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Laminar Flame Burning Velocity of Fuels/Air Mixture at Different Pressure, Temperature and Equivalence Ratio

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Abstract

Fuel laminar flame speed is an important property in internal combustion engine modeling and combustion analysis.

The aim of this paper is to develop a mathematical model able to provide laminar flame speed for any fuel at any reagent thermodynamic condition. Therefore a mathematical investigation of laminar burning velocity in some main fuels was carried out.

Fifth order logarithmic polynomial functions were used to predict the propagating flame speed of several combusting fuels as hydrogen, methane, ethane, iso-octane, etc. at different temperature and pressure conditions.

On the basis of results obtained, the mathematical model proposed in this paper showed a higher precision in experimental data interpolation (about 2 % error) and the possibility to interpolate and use a single function for a wider operation field.

Keywords: Mathematical Modeling, Combustion, Laminar Burning Velocity, Fuels.

Introduction

Laminar flame speed is among the most fundamental and intrinsic property characterizing the combustion of homogeneous fuel-air mixtures. It can be defined as the velocity, relative and normal to the flame front, with which unburned gas moves into the front and is converted into products under laminar flow conditions. A flame is correlated to the process of self–sustaining chemical reaction occurring within a space region where unburned mixture is heated and turned into products. This region, called flame front, consists of a preheat zone and a reaction zone. In preheat zone, no significant reaction or energy release occurs. A slight temperature increase of the unburned mixture is mainly due to heat transfer from the reaction zone. Exothermic chemical reactions are activated when a critical temperature is reached. In this region where the temperature increase is strong, heat release takes place. The reaction zone is placed between the region of reaction activation and the downstream hot region where burned gas reaches equilibrium temperature.

The laminar flame speed is also an important parameter that can be used for both practical applications and theoretical model of internal combustion engines and burners. Most of combustion system mathematical models use this parameter to determine turbulent flame front velocity [1]. Both ICI and combustion turbine mathematical modeling needs to take into account laminar flame velocity in the equations. That is much more important in combustion studies of not conventional fuels [2] and synthesis gas [3, 4].

Several authors measured laminar burning speed for a wide variety of fuels as a function of equivalence ratio and highlighted its strong temperature and pressure dependence [5-10].

When air-fuel mixture temperature increases, oxidation chemical reactions are sped up bringing to a laminar burning velocity rise. A slight decrease in laminar burning velocity is observed at higher air-fuel mixture pressures, which have low influence in chemical reactions while they reduce mass and energy transfer processes in flame front.

The most common equation used to fit flame burning velocity data for hydrogen, methane, propane, iso-octane, methanol and gasoline, at different pressure and temperature of unburned mixture, is a power law of temperature and pressure where exponents are a function of equivalence ratio. The equation also depends on the laminar speed at reference conditions (S_{L0}). Iijima et al. [5] proposed an expression for temperature and pressure exponents that depend linearly on the equivalence ratio, used by most of authors [5-10]. Metghalchi et al. [6, 7] used a second-order polynomial function of fuel ratio for laminar flame velocity at the reference conditions for methanol, isooctane, indolene and propane, while Galmiche et.al used a forth-order polynomial function for iso-octane [8]. Verea et al. recently extended the linear power exponent of pressure to contain quadratic term of equivalence ratio. During their calculation for n-butanol, isooctane, Liu K. et al. [9] found that it is difficult to compromise such range of equivalence ratio of interest unless the power exponent of pressure is extended to include the cubic term. Ravi et al. [10] assumed the laminar speed at reference conditions and the two exponents to be different order polynomial functions of equivalence ratio for hydrogen-oxygen mixture. To cover whole range of equivalence ratio data, Ravi et al. used different polynomial functions calculating the corresponding coefficients. In order to integrate renewable energies, such as wind energy [11-13], into generation systems, conventional power generation efficiency should be increased. Thus, studying internal combustion engine combustion is fundamental for fuel energy conversion efficiency.

