SSA 3

Dolf Eck and Thomas Driessen

Name

February 21, 2021

Goal

- The goal of this SSA is to make a plan for executing the upcoming experiment.
- An other goal of this SSA is to structuring the report and fill in some parts which already are written.

Conclusion

- the experimental plan is written
- The thermodynamic part is in the report
- the introduction is report ready
- the calculations of (complete) combustion have been written

Problems

- The provided documents on canvas poorly outline how the experiment is meant to take place. There is a lack of details. For example there is no mention of that there will be laptops with appropriate software available on site. (solved through canvas)
- there were a couple mistakes in Vito's SSA about AF, and it was not well documented furthermore difficulty with deciding what is necessary.

Follow up Steps

- Analyse the measurements.
- Implementing experimental part in the report.

Work Division and Time division

- Experimental plan (2.5h each person)
- Changing introduction (1h Thomas)
- Thermodynamic theory in report (2.5h Thomas)
- Fuels theory in report (3 hrs)

Overleaf Link

Experimental plan

It is advised for to have one person get the measurements from experiment 1. Whilst the other gets started with experiment 2. Due to limited time it is recommend to ask as many questions as necessary and not figure things out yourself.

Before continuing to experiment 2, get the required measurements for experiment 1:

1. Bore
   Use calipers to measure the diameter, and take it from 3 different diameters. (Diameter of cylinder)
2. Stroke
   Using ruler, measure stroke length, take 3 trials. (piston travel distance)
3. Length of the connecting rod
   Measure length of connecting rod using a ruler or possibly calipers.
4. Dead volume/compression ratio
   probably calculated using previous measurements, and total volume of cylinder
5. Timing of ignition
   Ask TA how to do, possibly turn the crank yourself and check when it opens
6. Valve timing
   Ask TA how to do, possibly turn the crank yourself and check when it opens

Checklist for experiment 2:

1. Check main supply.
2. Connect power supply, use the red input (+5V) and the black for grounding (+0V).
3. Check if the indicator (assuming a light indications) indicates something. If the indicator is off then the power supply is not correctly wired,
4. Connect the current source, there are two currents sources available (1 µA and 1mA). There can be assumed that a current of 1mA should be used, but please ask this beforehand to make sure!
5. Connect/Check the connection for the power supply of the sensors.
6. Connect the analog output with the analog input. The voltage should have values between -10 V and +10 V.
7. Check connection analog output.
8. Check connection counter
9. Turn on the power button

For visible descriptions of the connections see the handbook. Make sure to have the handbook ready while beginning the experiment. Keep in mind that the speed of the engine is equal to 3000 rpm.

The following measurements should be taken.

1. Gasoline: no load, half load, full load
2. E5: no load, half load, full load
3. E10: no load, half load, full load
4. E15: no load, half load, full load

1 Report work

2 Introduction

The use of fossil fuels is increasing in time, whereas the available fossil fuels are decreasing. This is not the only problem, since using fossil fuels most of the time emits relative much CO_2. After all, CO_2 is playing a big role in the pollution of the environment.

Therefore, it is important that green solutions are investigated and developed, in order to provide enough sustainable energy. Nowadays several new technologies like solar panels, heat pumps and electric cars are getting more usual. All these technologies help in some way to reduce CO_2 emissions, while providing the same services as in the past. However, it is really hard to implement total CO_2 neutral technologies so radically. Therefore, using already existing technologies and develop them into a more greener one, is a great contribution to the world's energy transition and a solution for running out of fossil fuels.

The company GreenGarden is looking for a consult how to apply this to their already existing gen-sets. These devices exist of a 4-stroke internal combustion engine that will activate the electricity generator. The generated electricity can be used to power machines in a garden or at a construction site. In theory when this 4-stroke engine uses a green fuel CO_2 emissions can be reduced.

The goal of this project, assembled by department Mechanical Engineering at the University of Technology Eindhoven, is to give GreenGarden a well-funded advice for working more efficient and as sustainable as possible with the focus on the 4-stroke engine.

To make greener fuel for the engine, gasoline and bio-ethanol are blended together in different ratios. This blending can be done with different E-numbers (ratio's of bio-ethanol). This blending should be done in such a way that the engine still runs properly and will not suffer any damage due to the blending. In order to calculate which E-number has the best ratio between producing the lowest CO_2-emission and giving the most useful energy output, the ideal and non-ideal cycle will be analyzed. A model will be made of the non-ideal cycle of the engine. This model will be compared to the measurements of the experiments done on the 4-stroke combustion engine. In this report, the effects of the use of green fuels are investigated. The advantages and disadvantages will be stated of using a blend instead of the regular gasoline. Eventually there will be given a reasonable advice by taking the technological, environmental and financial aspects into consideration. For formulating this advice the following questions will be answered:

- What is the efficiency of the engine when it is running on gasoline or gasoline/ethanol blends?
- How can efficiency of the engine be maximised with applying minimal changes to the engine?

