SSA 2

Theoretical model

Dolf Eck, Thomas Driessen

February 11, 2021

Goal

- The goal of this SSA is to start to work on implementing the theoretical knowledge into the Matlab script.

Conclusion

- We were able to write a code which calculates all the thermodynamic variables which are use full to plot a PV-diagram.
- A PV-diagram of a ideal 4-stroke engine has been plotted in Matlab.

Problems

- The script is based on the ideal scenario, so it is not representative of the experiment but a good way to start.
- The in and outlet part of the cycle is not yet implemented.

Follow up Steps

- Implement in- and outlet part of the cycle. (can be done easily all the data required is already computed)
- Research into possible heatlosses and method of computing non ideal scenario
- Try to make the script more accurate by not using the ideal gas law.(implementing heat losses and describing non ideal scenario)
- Calculate efficiency out of this plot. (Should be possible since work can already be calculated using trapz command in MATLAB)

Work Division with the time division

- Dolf first started on the script (3.5)
- Later on Dolf and Thomas together meet to work on the Matlab script an finnish it to a PV-diagram (3 hours)
- Thomas wrote the SSA (1,5 hours)

Overleaf Link

1 Theoretical matlab script

1.1 Beginning of the script

The script begins with some basic implantation's of variables which will be used. The data given by NASA about the thermodynamic properties of some substances. After this the global atmospheric pressure, reference temperature and ideal gas constant are defined. Some convention units are defined to always be able to easy convert units.
Before working on the cycle processes, some more useful variables will be introduced such as the:

- Ambient temperature and pressure.
- Molar composition of air.
- Molar mass of air.
- Mass compostion of air.
- required fuel rate.
- Air-fuel ratio.

There is assumed that E5 and E10 fuels stands for 5 and 10 percentage mass ethanol in the fuel, respective.

1.2 Adiabatic compression

In figure 1 an PV-diagram can be seen of an 4-stroke engine. The intake stroke and exhaust stroke will modeled in a later stage. The path from state 1 to state 2 is an adiabatice compression. In the first part of the script for the adiabatic compression the mole rates with the mass fractions are calculated. (See script in Github for detail)

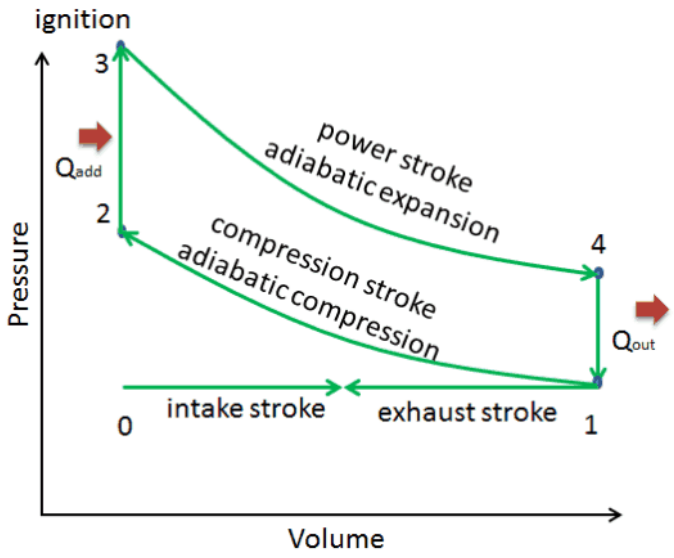

Figure 1: Theoretical PV-diagram of a Otto cycle. [1]

The pressure and temperature in state 1 are considered as the ambient values. For the Ideal gas law, equation 1 and equation 2 holds. Also there is known that V_1 is equal to the maximum volume of the cylinder. V_2 will be equal to $\frac{V_2}{r}$ in which r the compression ratio is. γ is equal to the $\frac{C_p}{C_v}$.

$$T_2 = T_1 \cdot (\frac{V_1}{V_2})^{(\gamma-1)} \tag{1}$$

$$P_2 = P_1 \cdot (\frac{V_1}{V_2})^{(\gamma)} \tag{2}$$

To simulate this in Matlab as one path the difference in volume is divided in small steps for which first each C_p and C_v value will be determined. Then it is assumed that for a small step γ is constant (k), allowing the use of the possion relations. Later on the temperature and pressure. This all is done in one for loop. This for loop can be seen below:

```
for i=2:steps+1;
    for ii = 1:NElements
       Cp(ii) = CpNasa(T23(i-1), Elements(ii));
       Cv(ii) = CvNasa(T23(i-1), Elements(ii));
    end
    Cp23(i) = Cp*Ypre_comb';
%     Cv23 = Cp*Xpre_comb';
    Cv23(i) = Cv*Ypre_comb';
    R(i) = Cp23(i) - Cv23(i);
    k(i) = Cp23(i)/Cv23(i);
    V23(i) = V23(i-1) - dV;
    T23(i) = T23(i-1)*(V23(i-1)/V23(i))^(k(i)-1);
    P23(i) = P23(i-1)*(V23(i-1)/V23(i))^(k(i));
%     T23(i) =  T23(i-1)*exp(Rpre_comb/Cv23(i))*(V23(i-1)/V23(i));
end
```

Figure 2: The used for loop in Matlab for the adiabatic compression path.

As can be seen in the for loop, there was tried to simulate the adiabatic process with not using the ideal gas law but the fact that the entropy difference is equal to zero. This did not work so far...

