# Laminar burning velocity of hydrogen-air mixtures as a function of temperature, pressure and equivalence ratio

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## 1 Introduction

Laminar burning velocity is one of the most important parameters of combustible mixtures. Knowledge of its properties can provide valuable information, such as the ignition delay, the thickness of the wall quench layers and the minimum ignition energy. It is also known, that laminar burning velocity is highly helpful for modeling turbulent burning velocity.

In order to comprehend the problem of an in hand subject better, it might be useful to start from some of the basics of combustion phenomena.

### 1.1 Laminar and turbulent combustion

Based on the flow velocity there can be distinguished two types of combustion:

**Turbulent burning**
: Occurs after crossing sufficiently high velocity. Fluid undergoes irregular fluctuations and mixing

**Laminar burning**
: Laminar flows propagates uneventfully in organized paths or layers.

### 1.2 Classification of flames

Depending on the way the reactants are brought together to initiate the combustion, there are two types of flames:

**Premixed flames**

They develop when oxidizer is mixed with the fuel before it reaches the flame front. These flames are used when there is a need for intense combustion within a small volume.

**Diffusion flames**

When oxidizer and fuel are initially separated. The fuel mixes with the surrounding air and the reaction occurs at the same time.

The structures of mentioned laminar flames, that come from a tube burner, are shown on Figure 1.

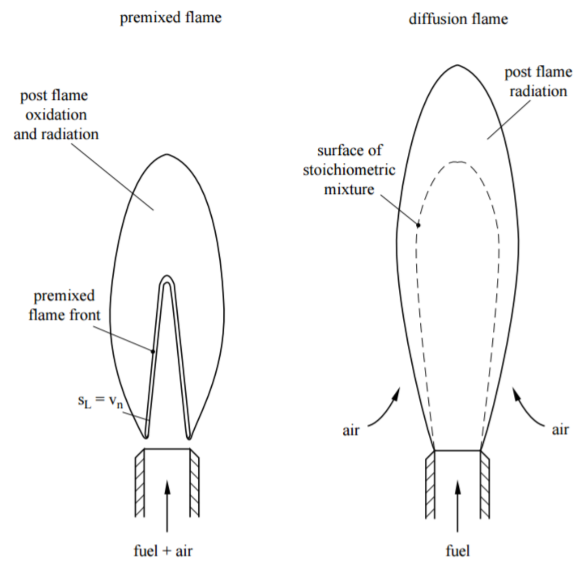


Figure 1: Structures of premixed and diffusion flames [1]

## 1.3 Laminar burning velocity

It can be described as the measured rate with which flame front propagates into the unburned mixture.

Laminar burning velocity models are a function of three parameters:

- temperature,
- pressure,
- equivalence ratio.

## 2 Mathematical model

The objective of this work is to explore a numerical method that describes and allow to predict the laminar burning velocity of hydrogen-air mixtures as a function of temperature, pressure and the chemical composition of a gas mixture. To this end, the solution presented in A.E. Dahoe article for Journal of Loss Prevention in the Process Industries [2] is going to be used.

The above-mentioned paper defines the laminar burning velocity of hydrogen-air mixtures as follows:

$$\frac{S_L}{(S_L)_0} = (\frac{T}{T_0})^{\beta_1}(\frac{P}{P_0})^{\beta_2}$$

Where:

$S_L$ - laminar burning velocity
$(S_L)_0$ - laminar burning velocity at reference conditions of pressure and temperature
$T_0, P_0$ - reference conditions of temperature and pressure
$\beta_1, \beta_2$ - functions of equivalence ratio for the exact type of gaseous mixture

In the experiment following referenced conditions are used:

$$T_0 = 298K$$

$$P_0 = 1bar$$

$$(S_L)_0 = 2,42\frac{m}{s}(true for \phi = 1)$$

### 2.1 Relationship between laminar burning velocity and equivalence ratio

The aim of the first paragraph of this section is to determine the dependency of laminar burning velocity on equivalence ratio of the hydrogen-air mixture.

If we assume temperature and pressure to be the same as reference conditions, then naturally $S_L$ is equal the value of $(S_L)_0$.

Relationship of $(S_L)_0$ and $\phi$ is shown on Figure 2 [2].

As can be seen the laminar burning velocity reaches its maximum at equivalence ratio $\phi$ around 1,6. Then $S_L$ decreases simultaneously with approaching flammability limits of the hydrogen-air mixture.

