

THE IMPACT OF TURBULENCE ON THE BURNING SPEED OF A COMBINATION OF AIR, AMMONIA, AND LPG GAS AT CERTAIN CONCENTRATIONS

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Abstract. A combustion chamber experiment utilizing Iraqi liquid petroleum and ammonia gas to examine turbulent combustion. The experiment used high-speed impellers to whirl the combustion chamber, creating turbulent combustion conditions. Researchers employed Schlieren imaging to track flame propagation under different settings. The experiment used 100, 200, and 300 kPa beginning pressures with 0.8, 1, and 1.3 equivalency ratios. The Schlieren system pictures were analyzed in MATLAB. The study was to calculate turbulent combustion speed using the combustion flame's average diameter, which is impacted by turbulence's uneven diameter. The calculated turbulent combustion speed when the conditions were changed to have the same equivalence ratio and different initial pressures or the same initial pressure and different equivalence ratios. Turbulence increases combustion efficiency, which increases combustion speed. Turbulence increases combustion speed, making fuel combination burning more efficient, as shown in this experiment. The setup and findings of this study contribute to the understanding of combustion processes and can have implications for improving combustion efficiency in various applications, such as engines and furnaces.

INTRODUCTION

The process of blended turbulent combustion is complex and poorly understood. The turbulent flame velocity of two fuels under tough conditions is still hard to compare [6]. While considerable study remains, we now understand the general features of blended turbulent flame formation. Lipatnikov and Chomiak [7] examined turbulent flame velocities (ST) using the latest experimental datasets. This meta-analysis presents its most important results and others. The wrinkling of turbulent eddies increases flame surface area, resulting in greater ST than laminar flames. "Turbulent extending" characterizes it. Energy cascading between major and tiny eddies rapidly increases a material's surface area [2, 5]. The turbulent extending surface area is restricted by self-propagation mechanisms, allowing wavy laminar flames to join.

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1. Turbulent flame speeds grow nonlinearly with turbulent intensity. ST increases when turbulent intensity peaks and falls (bending effect), extinguishing flames by excessive turbulence. Maximal intensity varies on fuel and equipment and cannot be generalized.
2. The lack of information on the influence of turbulent scales of length on ST is the fundamental reason of this difference. As pressure rose, the mixture's thermal diffusivity decreased. ST promoted flame instability and reduced flame thickness. Recent investigations by Ikeda, et al. [4] suggest that pressure increases turbulent Reynolds number (Re) and combustion velocities.

Like laminar flame velocities at a given Reynolds number, ST fell with rising pressure in a fan-stirred explosive. However, by modifying intensity and integral length scale, they could maintain Re constant at high pressures. Thus, a drop in u' may explain the decrease in ST with higher pressure. Lower Lewis numbers (This is the ratio between the thermal diffusivity of the mixture and the mass diffusivity of the deficient species in the diluent.) are associated with greater ST values, whereas mixes with $Le > 1$ have lower ST values. Le-containing mixtures greatly increase the local burning rates of extended flamelets (laminar flame segments in turbulent flow), raising ST values.

3. ST is non-linear, making it hard to estimate its sensitivity to a single parameter. The main goal of this study was to autonomously regulate turbulence size and magnitude.

Classifying these vocabulary as meaningful subsets simplifies investigation. First, laminar flames are briefly reviewed.

The turbulent flame brush classifies the different flame forms utilized in premixed turbulent combustion research [8].

Exploring reaction progress factors leads to distinct flame surfaces using various diagnostics. The uncertainty in estimating turbulent propagation rates is no longer definition-dependent.

Analysis of turbulent combustion regimes (Borghi diagram) has been done.