Therefore, in the present work authors proposed a fifth order logarithmic polynomial for the laminar speed at the reference conditions and for both power exponents of pressure and temperature to describe the burning velocity as a function of equivalence ratio, pressure and temperature. In particular, a coefficients database of several conventional and non-conventional fuels was implemented.

The proposed method allows predicting laminar burning velocity of combusting air/fuel mixtures in several engineering applications such as Internal Combustion Engine and Gas Turbine modeling.

Mathematical model

Laminar flame speed of fuels strongly depends on temperature and pressure. This simultaneous dependence in temperature and pressure was taken into account by authors adopting the commonly used function described by a power low expression as in equation 1.

$$S_L = S_{L0}\left(\frac{T}{T_0}\right)^{\alpha}\left(\frac{p}{p_0}\right)^{\beta} \quad (1)$$

where S_L is the laminar flame speed at arbitrary conditions of temperature T and pressure p, T_0 and p_0 are the reference temperature and pressure, S_{L0} is the laminar flame speed at reference conditions, α and β are respectively the power exponent of temperature and pressure. In this paper authors proposed fifth order logarithmic polynomial functions to define the laminar speed S_{L0} and the exponent α and β as a function of equivalence ratio ϕ (see equation 2).

$$S_L(\phi) = \left(\sum_{i=0}^{5} a_i (\ln\phi)^i\right)\left(\frac{T}{T_0}\right)^{\left(\sum_{i=0}^{5} b_i(\ln\phi)^i\right)}\left(\frac{p}{p_0}\right)^{\left(\sum_{i=0}^{5} c_i(\ln\phi)^i\right)} \quad (2)$$

In this mathematical model used to fit experimental data of laminar flame speed, the coefficients a_i, b_i and c_i are determined for a given fuel with the least square method. The calculation procedure of all coefficients for each fuel consists in three main steps.

The coefficients a_i are firstly obtained starting from the experimental data of the laminar flame speed at reference conditions and solving the over-determined matrix system (3).

$$Y_0 = X\,A \quad (3)$$

where:

$$Y_0 = \begin{bmatrix} S_{L0}(\phi_1) \\ S_{L0}(\phi_2) \\ \cdot \\ \cdot \\ \cdot \\ S_{L0}(\phi_n) \end{bmatrix} \quad (4)$$

column vector of experimental data $S_{L0}(\phi_j)$ at reference temperature and pressure (T_0, p_0) (j = 1, 2, …, n) with n > 5.

$$X = \begin{bmatrix} 1 & \ln\phi_1 & (\ln\phi_1)^2 & (\ln\phi_1)^3 & (\ln\phi_1)^4 & (\ln\phi_1)^5 \\ 1 & \ln\phi_2 & (\ln\phi_2)^2 & (\ln\phi_1)^3 & (\ln\phi_1)^4 & (\ln\phi_1)^5 \\ & & & \cdot & & \\ & & & \cdot & & \\ & & & \cdot & & \\ 1 & \ln\phi_n & (\ln\phi_n)^2 & (\ln\phi_n)^3 & (\ln\phi_n)^4 & (\ln\phi_n)^5 \end{bmatrix} \quad (5)$$

with ϕ_j data values of equivalence ratio (j = 1, 2, …, n)

$$A = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} \quad (6)$$

with a_i coefficients of fifth order logarithmic polynomial relative to laminar flame speed at reference conditions.

The column vector A of unknown coefficients can be easily determined by solving the matrix system 7.

$$A = (X^T X)' X^T Y_0 \quad (7)$$

where X^T is the matrix transpose of X and $(X^T X)'$ is the matrix inverse of $X^T X$.

