SI engine exercise 2025

All modern (spark ignition) SI engines have an engine control unit (ECU) also called motor computer. It controls many engine parameters to ensure optimum performance at varied engine conditions. The purpose of this exercise is to experience how some of the most important engine parameters are influencing each other and the engine performance. We will also try some different fuels to see the effect of that. This year we are planning to try pure methane, propane and ammonia.

The compression ratio is affecting the IC engines efficiency significantly. With the SI engine there is an upper limit for the compression ratio that may be used. It is mainly determined by the knocking resistance of the fuel. For typical SI fuels the knocking resistance is rated with an octane number using a mixture of n-heptane and iso-octane as reference fuels to compare with. The fuels to be tested in this year's experiments are all outside the range of those reference fuels, thus the octane numbers are higher than 100. We will try different compression ratios to challenge the knock limit of those high-octane fuels to determine how efficiency is affected.

To get the maximum potential of a certain geometrical compression ratio, it is important that the combustion occurs close to the top dead center of the piston movement. The timing of the combustion is controlled by the spark timing, but the optimum spark timing depends on different engine conditions causing the ignition delay and the combustion duration to vary.

The best efficiency of an SI engine is obtained at full load with high-octane fuel, optimum ignition timing and optimum compression ratio. However, for a normal driving pattern of a road vehicle, the engine is seldom running at full load.

The load of a conventional gasoline engine is regulated by restricting the intake air with a throttle, while the air fuel ratio is kept constant. This is causing additional negative work on the piston during the intake stroke and reduces the efficiency at low loads. For a conventional diesel engine, the load is regulated by varying the injected amount of fuel without restricting the air inlet. Thus, only the air excess ratio is varied, and no additional negative work is caused by throttling. This is one of the reasons for the diesel engine being more efficient than gasoline engines at partial loads. One of the reasons for running the SI engine at air fuel ratio around 1, even at part load, is that the mixture is burning slower and is harder to ignite with a lean mixture. Another reason is that efficient exhaust after treatment with a 3-way catalyst requires an air fuel equivalence ratio of 1. But the efficiency is often better if the mixture is slightly lean. In this year's experiments we will vary the manifold pressure for part load tests but we will also run quite lean enabled by a high discharge spark ignition system to see the difference.

Ammonia is a very different SI engine fuel compared to the more conventional fuels, while propane and methane behaves more similar to gasoline. Particularly ammonia but also methane have high knocking resistance enabling high compression ratio and leaner combustion. Thus, diesel engine efficiencies may be achieved with those fuels in SI engines. However, the high knocking resistance is also an indication of high activation energy, which reduce post-oxidation of unburned fuel in the late part of the expansion stroke. This is a challenge with ammonia due to smell and toxicity. In addition, small amounts of N2O (laughter gas) is formed during quenched post oxidation of ammonia and N2O has a 300 times larger GWP than CO2. This will be investigated further in this year's SI assignment. Methane also has a large GWP, which should be investigated particularly as unburned fuel from the Methane operation but also formaldehyde (CH2O) may be an issue from incomplete combustion of hydrocarbons due to toxicity. The attached paper by Jespersen may serve as inspiration to understand the ammonia emissions.

The engine speed will be 1100 rpm for all groups testing the different fuels and all data produced by the groups will be provided and should be used in the assignment.

The test matrix for each fuel is composed of 5 measurement series as shown below.

<table>
<tr><th>Test series</th><th>Compression ratio [V/V]</th><th>Ignition timing [Deg]</th><th>Air/fuel equivalence ratio [-]</th><th>Intake pressure [bar]</th></tr>
<tr><td>1</td><td>Increased from 8 (10 with NH3) in steps of 1 until knocking occurs</td><td>CA50 at 9 CAD</td><td>1.2</td><td>1.2</td></tr>
<tr><td>2</td><td rowspan="4">Two steps lower than the knocking limit</td><td>Varied from -40 to 0 with increments of 5 CAD</td><td>1.2</td><td>1.2</td></tr>
<tr><td>3</td><td>CA50 at 9 CAD</td><td>0.9 (not NH3), 1, 1.1, 1.2, 1.4, 1.6…LBL</td><td>1.2</td></tr>
<tr><td>4</td><td>CA50 at 9 CAD</td><td>1.2</td><td>Range in increments of 0.1 bar around 1.2 bar</td></tr>
<tr><td>5</td><td colspan="3">Motoring with 1.2 bar air only</td></tr>
</table>

The assignment

This assignment should not be shaped like an ordinary report but more like a test report. It should only contain a brief description of the experimental setup and results in terms of plots showing the effect of parameter variations. The only (but important) writing should be discussions of the physics behind the trends you see in the plots. For discussions about trends of the emissions, you can find inspiration in the attached article by Alkidas about crevice mechanisms. Try to explain the effects of the varied parameters as well as varied fuel. You should also attach your Matlab code in the appendix (as pdf).