EXPERIMENTAL SETUP AND PROCEDURE

A description of the experimental rig the chamber and measuring instruments used to investigate experimentally the effect of ammonia blending ratio with LPG on combustion system safe operation and flame stability are presented [1, 6]. The complete setup rig is shown in figure (1). It consists of the following units:

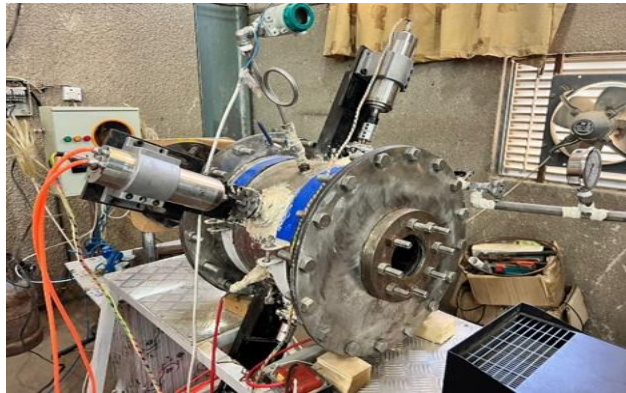


Figure 1. Mixing Process inside the Combustion Chamber

The gases are admitted into the combustion chamber after it is completely emptied from the air. Ammonia gas is injected, then liquefied petroleum gas, and then air from the special storage tanks for each gas. The mixture enters into the combustion chamber at required initial pressure, and after that, it closes all the fuses and waits for a period of 10 minutes prior to the ignition for the purpose of stabilizing the mixture, obtaining laminar flame, and sustaining a mixture free of the eddies and turbulence.

Combustion and Recoding Processes:

The homogeneous mixture was prepared in the preceding steps thereafter.

- a) The initial values of the temperature and pressure shall be adjusted on the initial status of the test.
- b) The electronic transformer of pressure begins recording the pressure of combustion.
- c) Determine the ignition duration (5-second ml).
- d) D. High – Speed camera have to size at the time of formation (1.2) seconds with 10% pre – operability and the illuminating system begins to lighten.
 - a) Both the ignition logging operators and the camera are moved.
 - b) The data is recorded and photos are captured. Step (a) has been repeated with a variety of initial conditions.

Analysis Assumption

The laminar burning velocity may be determined by using a series of computations based on the analysis of Schlieren pictures obtained after each experimental trial. In order to use the data obtained from the bomb, certain assumptions must be made. These have been produced by several writers [9]. Which include:

1. The non–burned regular gas is in a state of restin principle.
2. The total mass and volume of the contents of the receptacle are preserved.
3. Pressure is supposed to be regular through flame during combustion analysis.
4. The mixture is burning in the middle of the pot with a small temperature entrance.
5. The flame speed is quick enough that the buoyancy is minimal and the prelude of flame extends to the exterior spherically.
6. The flame front itself is an external heat constant system.
7. The flame front is infinitely thin.
8. No chemical reaction and no dissociation occur in the unburned gas.
9. There is no heat transfer between the zones.

Stretched Flame Speed Analysis

The density gradient emerges within the combustion chamber when the flame radius is determined directly by Schlieren photography, but the flame radius may be in the shadow picture because the photographic image does not show the flame edge. Schlieren photography measures flame radius, and radius – duration of flames determines laminar flame speed (S_n).

$$S_n = \frac{dr_{sch}}{dt} \quad (1)$$

Software (Tracker version 4.87) collects Cartesian coordinates by viewing the front of the flame for each frame. The high-speed camera records the film and outputs (S_n , r , and t). Table (3.4) illustrates how to set up Tracker Software and measure flame speed.

$$S_n = \frac{dr}{dt} = \frac{r_{j+1} - r_j}{t_{j+1} - t_j} \quad (2)$$

The mean radius is assumed to be the radius that corresponds this speed.

$$R_{(j+1/2)} = \frac{r_{j+1} + r_j}{2} \quad (3)$$

The data are necessary as a result of this method, the data is dispersed, making it impossible to see a distinct pattern, because of averages of four half-diameters for time per direction to calculate the speed of the flame given by.

$$S_n = \frac{dr}{dt} = \frac{((r_{i,j+n+1} - r_{i,j+n+2}) + (r_{i,j-n-1} - r_{i,j-n-2}) + (r_{i+n+1,j} - r_{i+n+2,j}) + (r_{i-n-1,j} - r_{i-n-2,j}))}{t_{j+1} - t_j} / 4 \quad (4)$$

The only advantage of the average technique with the tracking software is particularly sensitive to small elevations compared to the endpoints. Large radius effect becomes apparent due to the consequences of the thickness of the electrical code and this increase the error due to a lack of the clarity in the photograph on film and could arise from multi-sources [10].

