prime mover so that its instantaneous power may be calculated and the equation for brake horsepower is:

$$BHP = 2\pi FLn/33,000$$
$$BHP = Fn/5,000$$

List of Apparatus

Figure 1: The Chevy engine

Figure 2: The Dynamometer Load Cell

Procedure

The lab instructor started the engine and let it warm up for 5 minutes. The engine was also made sure to be properly fuel and all the measuring instruments were set up appropriately. The class was divided into three groups and each group will be responsible for each engine throttles. The engine was started at ¼ throttle and it increased within runs to half and full throttle. While the system is running, students started to obtain the values for air temperature and pressure, as well as the water temperature and pressure. Moreover, the dynamometer load cell was also used to obtain the water weight. The engine speed was also captured using a stroboscope. While the experiment was going, a student recorded the duration of each run. The process repeated for the next two throttles. After acquiring the raw data, students calculated the thermodynamic properties of the engine including engine power, heat transfer, and the efficiency of the system. In the end, students will conclude which conditions of the engine would be efficient.

Table of Data and Results

Data Table

	units	Run 1 (¼)	Run 2 (½)	Run 3 (Full)
Intake manifold pressure	In Hg	13.37	21.37	25.47
Cooling water inlet temp	℃	20	20	21
Cooling water outlet temp	℃	39	42	44
Inlet air temp	℉	69	69	69
Inlet air pressure	In Hg	30	30	30
Exhaust temperature	℃	199	255	287
Engine speed	RPM	1392	1333	835
Dynamometer load	lb	23	63	93
Time of run	seconds	183	108	53.73
Total fuel burned	ml	300	300	300
Weight of the cooling water	lb	78	42	18

Table 1: Raw Data

Result

T1		529	529	529
V1		0.02121	0.02121	0.02121
R		53.34	53.34	53.34
T2		1245.154	1245.154	1245.154
P2		23533.28	12212.4	6410.448
T3		6548.589	19328.35	111789.9
P3		123767.6	189571.2	575529.9
T4		2782.148	8211.588	47493.61

Table 2: P,V,T Results for 3 runs

Result	Unit	Run 1(0.25	Run 2	Run 3
m fuel	g/s			
q in	cal/s	14065.57	23833.33	47906.2
q in	btu/hr	199731.1	338433.3	680268
m air	lbm/cyl			
m air	lbm/hr	221.5336	110.0903	36.19869
eff otto	%	135.3789	135.3789	135.3789
BHP	hP	6.4032	16.7958	15.531
W out	btu/hr	16296.14	42745.31	39526.4
Torque	ft-lbm	24.17197	66.21019	97.73885
effactual	%	8.15904	12.63035	5.810415

m fuel	lbm/hr	1.278689	2.166667	4.355109
BSFC	lb/hp	0.199695	0.129001	0.280414
q loss water	btu/hr	101579	100240	88522.61
q loss water	% heat input	50.85787	29.61883	13.0129
q loss exaus	btu/hr	17077.58	11149.95	4166.614
q loss exaus	% heat input	8.550285	3.294577	0.612496
q loss other	btu/hr	64778.4	184298.1	548052.4
q loss other	% heat input	32.4328	54.45624	80.56419

Table 3: Overall Results

Sample Calculations

V_{BDC} - V_{TDC} = 194/6

$\frac{V_{BDC}}{V_{TDC}} = 8.5$

Substitution: V_{TDC} = 4.311 in^3 = 0.00249 ft^3

V_{BDC} = 36.644 in^3 = 0.02121 ft^3

$T_2 = T_1(CR)^{k-1} = 528.67(8.5)^{1.4 - 1} = 1244.38$ R

$P_2 = P1(CR)^k = 320.407(8.5)^{1.4} = 6410.45$ psfa

$Q_{in} = \frac{(300)(0.78)(11000)}{53.73} = 47906.2$ cal/s = 684580 Btu/hr

$m_{air} = \frac{P_1V_1}{RT_1}\ x\ 6\ x\ \frac{RPM}{2}\ x\ 60 = \frac{(320.407)(0.02121)}{(53.34)(528.67)}\ x\ 6\ x\ \frac{835}{2}\ x\ 60 = 36.2145$ lbm/hr

$T_3 = \frac{Q_{in}}{m_{air}\ x\ 0.17} + T_2 = \frac{684580}{(36.2145)(0.17)} + 1244.38 = 112441$ R

$P_3 = P_2\frac{T_3}{T_2} = 6410.45\frac{112441}{1244.38} = 579245$ psfa

$T_4 = \frac{T_3}{CR^{k-1}} = \frac{112441}{8.5^{1.4-1}} = 406048$ R

Discussion and Analysis of Results

In general, the Otto efficiency is significantly large, however the actual efficiency is more reasonable considering it ranges from 5% to 13%. When comparing between different throttles(quarter, half, full), we can recognize the trend within the water heat loss, the exhaust heat loss, and the other heat loss. First of all, the energy lost from the water is decreasing as the throttle increases. With the lower of work in the full throttle (39526 Btu/hr) compared to the half throttle(42745 Btu/hr), the third run would manage to lose less energy than the second one. Next to that, the energy loss from the exhaust (4166 Btu/hr) would be significantly less than the ¼ and ½ throttle (around 11000 and 17000 Btu/hr). By observation, we can determine that the full throttle would be more ideal when we want to focus on efficiency. The errors can potentially come from human errors, machine malfunction, and even unideal conditions. For human errors, operational mistakes can happen and also data may not be correctly obtained (misuse of stroboscope,...). The energy can also be lost by transforming into sound energy or sparks. The instruments were not calibrated properly can also also be a reason. During the experiment, the loud noise was present therefore miscommunication between students can also be a factor.

Conclusion and Recommendations

The purpose of this experiment was to determine the P-v and T-s diagrams of a SI (Spark Ignition) engine, idealized to the air standard Otto cycle, and the operating characteristics of the engine. A 6 cylinder chevy engine was used, the engine had a swept volume of $194in^3$ and a compression ratio of 8:5:1. The gasoline used had a lower heating value of 11,000 cal/gr and a density of 0.78 g/ml. The experiment was done by first warming up the engine these running it at a quarter throttle and ran until 300ml of fuel was burned, then repeated at half throttle then full throttle, during these runs the following parameters were recorded, intake manifold pressure, inlet and outlet water temperatures, inlet air temperatures, barometric pressure, exhaust gas temperature, engine speed (RPM), dynamometer load, time to consume 300 ml of fuel, and weight of the cooling water. The results from this experiment appear to be incorrect either due to wrong calculations or mistakes in data recorded during the experiment therefore the numbers cannot be used.

References

Çengel, Yunus A. Thermodynamics : an Engineering Approach. Boston :McGraw-Hill Higher Education, 2008.

Member's Contribution

Hung Ngo: Abstract, List of Apparatus, Procedure, Calculations and Results

Paul Yousefian: Introduction, Procedure, Conclusion and recommendations

Ricardo Jimenez: Calculations, Sample Calculations