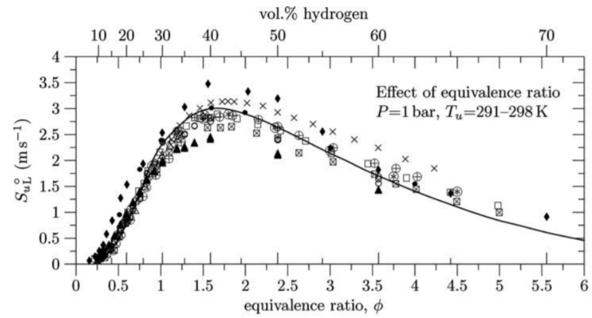


Figure 2: Relationship between laminar burning velocity and equivalence ratio

According to the article [2] exponents $\beta_1$ and $\beta_2$ are a weak functions of equivalence ratio $\phi$. Because of that, in this paper, $\beta_1$ and $\beta_2$ are taken to be constants, same as in the mentioned above article:

$$\beta_1 = 1,437$$

$$\beta_2 = 0,194$$

## 2.2 Relationship between laminar burning velocity and pressure

To determine dependency of laminar burning velocity on pressure, temperature $T$=298 K, equivalence ratio $\phi$=1 are assumed. Then the equation for $S_L$:

$$S_L = (S_L)_0(\frac{P}{P_0})^{\beta_2}$$

The result of using the above equation is shown on Figure 3.

Calculation where started at the pressure $P_{min}$=0,5 bar and conducted up to $P_{max}$=6 bar. As can be seen on the chart, laminar burning velocity $S_L$ increases nonlinear with pressure, with the minimum value of $S_L$ around 2,11$\frac{m}{s}$ for $P_{min}$ and maximum around 3,42$\frac{m}{s}$ for $P_{max}$.

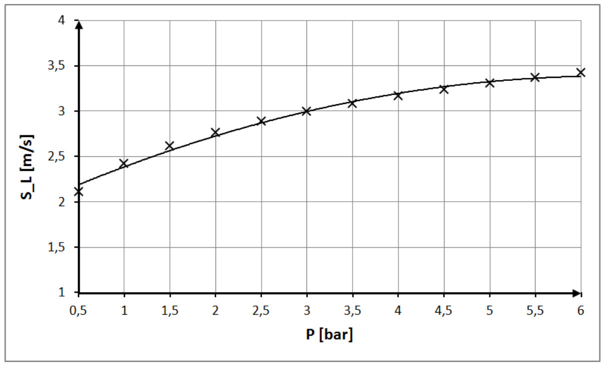


Figure 3: Relationship between laminar burning velocity and pressure

## 2.3 Relationship between laminar burning velocity and temperature

The next step of calculations is determining changes in laminar burning velocity with the change of temperature.

Variations are checked at pressure P=0 bar and equivalence ratio $\phi$=1. For that variables the laminar burning velocity is calculated from the below equation:

$$S_L = (S_L)_0(\frac{T}{T_0})^{\beta_1}$$

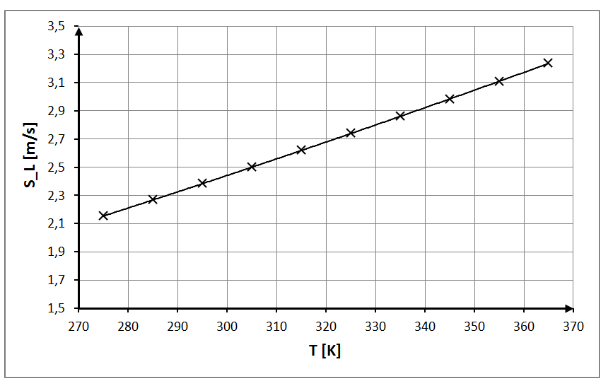


Figure 4: Relationship between laminar burning velocity and temperature

In the Figure 4 can be seen that like with pressure in the previous subsection 2.1 the laminar burning velocity increases with temperature. This time the dependency is clearly linear.

Calculations where conducted for temperatures from range between 275 K and 365 K. The minimum value of $S_L$ total approximately 2,15$\frac{m}{s}$ and maximum about 3,24$\frac{m}{s}$.

# 3 Conclusions

## 3.1 Effect of equivalence ratio

Equivalence ratio can be defined as the ratio of the actual to the stoichiometric air-fuel ratios [3]. As can be seen on Fig. 2 both for the very lean and the very rich hydrogen-air mixtures are not able to support the propagation of the flame, either because there is too little fuel or oxidant. The highest laminar burning velocity can be obtained for the equivalence ratio $\phi = 1,6$.

## 3.2 Effect of pressure

Using the mathematical model presented in the article [2] for calculations, the laminar burning velocity of hydrogen-air mixture, tends to increase nonlinearly with rising initial pressure (Fig. 3).

## 3.3 Effect of temperature

As can be seen on Fig. 4 there is a linear increasing dependency between initial mixture temperature and laminar burning velocity. According to explanation presented in paper [3], that is because of the preheating effect. It increases the heat release rate as the result of increasing the initial enthalpies of reacting materials.

# 4 References

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