Secondly, the temperature exponent coefficients b_i and the pressure exponent coefficients c_i are determined by the matrix system 8.

$$B = (X^T X)' X^T Y_{Tp} \quad (8)$$

where:

$$B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ c_0 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{bmatrix} \quad (9)$$

$$Y_{Tp} = \begin{bmatrix} \ln\left(\frac{S_{Tp}(\phi_1)}{S_{L0}(\phi_1)}\right) \\ \ln\left(\frac{S_{Tp}(\phi_2)}{S_{L0}(\phi_2)}\right) \\ \cdot \\ \cdot \\ \cdot \\ \ln\left(\frac{S_{Tp}(\phi_m)}{S_{L0}(\phi_m)}\right) \end{bmatrix} \quad (10)$$

$$X = [X_T \cdot X_p] \tag{11}$$

Where

$$X_T = \begin{bmatrix} ln\left(\frac{T}{T_0}\right) & ln\left(\frac{T}{T_0}\right)\cdot ln\phi_1 & ln\left(\frac{T}{T_0}\right)\cdot (ln\phi_1)^2 \dots\dots\dots\dots ln\left(\frac{T}{T_0}\right)\cdot (ln\phi_1)^5 \\ & \vdots & \\ ln\left(\frac{T}{T_0}\right) & ln\left(\frac{T}{T_0}\right)\cdot ln\phi_m & ln\left(\frac{T}{T_0}\right)\cdot (ln\phi_m)^2 \dots\dots\dots\dots ln\left(\frac{T}{T_0}\right)\cdot (ln\phi_m)^5 \end{bmatrix} \tag{12}$$

$$X_p = \begin{bmatrix} ln\left(\frac{p}{p_0}\right) & ln\left(\frac{p}{p_0}\right)\cdot ln\phi_1 & ln\left(\frac{p}{p_0}\right)\cdot (ln\phi_1)^2 \dots\dots\dots\dots ln\left(\frac{p}{p_0}\right)\cdot (ln\phi_1)^5 \\ & \vdots & \\ ln\left(\frac{p}{p_0}\right) & ln\left(\frac{p}{p_0}\right)\cdot ln\phi_m & ln\left(\frac{p}{p_0}\right)\cdot (ln\phi_m)^2 \dots\dots\dots\dots ln\left(\frac{p}{p_0}\right)\cdot (ln\phi_m)^5 \end{bmatrix} \tag{13}$$

with T and p arbitrary temperatures and pressures, $S_{Tp}(\phi_k)$ experimental data of laminar speed at the arbitrary temperatures and pressures (T, p), ϕ_k data values of equivalence ratio (k = 1, 2, …., m), $S_{L0}(\phi_k)$ laminar speed values at reference conditions (T_0, p_0) calculated using equivalence ratio data ϕ_k and coefficients a_i in equation 3.

Results and discussion

In order to determine all coefficients of mathematical model proposed by authors and validate it, experimental data from literature for different fuels were used. Data fitting was performed for some fuels such as methane, ethane, iso-octane, hydrogen, dimethyl ether, tert-butanol, etc.

For the sake of simplicity, validation model results are shown only for iso-octane, since the same assessments can be extended to all other fuels.

The calculation procedure could be divided in the following main steps:

1. Determination of laminar burning velocity coefficients at reference conditions;
2. Determination of laminar burning velocity coefficients at different pressure and temperature;
3. Correlation validation at different pressure and temperature;
4. Verification of correlation extrapolation capabilities.

In the first step, the constant parameters a_i were optimized using the experimental values of laminar burning velocity at reference conditions T_0 = 323 K and p_0 = 1 bar [10]. The comparison between experimental data and the correlation curve is shown in Fig. 1 and highlights an average error less than 1 %.

In the second step, the parameters b_i and c_i were optimized using experimental data set at reference pressure and variable temperature of 373 K, 423 K, and 473 K as well as at reference temperature and variable pressures of 2, 3, 5, and 10 bar, respectively [10]. In the graphs in Fig. 2, laminar burning velocity is reported as a function of equivalence ratio at mentioned temperatures (Fig. 2a) and pressures (Fig. 2b). In the same figures experimental data and interpolation curves are shown. It is well evident that interpolation curves match experimental data very well (average relative error of 1.63 % and 2.34 % for Fig.2a and Fig. 2b, respectively). Moreover, in Fig. 2b some extrapolation capabilities are observed for higher equivalence ratios.

