Experimental study of turbulent burning velocity at an initial pressure (100,200,300) kPa

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ABSTRACT

The combustion chamber was developed in the laboratories of the University of Babylon for the purpose of conducting the study to measure the speed of turbulent combustion, where four high-speed impellers were installed symmetrically in the vicinity of the combustion chamber, where they formed a homogeneous swirling disorder. Iraqi liquefied petroleum, where the percentage of ammonia gas was (10) using the Schlieren imaging system to photograph the growth of the flame under conditions of initial pressure (100, 200, 300) kPa and the coefficient of equivalence (0.8 , 1 ,1.3), and the image was processed and analyzed using the MATLAB program, and the speed of turbulent combustion was calculated depending on the average diameter of the combustion flame due to the irregular diameter As a result of the turbulence, we obtained a laminar combustion speed whose value was (28.64 cm/sec)and at an initial pressure of an amount and an equivalence ratio, and at the same equivalence ratio and an initial pressure of an amount and the same conditions for the same equivalence ratio, the turbulent combustion speed was (49.11 cm/sec), and this explains the effect of turbulence by increasing the combustion speed

Keywords:

Introduction

Global warming results from increased greenhouse gas concentration (GHGs), in particular, carbon dioxide (CO_2) in the atmosphere. This atmospheric accumulation of greenhouse gases is largely the result of fossil fuel combustion and other human activities.

Many possible reforms were suggested to address this study, and the search for fossil-fuel replacements is a significant task for society. Various researches were conducted to evaluate alternative fuel's energy efficiency and environmental impact. The use of ammonia gas represents a possible solution for the storage of intermittent renewable energy.

Ammonia is considered more suitable for storage and transportation compared to Hydrogen gas because the tanks in which ammonia is stored is light, not expensive and its storage is also safer due to the low pressure.

The ammonia energy storage system has great advantages over a wide range and less restriction of geographical conditions compared to many other conventional energy storage method (De Bellis, Malfi et al. 2019) **[1]**.

Flame propagation speeds under laminar conditions have been measured with great success. The system pressure, system temperature, and equivalency ratio are the only factors that influence the laminar flame speed of an explosive mixture. After accounting for geometry and flame stretch, the observed laminar flame speed may be used to verify chemical kinetics. Another application of laminar flame speeds is to predict the propagation rates of turbulent flames using correlations that are generally appropriate for a particular experimental database. This makes such propagation rates puzzling, in contrast to the laminar case **(Zhang, Zirwes et al. 2021)[2]**. Self-similar scaling of spherically spreading flames was recently found using data from various fan-stirred explosives, including data from the rig constructed here **(Morones, Turner et al. 2019)[3]**. These results are exciting because they show that it is possible to create a comprehensive database of turbulent propagation rates for established and emerging fuels relevant to gas turbines and IC engines. Inside such flame bombs, mixing fans are attached to provide the necessary turbulence. This goal was attained by employing a systematic strategy. The following are explanations of the five most important ones **(Martínez-Sanchis, Sternin et al. 2022)[4]**

1. The primary objective was to modernize the current facility cost-efficiently while minimizing the need for adjustments to the original equipment. Post-combustion pressures and temperatures did not compromise the vessel's structural integrity.

2. Refine the shape of the fans such that the turbulence inside the flame bomb is consistent. After that, the fan-generated flow fields were meticulously measured. The major objective of this dissertation was to enhance the scalability monitoring capabilities of an existing high-pressure laminar flame bomb in the author's lab **(Zhang, Zirwes et al. 2021)[5]**.

3. Improve our control over turbulence parameters in such flame bombs, turbulence conditions are defined by the intensity level and the integral length scale. Therefore, the correlations between the fan-stirred data and the flame speed are affected by geometric factors. Adjustable intensity levels and a sliding scale for the duration of turbulence were included to address this concern.

4. The literature was scoured for various diagnostic techniques relating to fan-stirred bombs, and a process for monitoring turbulent flame speeds was established. Thanks to Schlieren imaging, time is saved, and accurate flame spread rates are provided. Automated image analysis and post-processing procedures were developed specifically for turbulent combustion. The capabilities of the rig were successfully shown by Experiment **(Xu, Nielsen et al. 2017)[6]**

5: Turbulent Flame Speed, in which preliminary measurements of LPG-Ammonia-Air mixtures were obtained in various conditions.