3 Research

3.1 Thermodynamic Processes

Otto combustion engine

The type of combustion engine that is used for this project is a so-called Otto combustion engine. Here an air-fuel is ignited with a spark. The name Otto comes from the thermodynamic process that describes the operation of the engine, also known as Otto cycle. The engine which will be researched is an 4-stoke engine. This means that the cylinder inside the engine moves four times for completing one thermodynamic cycle, the Otto cycle. In figure 1 this process is visualised.

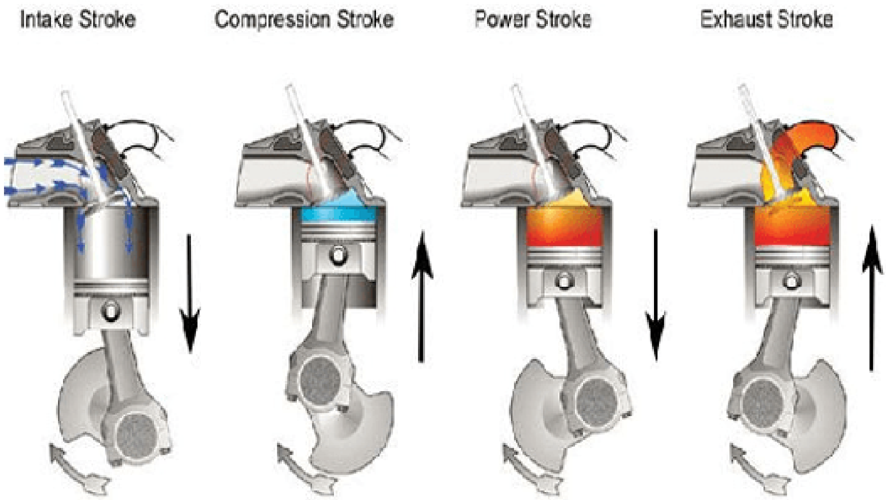

Figure 1: Four strokes Otto combustion engine.

During the full cycle, so after four strokes, five different thermodynamic processes take place. As already mentioned this cycle of processes is equal to an Otto cycle. In figure 2 this Otto cycle can be seen plotted with the pressure against the volume.

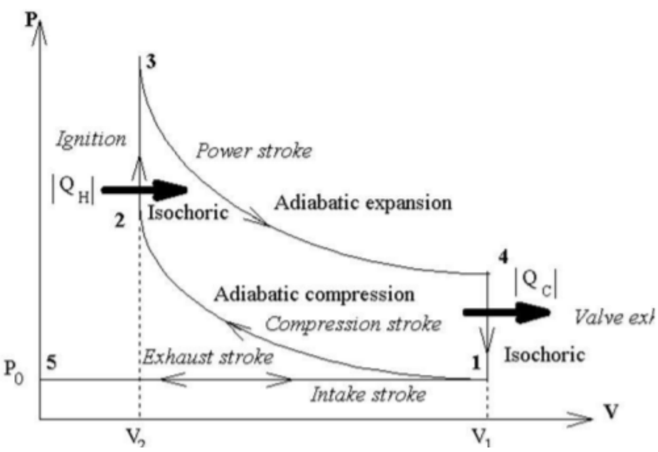

Figure 2: Otto cycle plotted in a PV-diagram.

At each of the five steps the following happens inside the engine:

1. The air-fuel mixtures comes in the combustion chamber

2. The mixture is compressed by the piston
3. Spark plug ignites the compressed mixture
4. Ignited mixture is then used as power (piston pushed down)
5. Left-over exhaust gasses are pushed out of the combustion chamber by the piston

These steps are more thoroughly explained in the next sections.

Intake and out take stoke

In this process the the pressure will be constant only the volume will change. The volume difference is equal to the volume of the air-fuel mixture which comes in and the volume of the residence after the combustion. This process is called an isobaric process. For further thermodynamic calculations the 1st thermodynamic law will be used, which is state in equation 1. In this equation Q is the heat in the process, U is the internal energy of the system and W is the work done by the system. [1]

$$Q = \Delta U + W \tag{1}$$

In the isobaric process the work can be calculated by pressure times the volume difference. Since for the Exhaust stroke and the Intake stroke this work is in absolute quantities the same but opposite in sign, this work in this part of the cycle will cancel out.