In order to verify the efficacy of the proposed mathematical model several extrapolation tests at different pressures and temperatures were carried out. In Fig. 3 tests results are shown. In particular, Fig. 3a, b, c and d show laminar burning velocity as a function of equivalence ratio at different reactant temperatures (323 K, 373 K, 423 K and 473 K) and at different reactant pressures (2 bar, 3 bar, 5 bar and 10 bar). In the same figures experimental data and interpolation curves are reported.

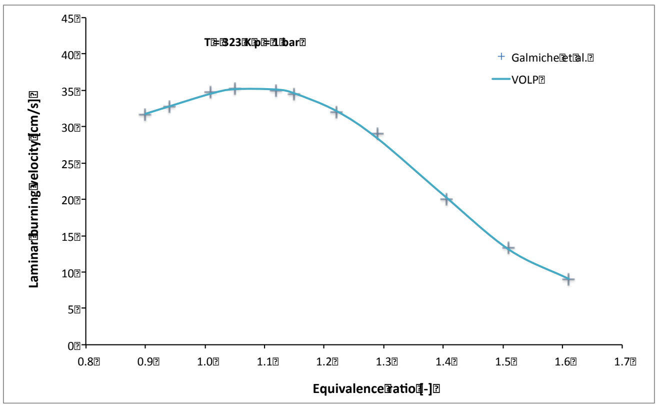
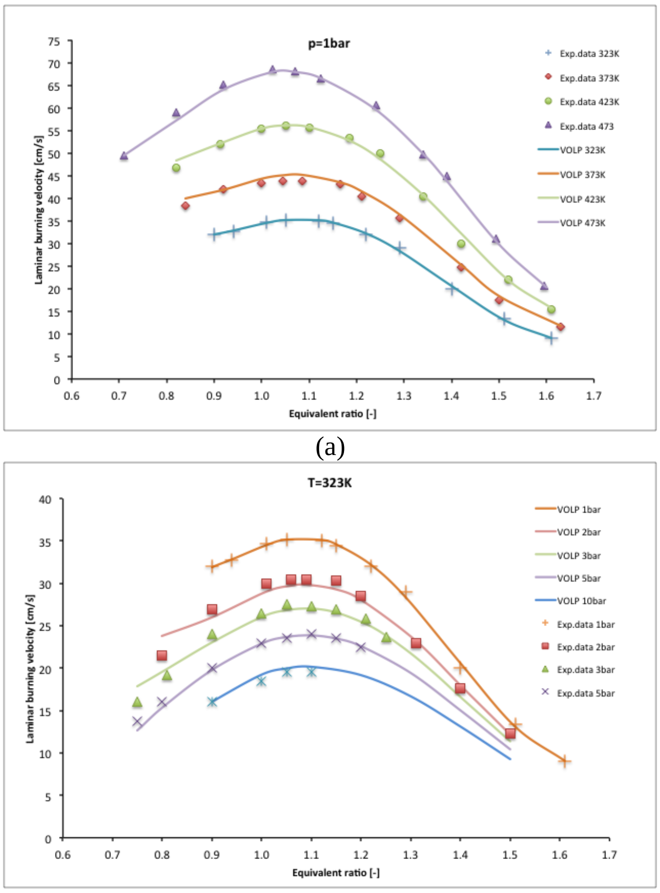


Fig.1. Experimental and calculated laminar burning velocity of iso-octane as a function of equivalence ratio at reference conditions



(a)

(b)

Fig.2. Experimental and calculated laminar burning velocity as a function of equivalence ratio at reference conditions