Turbulent flame speed refers to the rate at which a flame propagates through a turbulent flow. It measures how quickly the flame front advances through a mixture of fuel and oxidizer in the presence of turbulence.

In a turbulent combustion process, the reactants (fuel and oxidizer) are mixed by the turbulent flow, creating a highly complex and dynamic environment. The flame speed in such conditions is influenced by several factors, including turbulence intensity, flame stretch, and the interaction between turbulence and chemistry.

The turbulent flame speed is typically higher than the laminar flame speed, which refers to the flame speed in the absence of turbulence. This is because turbulence enhances mixing, allowing for a faster reaction between the fuel and oxidizer. **(CHAKRABORTY*, Mastorakos et al. 2007)[7]**

It is important to note that the turbulent flame speed is not a constant value but rather varies depending on the specific conditions. Different experimental and computational techniques are used to measure and model turbulent flame speeds under various operating conditions, such as different fuels, pressures, and temperatures.

Understanding the behavior of turbulent flames is crucial in various fields, including energy conversion, combustion engines, and fire safety, as it affects combustion processes' efficiency, stability, and pollutant emissions.

Studying the turbulent flame speed combustion process is important in several fields, including combustion science, energy production, environmental engineering, and safety. Here are some key reasons why this area of research is crucial:

Combustion Efficiency: Combustion processes are vital in various energy conversion systems, such as internal combustion engines, gas turbines, and industrial furnaces.

Understanding and optimizing the turbulent flame speed is crucial for improving the overall combustion efficiency, reducing fuel consumption, and minimizing harmful emissions **(Xing, Kumar et al. 2017)[8]**

Emission Control: Combustion processes are a significant source of air pollutants, including nitrogen oxides (NOx) and particulate matter (PM). By studying the turbulent flame speed, researchers can gain insights into the mechanisms contributing to pollutant formation and develop strategies to mitigate emissions through advanced combustion techniques and pollutant control technologies.

Safety Considerations: Combustion processes can pose serious safety risks, especially in industrial settings. Turbulent flames can exhibit complex behaviors, such as flame instabilities, flashbacks, and flame quenching, which can lead to hazardous conditions and even explosions. Engineers can design safer combustion systems and develop effective safety measures by understanding the turbulent flame speed and its interaction with various factors, such as fuel properties, flow conditions, and geometry. Alternative Fuels and Energy Sources: As the world seeks to transition to more sustainable energy sources, studying turbulent flame speed becomes crucial for evaluating the combustion characteristics of alternative fuels, such as biofuels, hydrogen, and synthetic fuels. Understanding how these fuels interact with turbulence can help assess their feasibility, performance, and emissions when used in different combustion systems.

Climate Change Mitigation: Combustion processes significantly contribute to greenhouse gas emissions, particularly carbon dioxide (CO2), the primary driver of climate change. By studying the turbulent flame speed and combustion processes, researchers can explore techniques for reducing CO2 emissions, such as low-emission combustion strategies, carbon capture and storage (CCS), and utilization of renewable energy sources.

Fundamental Science: The study of turbulent combustion is important for practical applications and advancing fundamental scientific knowledge. Turbulence-chemistry interactions in flames are complex and still not fully understood. Studying the turbulent flame speed and its interaction with various turbulent flow phenomena provides insights into combustion's fundamental physics and chemistry, helping to refine and develop more accurate combustion models and simulations **(Fries, Ochs et al. 2019)[9]**

In summary, studying the turbulent flame speed combustion process is crucial for improving combustion efficiency, reducing emissions, ensuring safety, advancing alternative energy sources, mitigating climate change, and advancing fundamental scientific understanding. This research has broad implications across various industries and is essential for sustainable and efficient energy conversion and utilization. **(Lipatnikov 2012)[10]**

The mechanism of blended turbulent combustion is extremely intricate and poorly understood. The turbulent flame velocity of two fuels in different harsh circumstances is still difficult to compare **(Lipatnikov and Chomiak 2007)[11]**, Although much work remains, our understanding of the broad characteristics of the development of a blended turbulent flame has advanced significantly. Using the most recent experimental datasets on turbulent flame velocities (ST), Lipatnikov and Chomiak **(Lipatnikov and Chomiak 2002)[12]** conducted a thorough assessment Some of the most crucial findings from that meta-analysis and others are presented here.

