Development of a thermodynamic analysis tool

Matlab algorithm to calculate test conditions in the Combustion Rig Laboratory at MARINTEK

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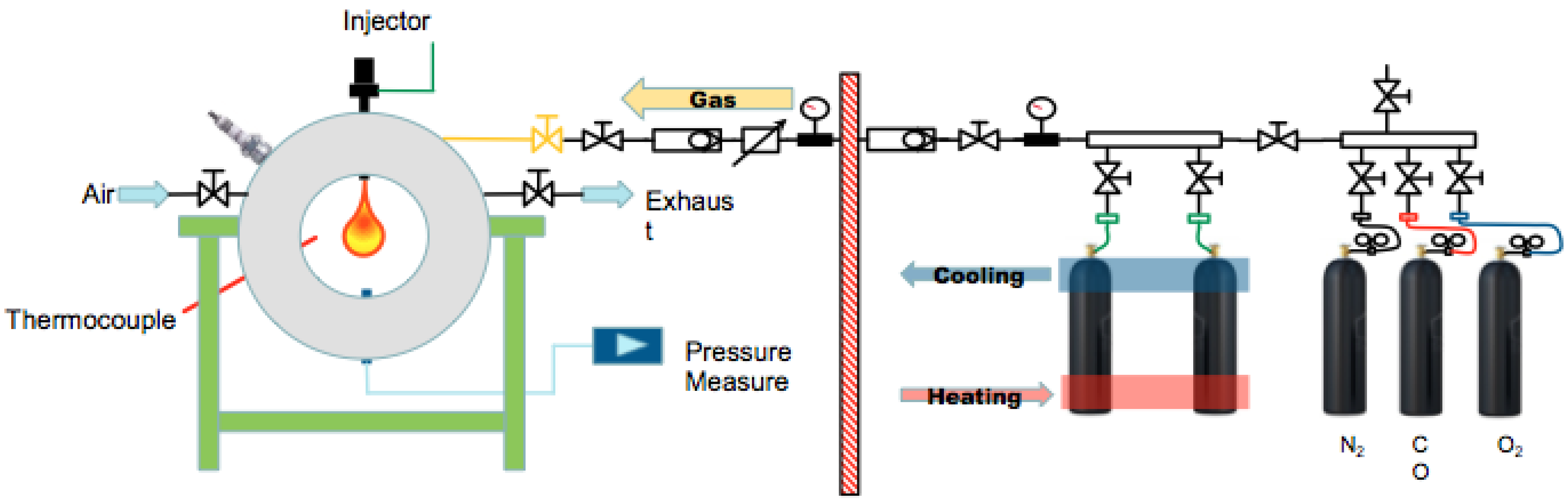


Figure 1: The Combustion Rig layout, made by Maximilian Malin, MARINTEK

Introduction

In the combustion laboratory at MARINTEK here in Tyholt, they have an Combustion Rig (CR). This is a fixed volume combustion chamber. The CR was developed to get visual access to the combustion. When performing an experiment, the CR is scavanged with air and charged with gas mixture. This burnable gas mixture is then ignited by a spark plug, seen as the first part in figure 2. After the pre-combustion is finished, the pressure drops due to heat losses. At a set time after ignition, test fuel is injected, see figure 2.