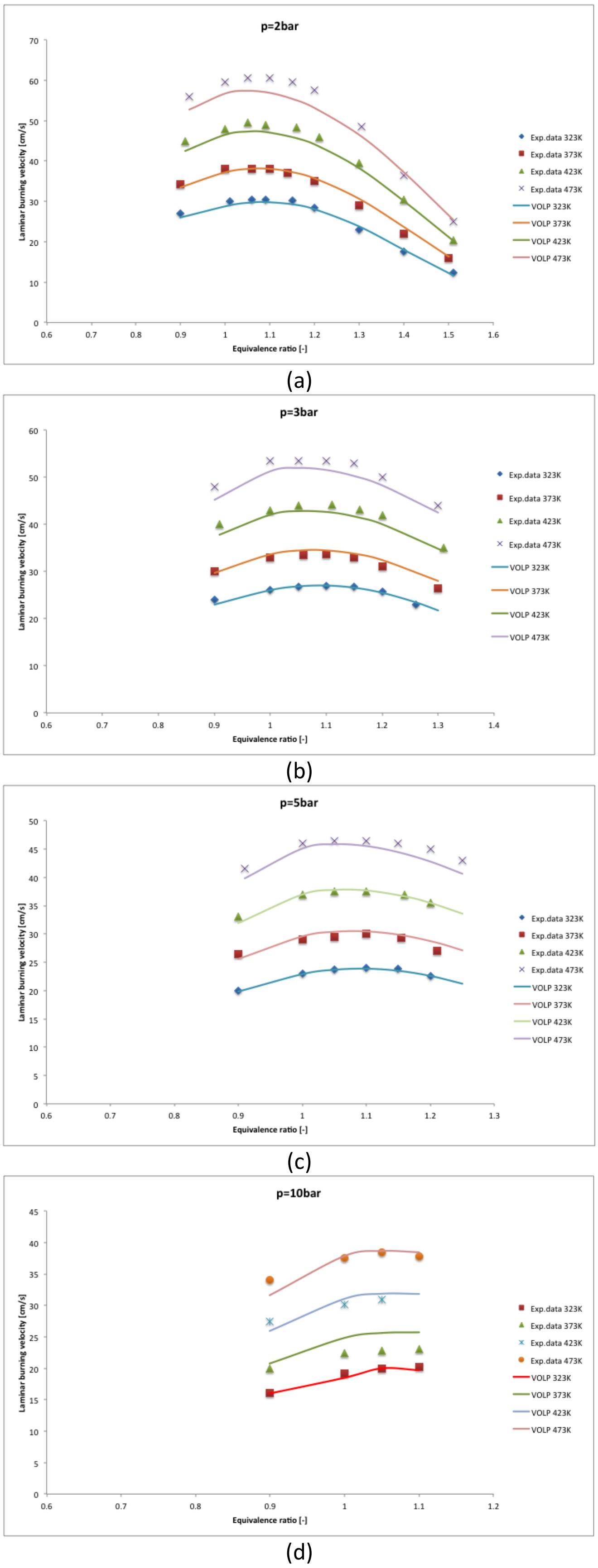


Fig.3. Experimental and calculated laminar burning velocity as a function of equivalence ratio at different pressures and temperatures

Result analysis leads to the consideration that laminar burning velocity increases with equivalence ratio up to about 1.1 and then decreases while equivalence ratio still increases. This behavior is well evident for all analyzed pressures and temperatures. Moreover, increasing reactant pressure (Fig. 2b and Fig. 3) a reduction in laminar burning velocity is observed at all equivalence ratios. The higher the pressure is the lower the laminar burning velocity. Temperature effects on laminar burning velocity are well evident in Fig. 3. A higher reactant temperature has the effect to speed up the combustion reaction increasing the laminar burning velocity. This behavior is observed for all studied reactant pressures, as well as at all equivalence ratios.

As far as the extrapolation capabilities it is concerned, it is possible to observe that extrapolating the curves for each pressure the average error increases with temperature, while increasing the pressure the extrapolation errors are almost constant for each temperature.

In conclusion, it is possible to state that the proposed mathematical model is able to predict laminar burning velocity as a function of equivalence ratio, pressure and temperature with a good agreement with experimental data. The mathematical model can be considered validated.