1. The wrinkle of turbulent eddies increases the surface area of the flame, leading to a higher ST compared to laminar flames. "Turbulent extending" describes this phenomenon. A material's surface area grows exponentially due to the energy cascading between big and minor eddies. **(Lipatnikov 2012)[17] (Batchelor 1952)[13]**. The surface area created by turbulent stretching is constrained by self-propagation processes, which enable wavy laminar flames to merge.
2. Turbulent flame speeds exhibit nonlinear behavior as a function of turbulent intensity increases ST rises as turbulent intensity levels rise, reach a maximum, and then fall (bending effect), culminating in flame quenching by excessive turbulences The maxima intensity

level strongly depends on the fuel and the equipment and cannot be generalized.

3. The main cause of this disparity is the absence of datasets concentrating on the impact of turbulent scales of length on ST, it was shown that a decrease in the mixture's thermal diffusivity as pressure increased ST decreased the flame's thickness and favored flame instability, Recent studies by Liu et al,**(Kobayashi, Tamura et al. 1996) [14]** imply that a rise in turbulent Reynolds number (Re) with pressure is responsible for increased turbulent combustion velocities.

They showed that, like laminar flame velocities at a fixed Reynolds number, ST dropped with increasing pressure in a fan-stirred explosive, However, they could keep Re constant at high pressures by adjusting the intensity levels and integral length scale.

As a result, the reduction in ST seen with increased pressure may also be explained by a fall in u′ Low Lewis numbers (defined as the ratio of the thermal diffusivity of the mixture to the mass diffusivity of the deficient species in the diluent) are related to higher ST values, whereas higher ST values are connected with mixes with Le > 1.

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. All experiments are conducted in the Mechanical Engineering Department Laboratories at the University of Babylon. **(Alsultani)[15]** The complete setup rig is shown in figure (3.1). It consists of the following units:

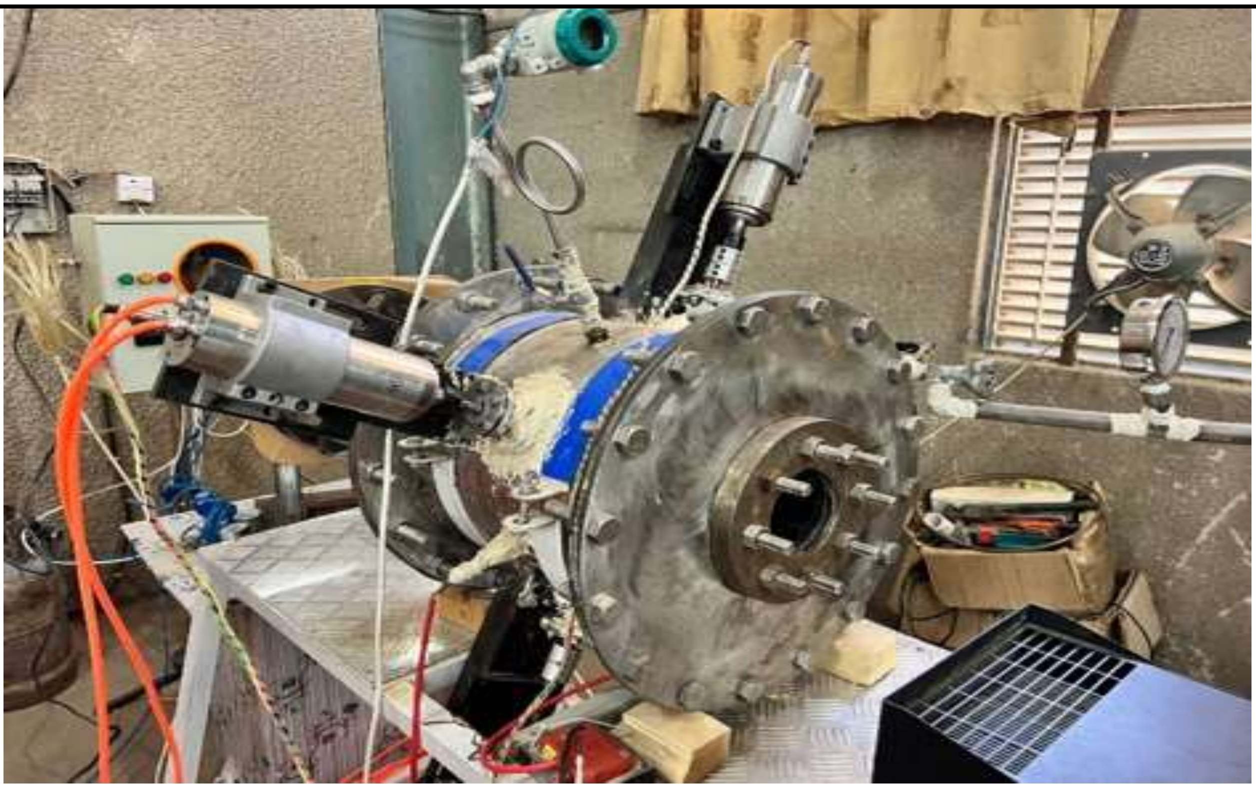
1. Combustion chamber unit
2. Ignition system and Control unit
3. Impeller Unit
4. Mixture Preparing Unit
5. capturing unit