The plots that you should show are specified in the following tasks. Don't be scared when you see the number of plots. When you have made Task 1 it is more or less a copy paste operation to produce the other tasks, **but** be careful with copy paste work.

Task 1: Investigate influence of compression ratio

- Plot BMEP, IMEP (from pickup), η_b and η_i against CR in four individual plots. Show all fuels together in same plots.
- Show AHRR and AHR of the two fuels with CR = 10 made in the CR sweep.
- Show AHRR and AHR of the two fuels when CR is highest.
- Show BSfuelslip (CH4/C3H8/ NH3), BSCO, BSNO, BSNO2, BSN2O/BSCH2O and exhaust gas temperature vs. CR in individual plots but with both fuels together.
- Show an energy balance for each fuel as CR is varied.

Task 2: Investigate influence of ignition timing

- Plot BMEP, IMEP (from pickup), η_b and η_i against ignition timing in four individual plots. Show both fuels together in same plots.
- Show AHRR and AHR of the both fuels as the timing is varied in four individual plots.
- Show BSfuelslip (CH4/C3H8/ NH3), BSCO, BSNO, BSNO2, BSN2O/BSCH2O and exhaust gas temperature vs. ignition timing in individual plots but with both fuels together.
- Show an energy balance for each fuel as ignition timing is varied.

Task 3: Investigate influence of air to fuel ratio

- Plot BMEP, IMEP (from pickup), η_b and η_i against lambda in four individual plots. Show both fuels together in same plots.
- Show AHRR and AHR of the both fuels as lambda varies in four individual plots.
- Show BSfuelslip (CH4/C3H8/ NH3), BSCO, BSNO, BSNO2, BSN2O/BSCH2O and exhaust gas temperature vs. lambda in individual plots but with all fuels together.
- Show an energy balance for each fuel as lambda is varied.

Task 4: Investigate influence of engine load

- Plot BMEP, IMEP (from pickup), η_b and η_i against engine load in four individual plots. The load should be in percent of BMEP's relative to highest BMEP measured in the load sweep. Show both fuels together in same plots.
- Show AHRR and AHR of both fuels as load varies in four individual plots.
- Show BSfuelslip (CH4/C3H8/ NH3), BSCO, BSNO, BSNO2, BSN2O/BSCH2O and exhaust gas temperature vs. load in individual plots but with both fuels together.
- Show an energy balance for each fuel as the load is varied.

Help

General:

- After you have made the raw data structure you should make a work data structure were you put power, xMEP's, efficiencies, AHRR, AHR, BSxx for all runs. Then you have everything right at hand in the workspace and can play around with plots almost without calculations. This will save you a lot of time.
- The energy balance should show the share of energy input converted into break power, cylinder head heat loss, thermal exhaust loss, chemical exhaust loss, mechanical friction, pumping loss and unaccounted losses. The energy fractions should be shown in percent of the fuel power. Simple line plots with legends are usually easier to read and faster to make than stacked plots.
- The flow of cooling water is given in g/s. The specific heat capacity of water is 4.182 kJ/(kg K).
- When calculating the chemical exhaust loss you use the lower heating value of the respective fuel and CO. For thermal exhaust loss you can use a temperature independent Cp of 1.2 kJ/(kg K).

Engine:

Spark ignition with manifold gas admission, 1 cylinder, 4 stroke and variable compression ratio
Bore: 82.6 mm
Stroke: 114.3 mm
Connecting rod: 254 mm

Fuels:

You can look up lower heating values of fuels and CO on wikipedia under heat of combustion.

BSxx

Brake Specific emissions (BSfuelslip, BSCO, BSNO, BSNO2, BSN2O, BSCH2O) and Brake Specific Fuel Consumption BSFC is used to specify mass of emissions or fuel consumption per unit mechanical energy output. Units are typically g/kWh. Remember that kWh is a measure of energy not power (like kW or W).

An easy way to do the calculation is simply by dividing the mass flow in g/h with the brake power in kW. Then the units become correct. See also Spencers book (eq. 15.57).

Emission analyzers measures in volume fractions (in % or ppm) and assuming ideal gas law this is the same as mole fractions.

You may assume that the mean molecular mass of exhaust gas is 25.6 g/mol with NH3 as fuel and 28.4 g/mol with C3H8 as fuel. It varies slightly with lambda but not much.

Cylinder pressure:

- The data is recorded with a resolution of 0.5 CAD. Due to heat loss, the max motoring pressure may be assumed to be 0.5 degree earlier than the geometrical TDC.
- The piezoelectric pickup has an output of 10 bar/V.
- Heat capacity ratio (or isentropic expansion factor) may be assumed to be $\gamma = 1.35$.