1.3 Isochoric ignition

In this process no work is done, and the volume will stay constant. First there will be looked at the stoichemetric relation which will take place when igniting the ethanol and gasoline. These reactions can be seen below:
Ethanol:

$$C_2H_5OH + 3O_2 \rightarrow O_2 + 3H_2O \tag{3}$$

Gasoline:

$$C_8H_8 + 12.5O_2 \rightarrow 8O_2 + 9H_2O \tag{4}$$

Out of these reactions the mass after the reaction can be calculated, which will be used to compare the enthalpy of before the ignition and the enthalpy of after the reaction. The difference in this enthalpy will be equal to the energy per mass exchanged out of the combustion. Below the script for this can be seen:

```
hpre_comb = h_comb*Ypre_comb';
hafter_comb = h_comb*Yafter_comb';
Q_comb = hafter_comb - hpre_comb
```

Figure 3: Part of the script for calculation the exchanged energy when igniting.

For a constant volume which will be heated up the following equation holds for a ideal gas:

$$T_3 = \frac{Q_{comb}}{C_v} + T4 \tag{5}$$

Hence the fact that Q_comb is in J per kilograms. T_3 is the temperature before ignition ans T_4 after the reaction. This will be also be simulated with a for loop in which now the temperature and the energy out of the reaction will be taken in small steps to calculate the pressure for each step.

1.4 Adiabatic expansion and isochoric heat rejection

The adiabatic expansion ans isochoric heat rejection paths will be described in one subsection since the mean important parts are just the same as the first two paths.
For the adiabatic expansion the beginning volume V_3 is known and the end volume of this path V_4. Hence the fact that $V_3 = V_2$ and $V_4 = V_1$. Equation 1 and equation 2 will be used again to but now for V_3 to V_4 in positive steps between the volume difference.
The last path is the isochoric heat rejection. This last part will theoretical just connect the conditions 1 to conditions 4. This is exactly what will be done, since these conditions (P,V,T) are known and the volume will stay constant, the only variable which will be variate in the PV-diagram is the pressure. The difference between P_4 and P_1 will be divided in small steps and connected. Below the used for loop for this path can be seen:

```
P56(1) = P5
Delta_P = (P5- P2)
dP = Delta_P/steps
V56(1) = V5;
for i=2:steps
  V56(i) = V5;
  P56(i) = P56(i-1) - dP;
end
```

Figure 4: The for loop for the last isochoric path of the cycle.

When combining all the paths in one plot for the pressure and volume a plot can be seen which looks similar to a four stroke PV-diagram. This plot can be seen in figure 5.

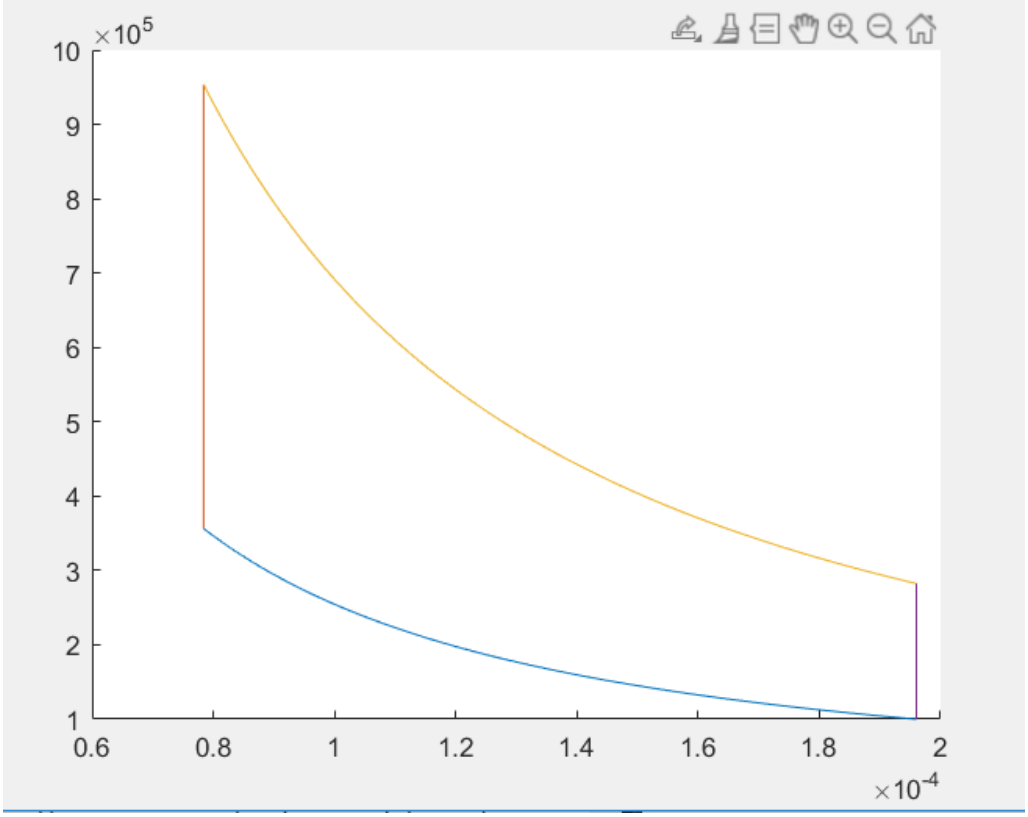

Figure 5: The final PV-diagram when combining all the simulated steps.

References

[1] https://www.nuclear-power.net/wp-content/uploads/2017/03/Otto-Cycle-PV-Diagram.png

[2]

[3]