Introduction to Ignition Thermochemistry

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## Ignition in Rocketry

Upon allowing propellants to enter the chamber before ignition, the propellant will mix in the chamber and potentially begin to build up. In the event that propellant is allowed to build up in sufficient quantities before ignition is achieved, a “hard start” may result in which all of the propellant quickly combusts causing a detonation and placing the engine at severe risk of structural damage or being destroyed. Similarly, if ignition occurs too far downstream in the engine, there is the possibility that as it propagates upstream it has enough room to accelerate that it propagates through the chamber as a supersonic detonation wave, again placing the engine at risk of damage.

Therefore, it is important to ensure that when propellants enter the chamber, the igniter is already active, well into the combustion chamber, and produces sufficient heat and temperature to guarantee complete ignition quickly after beginning propellant injection. Methods to determine the ignition temperature, heat, and thermal power output are listed below.

## Gibbs Function and Ignition Temperature

As outlined in the [Applied Chemical Equilibrium](https://docs.google.com/document/d/1ZVBXRmuQtC5bM-6-0qPzxw2AdipTyrMKoq8noYy711c/edit?usp=share_link) document [A], the change in Gibbs function of a reaction can be used to predict the direction of chemical reaction - if the change in Gibbs energy of a reaction, , is negative, then the reaction occurs forwards (products to reactants). If it is positive, then the reaction happens in reverse (products to reactants). The of the reaction is expressed as…

(1)

…where is the heat produced by the reaction, is the change in entropy from the reactants at the initial temperature to the products at the final temperature as outlined by thermodynamic tables/CoolProp, and is the initial temperature.

Therefore, for exothermic reactions with positive changes in entropy, the change in Gibbs function is positive at room temperature and then decreases with temperature. Eventually, the will reach zero, and continue to decrease into negative values. The temperature at which then is the minimum temperature required for ignition.

In order to generate a worst-case temperature, the heat of reaction and entropy change can be calculated using only the major products outlined in the [Basics of Combustion](https://docs.google.com/document/u/1/d/1d_NiXlDQG8T_QP-7L1u7jTly_aJhEoFRetvkPETi3QE/edit) document [B] (water, CO2, and N2), because these products will produce maximum , meaning maximum . This can be used to generate conservative estimates of the required temperature for reaction.

Therefore, a curve of can be generated for discrete points using this function. At the zero of the curve is , or the minimum desirable temperature for ignition. Therefore, any igniter must generate temperatures above .

## Required Heat for Ignition

In order to achieve ignition, the propellants must be at the minimum ignition temperature. Therefore, the propellants must be heated to a certain temperature from an initial temperature, or some . The injected propellants are a mixture of chemicals which can have its thermal properties found using the principles outlined in the [Chamber Conditions](https://docs.google.com/document/u/1/d/1d_NiXlDQG8T_QP-7L1u7jTly_aJhEoFRetvkPETi3QE/edit) document [C]. Following this, some heat addition required can be found using the heat capacity equation.

(2)

(3)

(4)

(5)

…where equation 3 described heat required on a basis of heat per unit mass of propellant mixture. It must also be accounted for that not all of the propellant must be heated to the ignition temperature . Instead, only enough of the propellant must be ignited to release enough heat . Therefore, the amount of propellant which must be ignited can be calculated from a nominal heat of reaction per kilogram of propellant, , at some arbitrary mixture ratio [B].

(5)

Using the mass of propellant which must be ignited shown in equation 5 and the specific heat of reaction, we can determine the

(6)

(7)

…where is the amount of heat that must be added in order to combust enough propellant to ignite the rest of the mass of propellant. For particularly low flow velocities, significantly less heat could be applied to the mixture to ignite the mixture locally, which could then propagate through a relatively stagnant mixture to achieve ignition. However, for high flow velocities flame wave propagation ought not to be counted on in order to ensure with some degree of certainty that sufficient heat will be provided for ignition.

## Thermal Power Required for Ignition

Estimating the required thermal power , or heat released per second by the igniter mechanism, is a relatively simple concept. The above sections detail how to estimate the amount of heat required to ignite some unit mass of mixed propellant. Using the methods outlined in the [Chamber Flow](https://docs.google.com/document/d/1EwtdHJscOhw51d0kd1JRHDjzPgklcJx-H6rjGxaLMqE/edit?usp=share_link) documentation [C] and [Injector Flow](https://docs.google.com/document/d/1EwtdHJscOhw51d0kd1JRHDjzPgklcJx-H6rjGxaLMqE/edit?usp=share_link) documentation [D], the mass flow rate through the chamber can be predicted. Therefore, since some known heat per unit mass is required, and some known mass per second through the chamber is known, equation 7 becomes:

(8)

… which gives the amount of heat per second, or thermal power expressed in Watts, required to ignite mass entering the chamber for some as estimated above, with some approximated for perfect combustion of the propellant mixture, the mixture’s specific heat capacity , and some total mass flow rate into the chamber .

## Related Documentation

[A] [CoolProp Documentation](https://docs.google.com/document/d/1SwY_JbAcMK3dY37hVzANKK0KHyNtMjkAvfUAsUOoy1Y/edit?usp=sharing)

[B] [Basics of Combustion](https://docs.google.com/document/u/1/d/1d_NiXlDQG8T_QP-7L1u7jTly_aJhEoFRetvkPETi3QE/edit)

[C] [Chamber Conditions](https://docs.google.com/document/d/1jLYpAgBIF4DAZvxFLMegq2dOw-f8xS7uXNU71RqToM4/edit?usp=share_link)

[D] [Injector Flow Modeling](https://docs.google.com/document/u/1/d/1EwtdHJscOhw51d0kd1JRHDjzPgklcJx-H6rjGxaLMqE/edit)