Flame Stretched Rate

A universal stretch at any point on the flame's surface is the Lagrangian time derivation of the logarithm of area (A) of any tiny element.

$$\alpha = \frac{d(\ln A)}{dt} = \frac{1}{A} \frac{dA}{dt} \quad (5)$$

The flame stretch rate for an outwards spreading spherical flame is given by 22.

$$\alpha = \frac{1}{A} \frac{dA}{dt} = \frac{2}{r_u} \frac{dr}{dt} = \frac{2}{r_u} S_n \quad (6)$$

The flame stretch rate α indicates the rate of flame area expansion in a spherically spreading flame. An acceptable unified tensor expression for flame stretches rate expressions.

The strain rate tensor α_s and flame curvature stretch rate α_c are

$$\alpha = \alpha_s + \alpha_c \quad (7)$$

Flame propagation speed and stretch rate are linearly related pre-pressure:

$$S_f - S_u = L_b \alpha \quad (8)$$

The intercept at $\alpha=0$ in the plot of S_n versus α represents the unstretched propagation speed, S_l . The burnt gas Markstine length L_b is the negative slope of the S_n - α fitting curve [11]. Markstine length is burning velocity per stretch reduction.

Turbulent burning speed

In the initial stage of flame propagation, the total volume of the burned gases is around 0.5% of the volume of the combustion chamber², the Unstretched laminar burning velocity, u_l , is related to S_l through the mass conservation across the flame front.

$$A \rho_b S_l = A \rho_u u_l \quad (9)$$

Where A is the flame front area, ρ_u , and ρ_b are the unburned and burned gas densities respectively. The Unstretched laminar burning velocity can be get from equation (3.22), [3].

$$u_l = S_l \frac{\rho_b}{\rho_u} \quad (10)$$

DISCUSSION

Laminar burning speed

Figures 2–6 demonstrate the connection between Laminar burning velocity S_l and

flame radius for NH_3 –LPG–air combination at 298 K, 0.1, 0.2, and 0.3 MPa. Laminar burning velocity decreases with beginning pressure. This is because starting pressure decreases fuel mixture thermal diffusivity. The Equivalence Ratio and Ammonia Gas Percentage effects indicate that laminar burning velocities are lowest in lean mixtures and greatest in stoichiometric mixtures, with decreasing values in rich mixtures. Figure (4.34) demonstrates that when $E_{\text{LPG}} = 100\%$ and $E_{\text{NH}_3} = 0\%$, the laminar burning velocity is lowest on the lean mixture and maximum on the stoichiometric combination and decreases on the rich mixture. When ammonia concentration surpasses 10%, laminar burning velocity increases. As ammonia gas concentration rises, laminar burning velocity falls. That is S_L 's highest value at 10% ammonia. The maximum laminar burning velocity is in stoichiometric mixture.

Turbulent burning speed

Figures (7–11) and (12) demonstrate the link between turbulent burning velocity S_t and flame radius, as well as laminar burning velocity S_L . The turbulent system inside the fixed combustion chamber increased the combustion speed of the mixture of gases (LPG, ammonia, and air) at ammonia concentration ratios (10-20-30) and pressure (100-200-300), where we obtained the best combustion speed increase is 100 pressure and 10% ammonia concentration, because pressure affects combustion speed and ammonia has a very low combustion speed compared to a high diffusion speed. Increasing ammonia concentration to a high percentage increases flame speed but decreases combustion speed. When compared to laminar circumstances, turbulent conditions increased combustion speeds the most in ratios.

As we raise mixing ratio and equivalence (1.3, 1), mixing equivalence (0.8) declines and approaches lamellar. The combustion chamber's combination of gases (LPG, ammonia, and air) has a fast chemical reaction speed, but it requires a suitable mixing tool and high proportions. Mixing (0.8), the combustion chamber has a high oxygen content, and while air mixing engines are functioning and big vortices develop, oxygen atoms approach the reactants, increasing combustion speed.