The new correlation model has been applied to several published experimental results for different fuels and reference, pressure and temperature coefficients have been calculated. A data summary table of laminar burning velocity was compiled (Table 1). This table contains all coefficients, reference conditions, pressure and temperature limits, equivalence ratio range, as well as allowed unit of measurement. A data summary table of laminar burning velocity was compiled. This table contains all coefficients, reference conditions, pressure and temperature limits, equivalence ratio range, as well as allowed unit of measurement. In the same table bibliographic data reference was reported.

TABLE.1. Data summary table of Laminar burning velocity

$$S_L(\phi) = \left(\sum_{i=0}^{5} a_i (\ln\phi)^i\right)\left(\frac{T}{T_0}\right)^{\left(\sum b_i (\ln\phi)^i\right)}\left(\frac{p}{p_0}\right)^{\left(\sum c_i (\ln\phi)^i\right)}$$

acetylene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.6 – 1.8	-	1-2	cm/s	[14,15]
Coefficients	a_0 136.78511185	a_1 106.60835888	a_2 -122.81180448	a_3 -99.99970747	a_4 -30.75220958	a_5 -243.79727130
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.19993383	c_1 0.29928146	c_2 -0.24935839	c_3 -3.80149819	c_4 -3.17858503	c_5 11.07670616
benzene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.8 – 1.6	298-450	1-3	cm/s	[16,17,18]
Coefficients	a_0 41.56611013	a_1 30.70705592	a_2 -141.80125318	a_3 -331.20081423	a_4 88.39415337	a_5 830.09909291
	b_0 1.35872952	b_1 -2.09133865	b_2 -1.45226502	b_3 -20.34059243	b_4 -36.75455809	b_5 80.76204838
	c_0 -0.07369291	c_1 0.53424273	c_2 1.88410735	c_3 9.61036883	c_4 -4.47408135	c_5 -1.22107814
carbon monoxide						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.4 – 2	-	-	cm/s	[19]
Coefficients	a_0 16.21398704	a_1 5.33200638	a_2 -3.42306594	a_3 6.47061936	a_4 -3.93588537	a_5 -15.01471807
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -

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	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
dimethyl ether						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
295.8	1	0.7 – 1.6	-	1-10	cm/s	[20]
Coefficients	a_0 42.99712120	a_1 42.56915207	a_2 -139.31400291	a_3 -196.81898059	a_4 189.17270883	a_5 43.19692640
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.24543320	c_1 -0.08510090	c_2 -0.73202771	c_3 4.96644080	c_4 -0.82890224	c_5 -28.55836623
ethane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.4	-	1-10	cm/s	[21,22]
Coefficients	a_0 40.44032677	a_1 29.37249480	a_2 -139.81618477	a_3 -219.68087332	a_4 71.61576662	a_5 288.00995728
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.5276942	c_1 0.20516715	c_2 0.43807940	c_3 -2.33706296	c_4 -13.78689194	c_5 -13.48470783