Compression stroke

In this step, the air-fuel mixture in the combustion chamber will be compressed by the piston, this is also known as the compression stroke. This process can be seen in figure 2 between points 1-4. This compression is adiabatic so it means that the the difference in Q is equalt to zero. Further more for this reversible adiabatic process equation 2 holds. In which P is the pressure, V the volume and γ equals $\frac{C_p}{C_v}$ in which C_p is the specific heat for constant pressure of the gas and C_v is the specific heat for constant volume. This equation can only be used for an ideal gas.

$$PV^\gamma = constant \tag{2}$$

It has to be kept in mind that this process is not perfectly adiabatic since heat can be lost to the cold cylinder and piston. The value of γ is a very important parameter in this process since the high-pressure and high temperature conditions at the beginning of combustion are defined by the calculations based on compression.

Ignition

The next step in the process is the ignition of the compressed fuel. This step is shown in figure 2 between points 2-3. This is an isochoric process in which the volume is constant. The ignition adds heat to the system and so also pressure due to the combustion of the fuel. The air-fuel mixture is firstly compressed so that more energy can be released. When looking at an ideal gas equation 3 holds, in which n is the number of moles in the gas, and R the gas constant.

$$PV = nRT \tag{3}$$

Since the volume is constant, $\frac{P}{T}$ will be constant during this process. The increase in heat and temperature can be calculated using the formula below.

$$Q_{ignition} = C_v(m_a + m_f)dT_{23} \tag{4}$$

Where m_a and m_f are respectively the fuel and air mass in the cylinder.

[1] https://web.archive.org/web/20081216231943/http://35.9.69.219/home/modules/pdf$_{m}odules/m158.pdf$

Adiabatic expansion

When the ignited fuel is ignited, it expands pushing the piston down (power stroke). This is step 4 of the process. This step is shown in figure 2 between points 3-4. The expanding of the ignited fuel happens in the form of adiabatic expansion. It can be assumed that this is a reversible process, so it is again an isentropic process which means that the Poisson relations, described in equation 2, can be used to make the thermodynamic calculations.

Valve exhaust

The last step of the process is removing the left-over gases in the combustion chamber. This is shown in figure 2 in steps 4-1. Firstly an exhaust valve is opened for some gases to escape, this makes the pressure go down. This is also known as rejecting heat. The amount of heat rejected can be calculated using the following formula:

$$Q_{reject} = C_v(m_a + m_f)dT41 \tag{5}$$

The work of each Otto cycle can then be calculated by the use of equation 6.

$$W = Q_{ignition} - Q_{reject} \tag{6}$$

An other method can be used to calculate the total work of the system, since the work is defined for ideal gasses as in equation 7 the total work can also be calculated by integrating the whole cycle. For this there already can be concluded that only the two adiabatic processes take part in this, since the work of the exhaust stroke counters the work of the intake stroke and the fact that in the isochoric processes the change in volume is equal to zero.

$$W = \int PdV \tag{7}$$

With the use of the work the efficiency of the cycle can be calculated. The general expression for this efficiency can be seen in equation ...

$$\eta = \frac{W}{Q_{ignition}} \tag{8}$$

3.2 Fuels

In addition to understanding the physics and mathematics of the Otto of the cycle, it is also important to understand how the different fuels impact the cycles. The scope of the investigation is focused on gasoline, and gasoline ethanol mixtures, of varying amounts of ethanol in the mixture. The demand for vast amounts of energy in the transport industry, prompted researchers to investigate alternative energy sources like the use of ethanol. Ethanol is added to gasoline to reduce fossil fuel consumption and emission of greenhouse gasses. An advantage of using ethanol is that it is a renewable resource, produced from plants.

Adding ethanol to the fuel mixture has multiple effects. First of all, due to the high octane-number in ethanol the chance of self ignite due to the pressure in the cylinder reduced. In compression ignition engines this means that the fuel compression can increase so it does more work and the thermal efficiency rises. In spark ignition engines like the one used in this case, self ignition would be premature and is unwanted. Here the benefit is that with added ethanol the premature self ignition called 'knocking' is less prone to take place. Furthermore there is research indicating a positive rend between the ethanol content and the efficiency of an engine. [**?**].

On the contrary, ethanol has some negative effects as well. Ethanol is a component based on water, meaning that it naturally doesn't blend well with oil, such as gasoline. As soon as too much water has entered the tank due to for example condensation and the saturation point is reached, the ethanol will 'disconnect' with the gasoline. This means that when the ethanol-gasoline blend is left untouched for too long, phase separate will take place, meaning that the ethanol will go to the bottom of the tank. The gasoline on top of the engine loses a lot of RON points and a few additives, making the gasoline far less efficient and more damaging than at first. Ethanol also erodes materials quicker, which can damage the engine. However nowadays engines are designed so that they're better resistant for these negative corrosive effects of ethanol.

