SSA 4

AF ratio and AnaMeDa summary

Vito Fransen

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Goal

- This assignment consists of several little tasks:
  - For the analytics of measurements data part of the course (henceforth called AnaMeDa), a summary needs to be written for fellow group members to make studying more efficient. It should also serve as a reference guide.
  - For the report we can already write a section that goes into detail on why using the stoichiometric ratio is optimal in terms of efficiency. This needs to be accompanied by a pressure-volume-diagram showing what would theoretically happen when an air to fuel ratio is used that is different from the stoichiometric ratio. The argumentation and the diagram can subsequently be used in the presentation.

Conclusion

- The summary has turned out shorter and more condensed than I thought it would be - which is good.
- It took considerably more time to figure out how to properly present all reasons why not using the stoichiometric fuel ratio is a bad idea, but this was not problematic.

Problems

- No problems were encountered making summary. Summarising the course was less work than expected. The formatting turned out poorly in LaTeX. The separate, well formatted file is available in Canvas.
- It took some time to adjust the model to be able to run air to fuel ratios that were not stoichiometric. The specifics were not very difficult, it just came down to rewriting the fluid compositions. however, most of the calculations have been done manually as the model was not designed to handle these suboptimal ratios.

Follow up Steps

- Once the measurements have been done and all AnaMeDa lectures are summarised, we can start working on the executive report without any issues.

Work Division

- Making the summary was done together with Mats. I summarised the first three modules. He summarised the fourth one. The division seemed fair as the fourth module is significantly larger than the others.
- The other two assignments were entirely done by myself. Though Dolf gave some useful advice on how to do the air to fuel ratio analysis last time.

Time Division

- Making the AnaMeDa summary: two hours;
- Writing the air to fuel ratio section (including research): three and a half hours;

- Writing the rest of the SSA: forty-five minutes;
- Total: six hours and fifteen minutes.

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1 Air to fuel ratio analysis

In order for the engine to work combustion is needed to provide work. This combustion can only take place when fuel and oxygen are supplied to the engine. These two ingredients can be supplied to the engine indifference ratios. this subchapter will detail which ratio is optimal.

1.1 Stoichiometry

Here follow the two combustion reactions of the two most prevalent molecules in the supplied fuel - octane and ethanol:

$$\begin{cases} 2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O \\ C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O \end{cases}$$

In these equations, it is assumed that all the oxygen and all the fuel in the engine is used for combustion. In this case no oxygen nor fuel would come out of the exhaust. The air to fuel mass ratio at which this phenomenon occurs is called the stoichiometric ratio.

1.2 Substoichiometric (rich)

When the air to fuel ratio is smaller than the stoichiometric ratio, less oxygen is provided to the engine than is needed for fuel to combust completely. This yields incomplete combustion products such as carbon and carbon monoxide. The reactions then become as follows - if the ratio is still more than half the stoichiometric ratio:

$$\begin{cases} 2C_8H_{18} + (25-n)O_2 \rightarrow (16-2n)CO_2 + (2n)CO + 18H_2O \ (n < \frac{25}{2}) \\ C_2H_5OH + (3-n)O_2 \rightarrow (2-2n)CO_2 + (2n)CO + 3H_2O \ (n < \frac{3}{2}) \end{cases}$$

These reactions produce less heat and with it less work than complete combustion would due to the higher specific energy of carbon monoxide relative to carbon dioxide [2]. Though carbon monoxide is not a greenhouse gas, it does not survive long in the atmosphere due to its reactivity becoming carbon dioxide [1]. Furthermore, carbon monoxide is toxic. Because having an air to fuel ratio that is less than the stoichiometric ratio is bad in terms of both efficiency and emissions, it is ill-advised to tune the engine below the stoichiometric ratio.

1.3 Superstoichiometric (lean)

When more air is supplied to the engine than needed, not all oxygen will combust. According to the manual provided by the manufacturer the engine “utilizes lean carburetor settings and other systems to reduce the emissions of carbon monoxide, oxides of nitrogen, and hydrocarbons.” [3]. Less fuel reduces the power generated by the engine since less heat can be acquired from the fuel as there is simply fuel supplied to the engine every second to combust. A common misconception exists that using less fuel makes your engine burn hotter, This stems from the practical observation that when a stoichiometric air to fuel ratio is used, not all fuel combusts due to bad mixing in the engine [4]. In practice this “misconception” mostly holds true - but not just due to the air to fuel ratio. To compensate for this effect, the engine is tuned to less than the stoichiometric air-fuel ratio, as using a perfectly stoichiometric ratio would cause incomplete combustion in practice.

In terms of carbon dioxide emissions, the manufacturer’s statement is technically correct in the sense that the engine produces less carbon dioxide per unit of time than when using the stoichiometric ratio. However, this effect is solely due to using less fuel every second, so the emissions per unit weight of burnt fuel are still the same. Not using enough fuel can I have the cause the engine to start malfunctioning as not enough work is provided to the piston to complete the engine cycle.