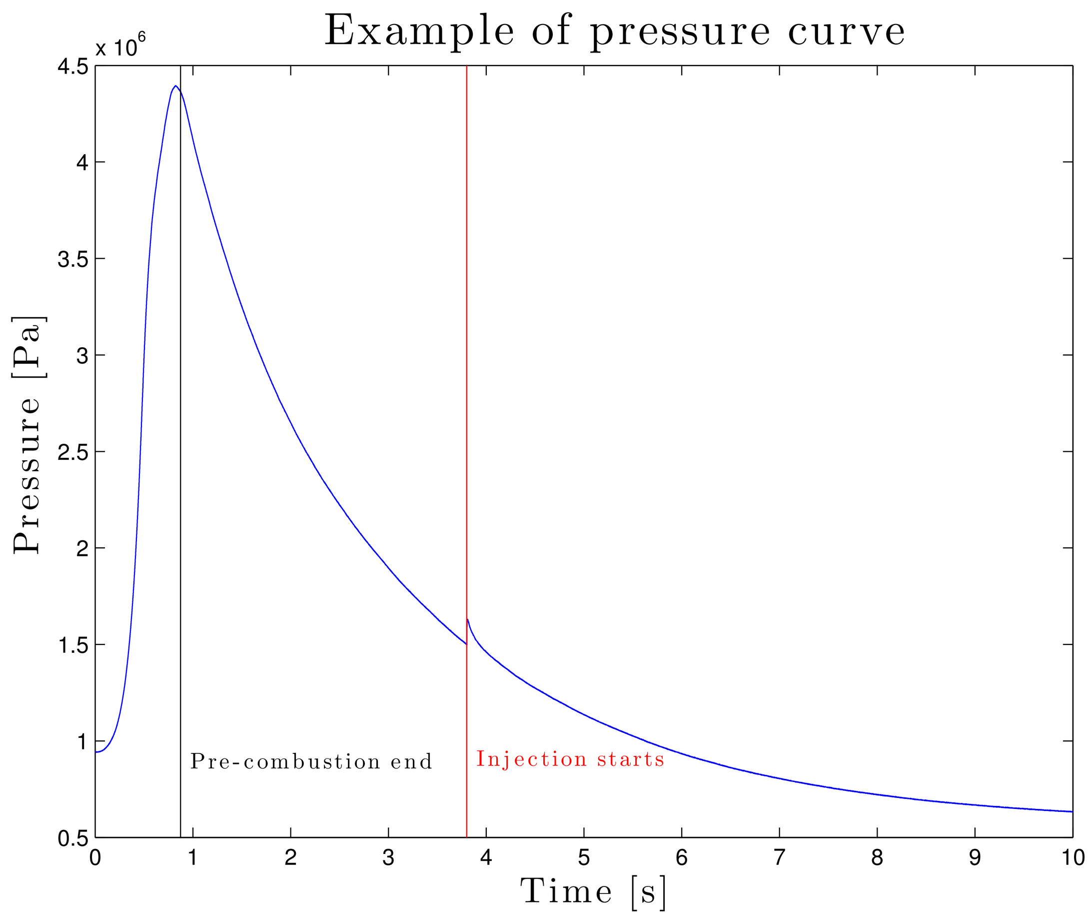
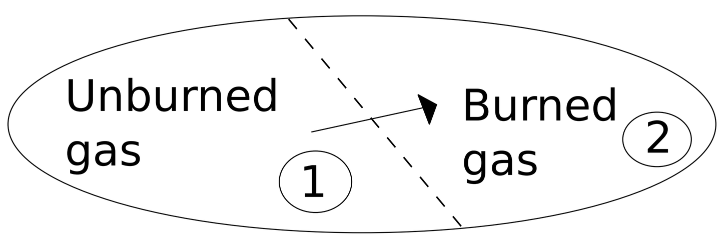


Figure 2: Pressure curve for the experiment

It is presently a problem to verify the conditions in the CR during the combustion experiments.The main objective for this master thesis have been to develop a thermodynamic analysis tool to better verify the conditions, such as temperature and pressure, when the test fuel is injected.

This verification have been done by using a two-zone model for the pre-combustion, visualised in the figure to the right. These two-zones, marked 1 and 2, have a common pressure, but different mass, temperature and volume.



Mathematical Development

The two zone-model are built up of the ideal gas law:

$$pV = mRT \tag{1}$$

and the first law of thermodynamics:

$$U = Q + W \tag{2}$$

Combinig the time derivatives of these two laws gives the two-zone model:

$$\begin{bmatrix} \frac{1}{m_1} & -\frac{1}{T_1} & \frac{1}{V_1} & 0 \\ (h_1 - u_1) & m_1 c_{v_1} & p & 0 \\ -\frac{1}{m_2} & 0 & \frac{1}{V_2} & \frac{1}{T_2} \\ (h_1 - u_2) & 0 & p & -m_2 c_{v_2} \end{bmatrix} \begin{bmatrix} \dot{m}_{12} \\ \dot{T}_1 \\ \dot{V}_1 \\ \dot{T}_2 \end{bmatrix} = \begin{bmatrix} -\frac{\dot{p}}{p} \\ \dot{Q}_1 \\ \frac{\dot{p}}{p} \\ -\dot{Q}_2 \end{bmatrix} \tag{3}$$

The thermodynamic properties needed in solving the two-zone model have been calculated using the NASA GLENN DATABASE, which have the advantage of beeing an continous function where only the temperature is required as input.

$$\frac{C_p^0(T)}{R} = a_1 T^{-2} + a_2 T^{-1} + a_3 + a_4 T + a_5 T^2 + a_6 T^3 + a_7 T^4 \tag{4}$$

$$\frac{H^0(T)}{RT} = -a_1 T^{-2} + a_2 \frac{ln(T)}{T} + a_3 + a_4 \frac{T}{2} + a_5 \frac{T^2}{3} + a_6 \frac{T^3}{4} + a_7 \frac{T^4}{5} + \frac{b_1}{T} \tag{5}$$

In these formulaes a_1 to a_7 is coefficients for each gas, while b_1 is an integration constant.