Parity (1, 1.3) indicates the combustion chamber's oxygen atom proportion. Equal or fewer than the number of moles needed reduces the turbulent process and converts the reaction into a quick chemical reaction.

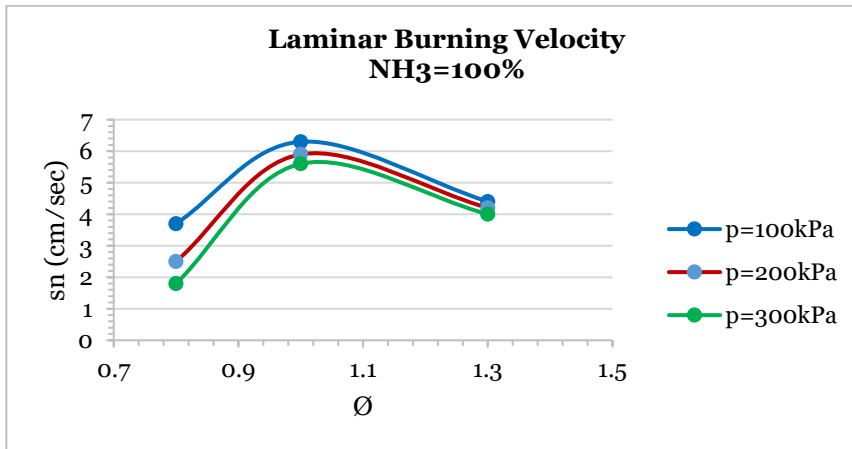


Figure 2. Laminar burning velocity S_L with a flame radius for 100% NH_3 with initial pressure (100, 200 and 300) kPa

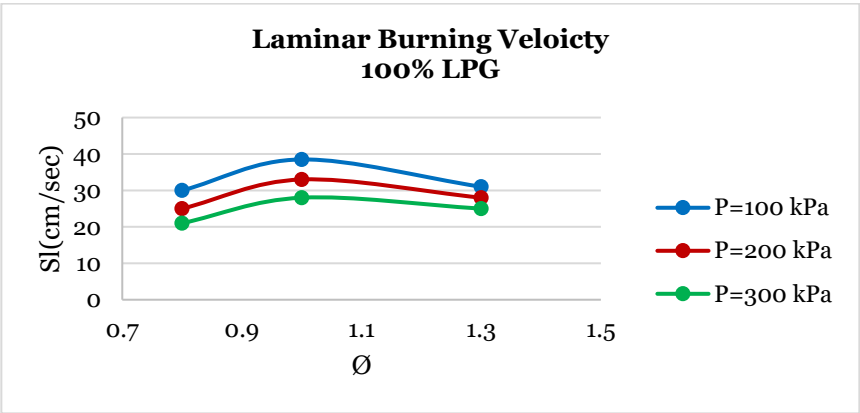


Figure 3. Laminar burning velocity S_l with a flame radius for 100% LPG with initial pressure (100, 200 and 300) kPa

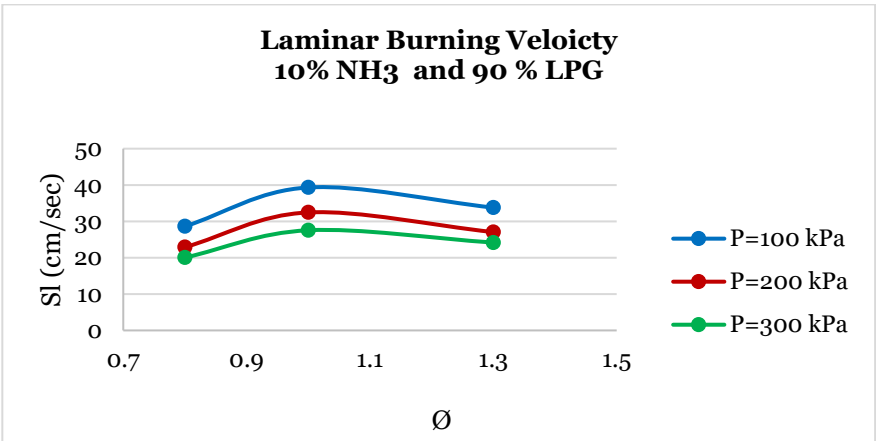


Figure 4. Laminar burning velocity S_l with a flame radius for 90% LPG and 10% NH_3 with initial pressure (100, 200 and 300) kPa