ethylene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.6 – 1.8	-	1-5	cm/s	[14,15]
Coefficients	a_0 66.80437248	a_1 59.69972119	a_2 -170.93608485	a_3 -248.25083376	a_4 136.48742398	a_5 279.88488016
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.26525992	c_1 0.35072003	c_2 -0.14199444	c_3 -4.24927205	c_4 -2.22778332	c_5 10.17275786
hydrogen						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.4 – 5	298-443	-	cm/s	[23,24]
Coefficients	a_0 219.46146284	a_1 215.43375572	a_2 -129.39840607	a_3 -121.38601445	a_4 49.33551040	a_5 5.25613402
	b_0 1.29917417	b_1 -0.01149843	b_2 0.26287014	b_3 -0.06612917	b_4 -23.99734251	b_5 24.03343908
	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
iso-butane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.4	-	-	cm/s	[25]
Coefficients	a_0 35.05287139	a_1 24.19165950	a_2 -109.91730005	a_3 -128.01412026	a_4 -112.50862166	a_5 -429.92903888
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
iso-octane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
323	1	0.9 – 1.6	323-473	1-10	cm/s	[8]
Coefficients	a0 34.31671322	a1 21.97847429	a_2 -70.50431081	a_3 -594.67571807	a_4 446.07057807	a_5 880.02623546
	b_0 1.80447644	b_1 -1.2448939	b_2 -3.68104341	b_3 38.43259875	b_4 -17.28138500	b_5 -65,84585451
	c_0 -0.25183188	c_1 0.15078487	c_2 -1.00231217	c_3 8.12170135	c_4 -19.92635384	c_5 -40.68229290
methane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.3	-	1-10	cm/s	[21]
Coefficients	a_0 33.59679954	a_1 30.28359554	a_2 -117.78370621	a_3 -230.39354920	a_4 -700.78036787	a_5 -1399.66424631
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.35514574	c_1 -0.07506395	c_2 -2.66181044	c_3 -2.31126275	c_4 10.45903786	c_5 20.77074323

n-butane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.4	-	-	cm/s	[25]
Coefficients	a_0 39.59778074	a_1 29.25115941	a_2 -168.79710074	a_3 -214.40969068	a_4 270.60605467	a_5 43.59890321
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
n-butylbenzene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
403	1	0.6 – 1.4	-	-	cm/s	[26]
Coefficients	a_0 58.49582711	a_1 14.28941121	a_2 -168.02012752	a_3 -184.20659254	a_4 -174.05575442	a_5 -246.10675053
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -	c_1 -	c_2 -	-	c_4 -	c_5 -
n-decane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
360	1	0.7 – 1.4	360-470	-	cm/s	[26,27]
Coefficients	a_0 56.876	a_1 34.826	a_2 -156.489	a_3 -469.581	a_4 -86.119	a_5 2332.520
	b_0 1.681	b_1 -0.761	b_2 0.421	b_3 31.038	b_4 25.713	b_5 -257.624
	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
n-dodecane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
400	1	0.7 – 1.4	400-470	-	cm/s	[27]
Coefficients	a_0 63.939	a_1 45.419	a_2 -159.395	a_3 -460.237	a_4 -28.607	a_5 1540.274
	b_0 1.806	b_1 -1.049	b_2 5.940	b_3 18.206	b_4 -39.848	b_5 -115.332
	c_0 -	c_1 -	c_2 -	c_3 -	c_4 -	c_5 -
n-heptane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.75 – 1.5	298-398	1-10	cm/s	[28, 29]
Coefficients	a_0 37.46685228	a_1 27.32138876	a_2 -128.93577404	a_3 -289.65771490	a_4 9.58150313	a_5 731.08583824
	b_0 1.63772876	b_1 0.18574128	b_2 -2.04728104	b_3 -8.79814733	b_4 39.34322469	b_5 47.64897317
	c_0 -0.21077176	c_1 0.03077341	c_2 -0.09012799	c_3 7.48937614	c_4 -6.42171393	c_5 -74.96475301