Each of the units mentioned above consists of many components:

3.2 Combustion Chamber Unit: -

1. Combustion chamber
2. Pressure transmitter
3. Thermal Gasket
4. Safety Valve
5. Vacuum pumps

Photograph of the experimental rig used in the study



Photograph of the Combustion Chamber Unit.

Figures (1 to 6)shows relationship between Turbulent burning velocity S_t with a flame radius and figure (6) shows relationship between Turbulent burning velocity S_t with a flame radius and Laminar burning velocity S_l with a flame radius and figure (6) The results showed that the use of the turbulent system inside the fixed combustion chamber leads to a clear increase in the combustion speed of the mixture of gases (LPG, ammonia, and air) at the ammonia concentration ratios (10-20-30), as well as when changing the pressure (100-200-300), where we obtained The best increase in the combustion speed at pressure (100) and ammonia concentration 10% , because the increase in pressure affects the combustion speed, as well as the concentration of ammonia reduces the combustion speed (LPG) gas, the higher the concentration of ammonia mixing, as ammonia has a very low combustion speed compared to a high diffusion speed As mixing ammonia with gas (LPG) improves the flame speed, but reduces the combustion speed with increasing the ammonia concentration to a high percentage. When comparing the combustion speed of turbulent conditions with the combustion speed of laminar conditions, the results showed that the best increase in combustion speed is when it is a turbulent state in ratios Mixing equivalence (0.8) then decreases and approaches lamellar as we tend to increase the mixing ratio and equivalence (1.3, 1). The reason for this is that the mixture of gases (LPG, ammonia and air) inside the combustion chamber has a relatively high chemical reaction speed, but it needs a good mixing tool and at high proportions Mixing (0.8)