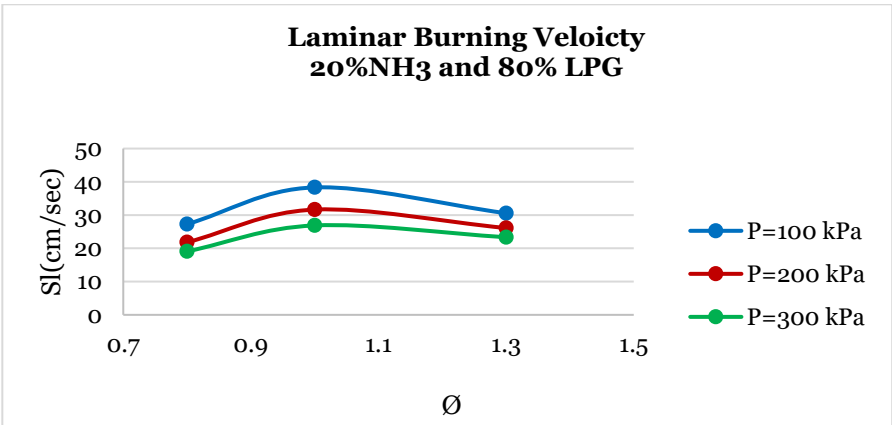


Figure 5. Laminar burning velocity S_l with a flame radius for 80% LPG and 20% NH_3 with initial pressure (100, 200 and 300) kPa

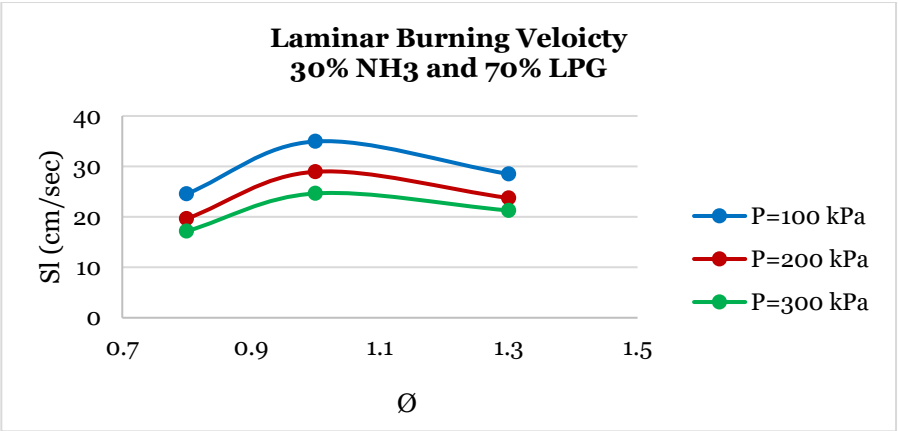


Figure 6. Laminar burning velocity S_l with a flame radius for 70% LPG and 30% NH_3 with initial pressure (100, 200 and 300) kPa

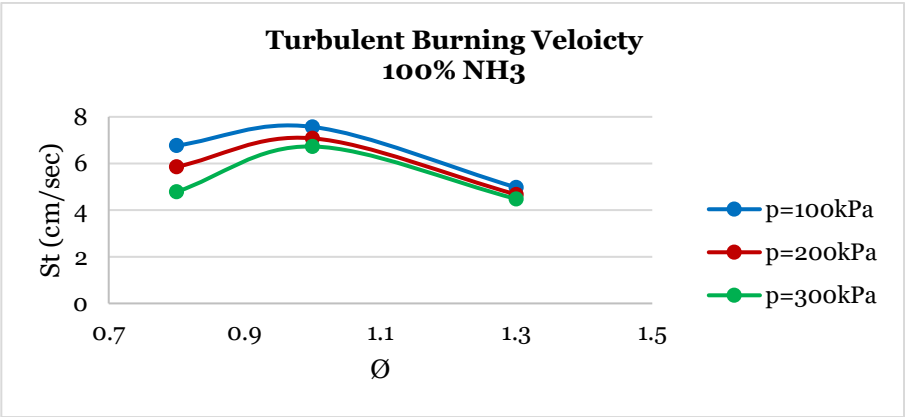


Figure 7. Turbulent burning velocity S_t with a flame radius for 100% NH_3 with initial pressure (100, 200 and 300) kPa