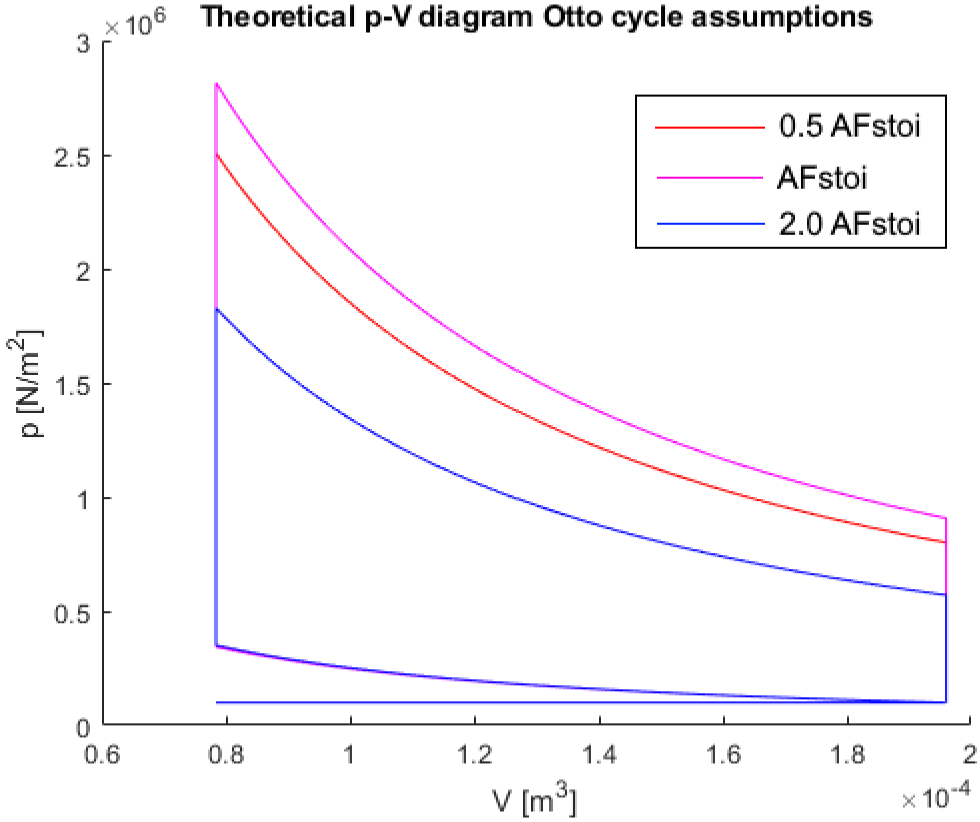


Figure 1: The result of using half and double the stoichiometric ratio on the theoretical thermodynamic model. The maximum efficiency has greatly been reduced by not using optimal air to fuel ratios.

1.4 Takeaways

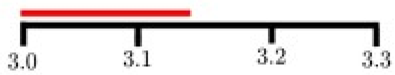
- Using the stoichiometric air to fuel ratio is optimal in terms of efficiency, work output and carbon dioxide emissions
- Supplying more fuel to the engine causes worse emissions (including carbon monoxide) and less efficiency
- In practice the mixture should be slightly lean to count for imperfect mixing
- Supplying more air to the engine that necessary neither increases nor decreases the efficiency or emissions. However, too much air can cause the engine to malfunction

2 Summary

A more readable variant has been uploaded as a PDF file in Canvas.

1 M01: Accuracy analysis

- When measuring, always report the digits you know surely plus one additional digit.
    - In this example, 3.14



- Using this, report the **reading accuracy**.
    - 0.05 in this case
    - This is usually half the distance between two measures in the case of rulers and such.
    - It is also hals the difference between the two smallest digits on an electronic measurement device.
- Report as follows: $d \pm \Delta_d = 3.14 \pm 5 * 10^{-2}$ cm
    - Report accuracies in <u>one</u> significant digit
    - Report accuracies in <u>two</u> significant digits when it is an intermediate result
    - Least significant digit final result = digit of reported accuracy

2 M02: Principles of experimental design

2.1 Component analysis

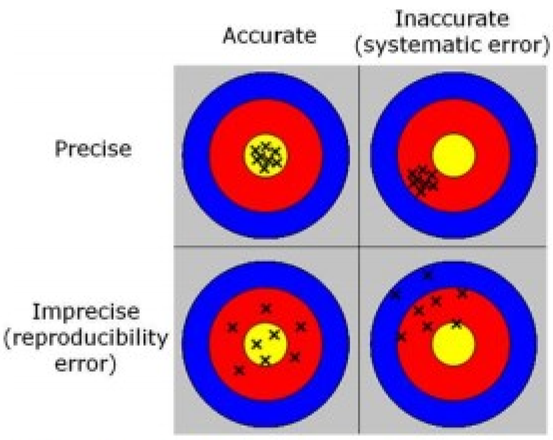
Important factors are:

- Physical system: performance of the GX200, intrinsic fluctuations
- Measurement system: instrumentation accuracy, time effects, calibration
- Observer: training, reaction time, familiar with procedure
- Environment: temperature fluctuations, wind, vibrations
- Model and theory enough detail to explain everything

2.2 Errors

- Systematic errors: consistent, repeatable errors
  - Usually have to do with poor equipment or bad design
  - In same direction/magnitude when repeated
  - Might be compensated for by calibration (rarely possible)
- Random errors
  - Completely unpredictable and unrepeatable
  - Can be compensated for using the average of multiple tests, possibly using more advanced statistics

2.3 Accuracy and precision



- Systematic errors → inaccuracies
- Random errors → imprecisions

2.4 Repeatability and reproducibility

Repeatable: *concerns the measurement procedure*

Can the same results be repeated by the same observers at the same location using the same equipment ... ?