Combustion of fuels

A particular focus is the combustion of fuels. There are two main sorts of combustion complete and incomplete combustion. Complete combustion occurs in the excess of air, with the following empirical relation for ethanol:

$$C_2H_5O + 3O_2 \rightarrow 2CO_2 + 3H_2O \tag{9}$$

By multiplying the respective amounts of moles with their molar mass, a mass balance can be created to determine the mass of air required to combust one kg of ethanol.

$$46.069m_{eth} + 3(32m_{O2}) = 2(44m_{CO2}) + 3(18m_{H2O})$$

From this equation the mass ratio of fuel to oxygen can be computed as followed:

$$m_{eth} = \frac{96}{46.069}m_{O2} \qquad \text{(kg)} \tag{10}$$

Which suggest for complete combustion of 1.00 kg of ethanol, 2.09 kg of oxygen are required. The same method can be applied for gasoline:

$$C_8H_18 + 12.5O_2 \rightarrow 8CO_2 + 9H_2O \tag{11}$$

$$114.232m_{gas} + 12.5(32m_{O2}) = 8(44m_{CO2}) + 9(18m_{H2O})$$

$$m_{gas} = \frac{400}{114.232}m_{O2} \qquad \text{(kg)} \tag{12}$$

Equation 12 suggests that for complete combustion of 1 kg of gasoline 3.50 kg of oxygen are required. However, air has more components then just oxygen, therefore an air to fuel ratio needs to be computed. The AF ratio is dependent on the fuel mixture composition. Since the gasoline - ethanol mixture is usually given in volume fractions they first need to be converted to a molar composition using the following formula:

$$Z_{fuel} = \begin{bmatrix} z_{gas}, & z_{eth} \end{bmatrix} \qquad \text{(-)} \tag{13}$$

Where Z is the volume mixture composition matrix, where the sum of the individual component, z_g volume fraction of gasoline and z_e volume fraction of ethanol is equal to one. To convert it to mass composition the volume fractions need to be multiplied with their respective densities, expressed by the following equation:

$$m_i = z_i \rho_i \qquad \text{(kg)} \quad (14)$$

Where m_i represents the mass of an element in Z, z_i volume fraction, ρ_i the density. With the mass of each component calculated the Mass composition of the fuel mixture can be computed

$$Y_{fuel} = \left[\tfrac{m_{gas}}{m_t}, \quad \tfrac{m_{eth}}{m_t}\right] \qquad \text{(-)} \quad (15)$$

Where Y represents the mass composition, m_t the total mass, and m_g and m_e the components of the fuel mixture. Equation 15 provides the ratio of fuel by mass. With this in mind the earlier determined mass of oxygen required for complete combustion, provide the following:

$$\left[\tfrac{m_{gas}}{m_t}, \quad \tfrac{m_{eth}}{m_t}\right] \begin{bmatrix} \frac{400}{114.232} m_{O2} \\ \frac{96}{46.069} m_{O2} \end{bmatrix} = \frac{m_{gas}}{m_t} \frac{400}{114.232} + \frac{m_{eth}}{m_t} \frac{96}{46.069}$$

$$m_{O2} = \frac{m_{gas}}{m_t} \frac{400}{114.232} + \frac{m_{eth}}{m_t} \frac{96}{46.069} \qquad \text{(kg)} \quad (16)$$

The mass fraction of oxygen in air is known to be around 0.233, and this can be used to compute the mass of air required for combustion of 1 kg of fuel mixture.

$$m_{air} = m_{O2}/0.233 \qquad \text{(kg)} \quad (17)$$

With the mass of air compute for the combustion of 1 kg of fuel mixture the air to fuel mixture can be computed using the following formula.

$$AF = \frac{m_{air}}{m_{fuel}} = m_{air} \qquad \text{(-)} \quad (18)$$

Equation 18 can be simplified to simply the mass of air because throughout the calculations it was always assumed the mass of the fuel was equal to one kg.

3.3 matlab version

I have quikcly written a matlab script to do compute the AF, and mass fractions of the fuel.

```
Zfuel  =[0.15 0.85 0 0 0 0];
rho_C8H18 = 0.7; %[g/cm^3];
rho_C2H5OH = 0.79; %[g/cm^3]
rho = [rho_C2H5OH, rho_C8H18, 0 0 0 0];
Yfuel = Zfuel.*rho./(sum(Zfuel.*rho));
Mair = ((12.5*32*Yfuel(2A)/114.2285) +(3*32*Yfuel(1))/46)/Yair(6);
Mfuel = 1;
AF = Mair/Mfuel
```

Figure 3: Matlab script

References

[1] https://intranet.tue.nl/universiteit/diensten/01-01-1970-information-management-services/software/01-01-1970-national-instruments-software/

[2]

[3]