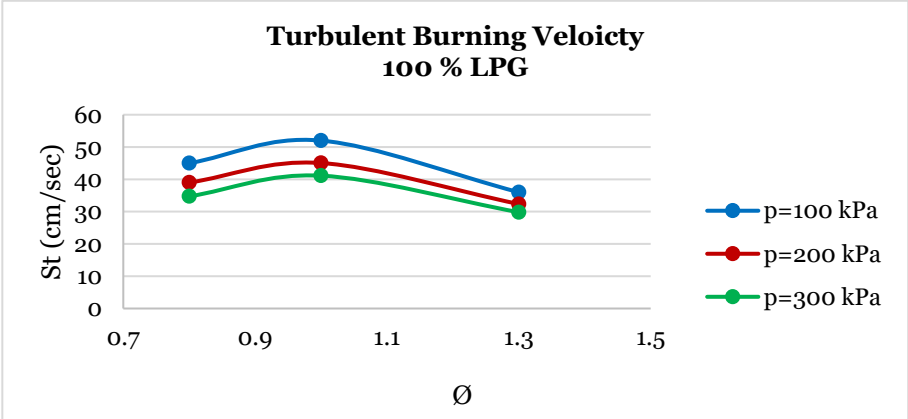


Figure 8. Turbulent burning velocity S_t with a flame radius for 100% LPG with initial pressure (100, 200 and 300) kPa

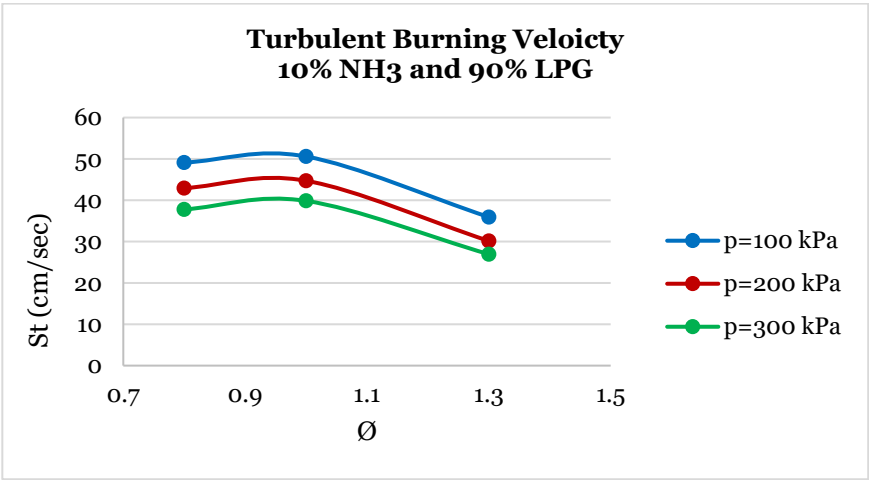


Figure 9. Turbulent burning velocity St with a flame radius for 90% LPG and 10% NH₃ with initial pressure (100, 200 and 300) kPa