Reproducible: *concerns the ability to replicate results by others*

Can the same results be reproduced by different observers at a different location using different equipment ... ?

2.5 Accuracies

$$\boxed{\rho \pm \Delta_\rho = 15 \pm 3 \text{ g/cm}^3}$$

If:

Absolute accuracy	$\boxed{\Delta_\rho = 3 \text{ g/cm}^3}$	With dimension
Fractional accuracy (*precision*)	$\boxed{\frac{\Delta_\rho}{\rho} = \frac{3}{15} = 0.2}$	Dimensionless
Percentage accuracy	$\boxed{\frac{\Delta_\rho}{\rho} * 100\% = 20\%}$	Dimensionless

3 M03 Propagation of accuracies

100% confidence interval

- Report the accuracy where you are 100% certain that is lays within the deviation you have set (the *maximum* deviation)

Mathematical rules:

- Sums: *Absolute accuracies*
  - $x = x_1 + x_2 \Rightarrow \Delta_x = \Delta_{x1} + \Delta_{x2}$
- Differences: *Absolute accuracies*
  - $x = x_1 - x_2 \Rightarrow \Delta_x = \Delta_{x1} + \Delta_{x2}$
- Linear combinations: *Absolute accuracies*
  - $x = ax_1 + bx_2 + cx_3 \Rightarrow \Delta_x = |a|\Delta_{x1} + |b|\Delta_{x2} + |$
- Products: *Fractional accuracies*
  - $x = x_1 \cdot x_2 \Rightarrow \frac{\Delta_x}{|x|} = \frac{\Delta_{x1}}{|x_1|} + \frac{\Delta_{x2}}{|x_2|}$
- Quotients: *Fractional accuracies*
  - $x = \frac{x_1}{x_2} \Rightarrow \frac{\Delta_x}{|x|} = \frac{\Delta_{x1}}{|x_1|} + \frac{\Delta_{x2}}{|x_2|}$

- Powers
  - $$x = x_1^a \cdot x_2^b \Rightarrow \frac{\Delta_x}{|x|} = |a|\frac{\Delta_{x1}}{|x_1|} + |b|\frac{\Delta_{x2}}{|x_2|}$$

Taylor's approximations:

- One variable functions
  - $$f(x \pm \Delta_x) \approx f(x_1) \pm \Delta_{x1} \cdot \frac{df}{dx}(x_1) + f(x_2) \pm \Delta_{x2} \cdot \frac{df}{dx}(x_2$$
  - $$\Delta_x \approx \Delta_{x1} \cdot |\frac{df}{dx}(x_1)| + \Delta_{x2} \cdot |\frac{df}{dx}(x_2)|$$
- Multivariable
  - $$\begin{aligned} f(x \pm \Delta_x, y \pm \Delta_y) \approx f(x_1, y_1) \pm \Delta_{x1} \cdot \tfrac{\partial f}{\partial x}(x_1) \pm \Delta_{y1} \cdot \tfrac{\partial f}{\partial y}(y_1) \\ +f(x_2, y_2) \pm \Delta_{x2} \cdot \tfrac{\partial f}{\partial x}(x_2) \pm \Delta_{y2} \cdot \tfrac{\partial f}{\partial y}(y_2) \end{aligned}$$
  - $$\begin{aligned} \Delta_{tot} \approx \Delta_{x1} \cdot |\frac{\partial f}{\partial x}(x_1)| + \Delta_{y1} \cdot |\frac{\partial f}{\partial y}(y_1)| \\ +\Delta_{x2} \cdot |\frac{\partial f}{\partial x}(x_2)| + \Delta_{y2} \cdot |\frac{\partial f}{\partial y}(y_2)| \end{aligned}$$

When you encounter a problem with fractions, consider analysing the inverse of everything under the denominator or use Taylor's approach.

References

[1] https://climate.nasa.gov/news/2291/fourteen-years-of-carbon-monoxide-from-mopitt/#:~:text=And%20though%20carbon%20monoxide%20does,as%20methane%20and%20carbon%20dioxide

[2] https://www.sciencedirect.com/topics/engineering/incomplete-combustion

[3] http://cdn.powerequipment.honda.com/engines/pdf/manuals/37Z4F603.pdf

[4] https://www.researchgate.net/post/Why-How-flame-temperature-gets-reduced-by-using-rich-mixtu