From these two polynominals the specific heat capacity at constant volume c_v, specific enthalpy h and specific internal energy u for each gas can be calculated. A model for the heat losses was developed using the convective law given by eq. 6 in the cool down phase.

$$\dot{Q} = \alpha \cdot A \cdot (T_{gas} - T_{wall}) \tag{6}$$

Results

The solution of the differential equations for $\dot{m}_{12}$, $\dot{T}_1$, $\dot{V}_1$ and $\dot{T}_2$ is shown in figure 3.

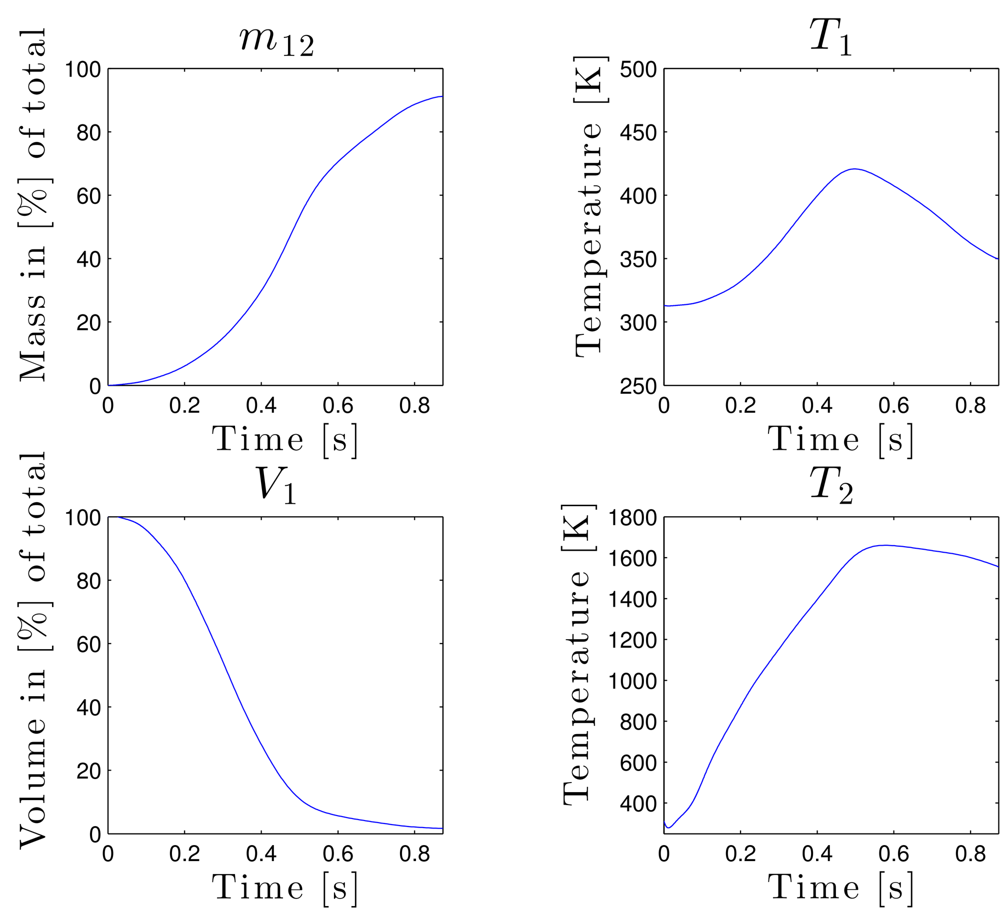


Figure 3: Resulting mass transport, temperatures and volume in zone 1

The graph in upper left corner in figure 3 shows the mass transport from zone 1 to zone 2, and then the resulting mass in zone 2. This is the total mass burned. With the rest of the mass conserved in the rig being unburned, the total composition of the the gas before the injection is known. This then gives the gas constant R. The precise temperature is found using the ideal gas law, having the precise pressure.

References

[1] Heywood, J. B. *Internal combustion engine fundamentals*. McGraw-Hill series in mechanical engineering. New York : McGraw-Hill, 1988.

[2] McBride, B. J., Zehe, M. J., and Gordon, S. *NASA Glenn Coefficients for Calculating Thermodynamic Properties of Individual Species*. Glenn Research Center, http://gltrs.grc.nasa.goc/GLTRS, September 2002.

[3] Moran, M. J., and Shapiro, H. N. *Fundamentals of Engineering Thermodynamics*, 6th ed. John Wiley & Sons, Inc, 2010.

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