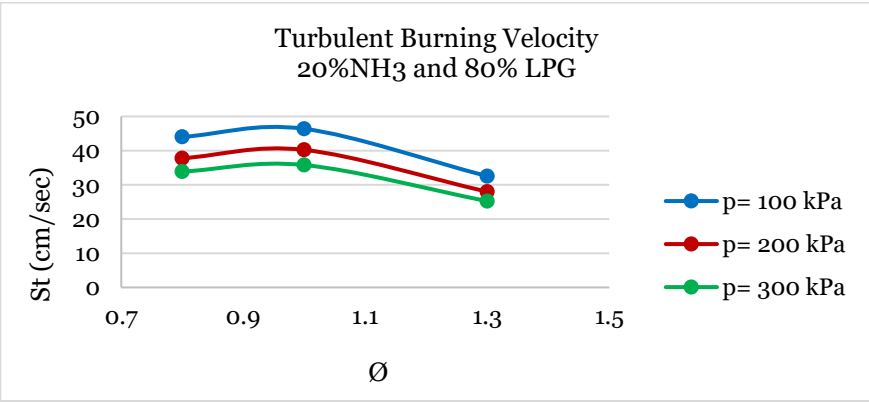


Figure 10. Turbulent burning velocity St with a flame radius for 80% LPG and 20% NH₃ with initial pressure (100, 200 and 300) kPa

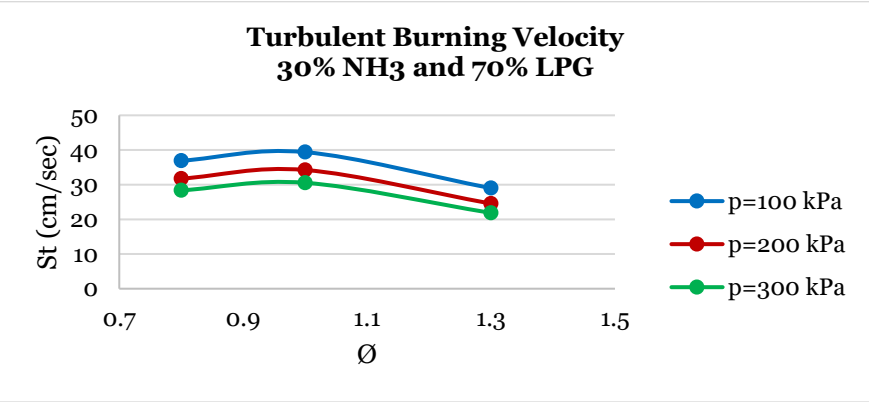


Figure 11. Turbulent burning velocity St with a flame radius for 70% LPG and 30% NH₃ with initial pressure (100, 200 and 300) kPa

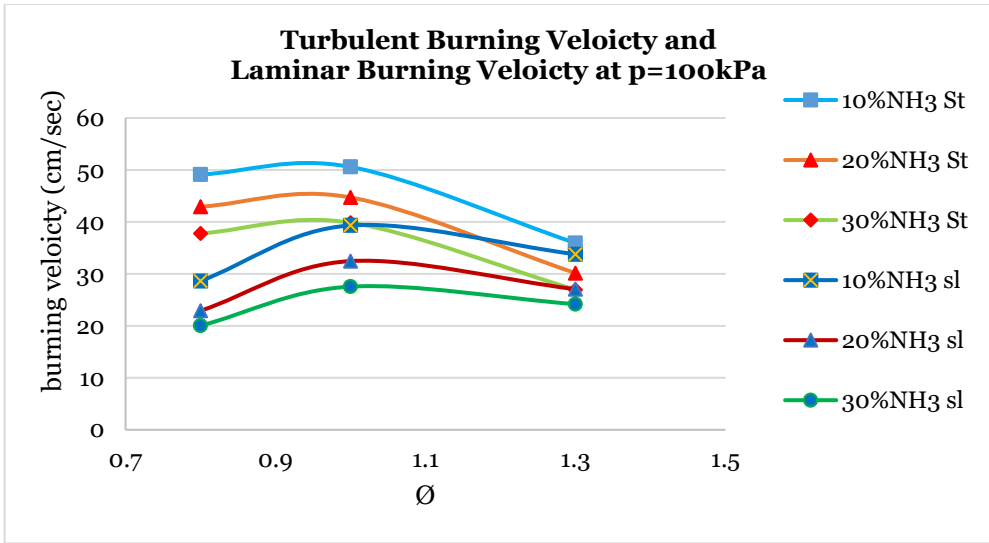


Figure 12. Turbulent burning velocity S_t comper with laminar burning velocity S_l at (10,20,30%) NH_3 with initial pressure (100) kPa

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