n-hexane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
296	1	0.75 – 1.4	296-398	1-10	cm/s	[17, 28]
Coefficients	a_0 38.91679933	a_1 30.03611671	a_2 -149.09366786	a_3 -256.81697898	a_4 -87.23105807	a_5 1062.28422461
	b_0 1.08017789	b_1 -0.48920719	b_2 3.17184567	b_3 -11.05926843	b_4 49.39552926	b_5 -61.85829637
	c_0 -0.21966405	c_1 0.04568317	c_2 1.56165121	c_3 7.09816604	c_4 -25.62622087	c_5 -80.25945054
n-octane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
353	1	0.7 – 1.3	-	1-5	cm/s	[28]
Coefficients	a_0 136.78511185	a_1 106.60835888	a_2 -122.81180448	a_3 -99.99970747	a_4 -30.75220958	a_5 -243.79727130
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.27971800	c_1 -0.27525733	c_2 3.06000133	c_3 19.32487132	c_4 -47.12147473	c_5 -178.32542840
n-pentane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
253	1	0.75 – 1.3	-	1-10	cm/s	[28]
Coefficients	a_0 46.81581245	a_1 32.56284273	a_2 -114.16096962	a_3 -395.63169242	a_4 -401.23187615	a_5 1650.87485661
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.23629608	c_1 -0.02993114	c_2 0.82422763	c_3 9.84014717	c_4 -18.45339947	c_5 -121.89193539
propane						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.4	-	1-5	cm/s	[14, 15]
Coefficients	a_0 39.07378490	a_1 27.49465957	a_2 -113.29578676	a_3 -248.74324189	a_4 -224.96663838	a_5 187.32103175
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.32026537	c_1 0.23570237	c_2 -0.88145774	c_3 -4.54207919	c_4 5.38849499	c_5 25.35016553
propylene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.7 – 1.4	-	1-5	cm/s	[16, 17]
Coefficients	a_0 41.98570131	a_1 37.48748827	a_2 -106.73032191	a_3 -179.56818539	a_4 -187.51161339	a_5 -108.47356976
	b_0 -	b_1 -	b_2 -	b_3 -	b_4 -	b_5 -
	c_0 -0.33517428	c_1 -0.02183993	c_2 -0.81043527	c_3 -2.44586924	c_4 7.37695179	c_5 25.59620248

tert-butanol						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
428	1	0.8 – 1.5	428-488	1-5	cm/s	[30]
Coefficients	a_0 49.60012772	a_1 12.33870721	a_2 -60.02138093	a_3 -391.50399530	a_4 -763.00223734	a_5 2371.55724619
	b_0 1.31851311	b_1 0.13035354	b_2 -3.15324076	b_3 26.78102775	b_4 58.70504492	b_5 -195.12014956
	c_0 -0.12009181	c_1 0.34257029	c_2 -2.09267434	c_3 0.39137248	c_4 30.81232216	c_5 -54.47956552
toluene						
T_0 [K]	p_0 [atm]	ϕ range [-]	T range [K]	p range [atm]	UOM	Ref.
298	1	0.8 – 1.4	298-470	1-2	cm/s	[17, 31, 32]
Coefficients	a_0 35.78407392	a_1 21.01348860	a_2 -90.99441920	a_3 -132.03193457	a_4 -199.86840684	a_5 -219.45572189
	b_0 1.66576338	b_1 -0.24027649	b_2 0.47965078	b_3 -2.36407108	b_4 18.02927030	b_5 28.06813188
	c_0 -0.05543636	c_1 -0.00089523	c_2 0.64551729	c_3 -2.24110263	c_4 -25.73469103	c_5 68.72776722

Conclusions

In this paper a study of laminar burning velocity of fuels/air mixture as a function of equivalence ratio, reactant pressure and temperature was presented.

Therefore, a mathematical methodology to interpolate and extrapolate experimental laminar burning velocity data was proposed and tested. Results analysis highlighted that simulated results, in the comparison between experimental data, presents an average relative error of about or less than 2 % at reference conditions. Thus, the proposed model is validated.

As mentioned the proposed model has some extrapolation capabilities. Thus, several tests were carried out at different pressure and temperature to test and demonstrate them. Results analysis highlighted that the proposed mathematical model is able to extrapolate data for pressure and temperature acceptable errors (maximum average error less than 5 %).

Coefficients determination for several fuels was carried out. For each studied fuel, reference, pressure and temperature coefficients were determined starting from experimental data. A data summary table of laminar burning velocity was compiled. This table contains all coefficients, reference conditions, pressure and temperature limits, equivalence ratio range, as well as allowed unit of measurement.

In conclusion, on the basis of the presented results it is possible to state that the proposed mathematical model is able to predict laminar burning velocity of fuel/air mixture for each equivalence ratio, pressure and temperature with very low errors.

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