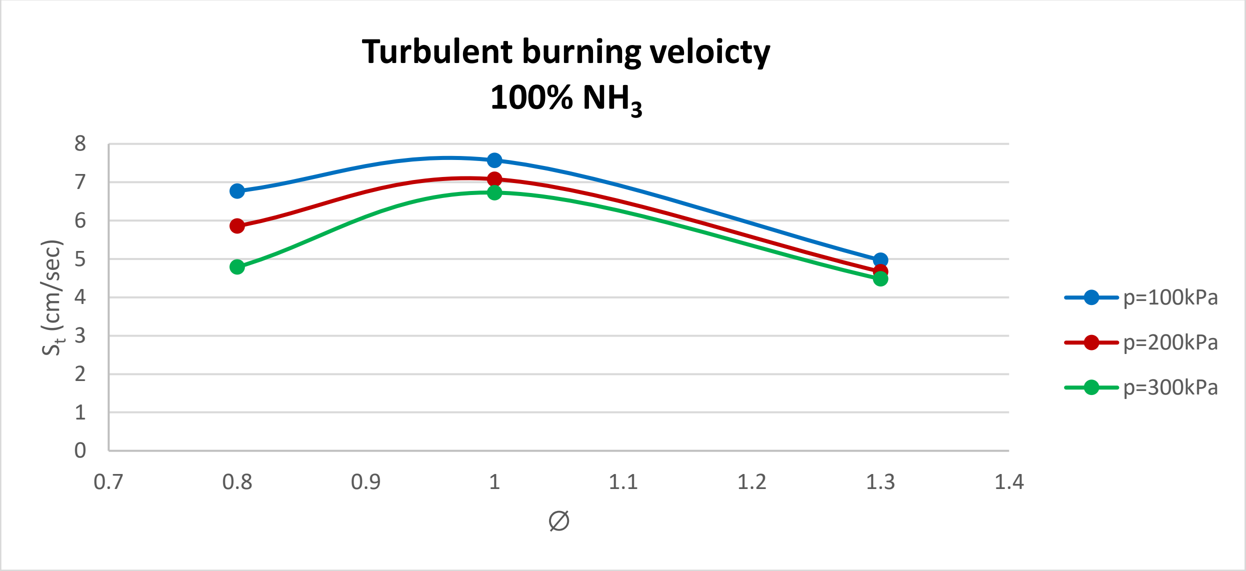


Figure (1) Turbulent burning veloicty S_t with a flame radius for 100% NH_3 with initial pressure (100, 200 and 300) kPa

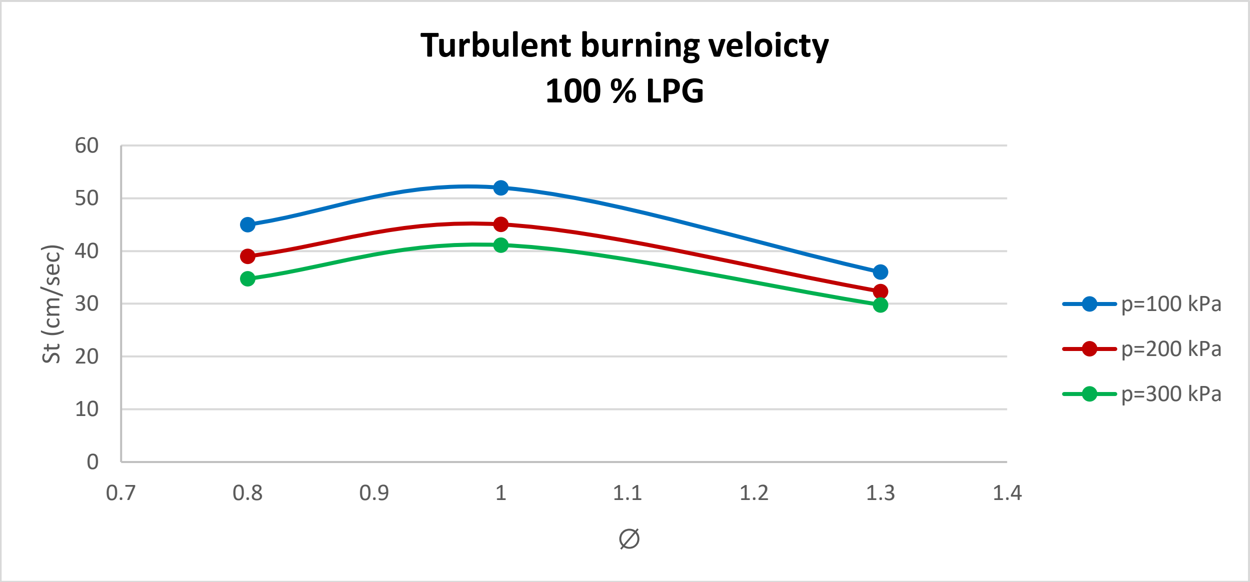


Figure (2) Turbulent burning veloicty S_t with a flame radius for 100% LPG with initial pressure (100, 200 and 300) kPa

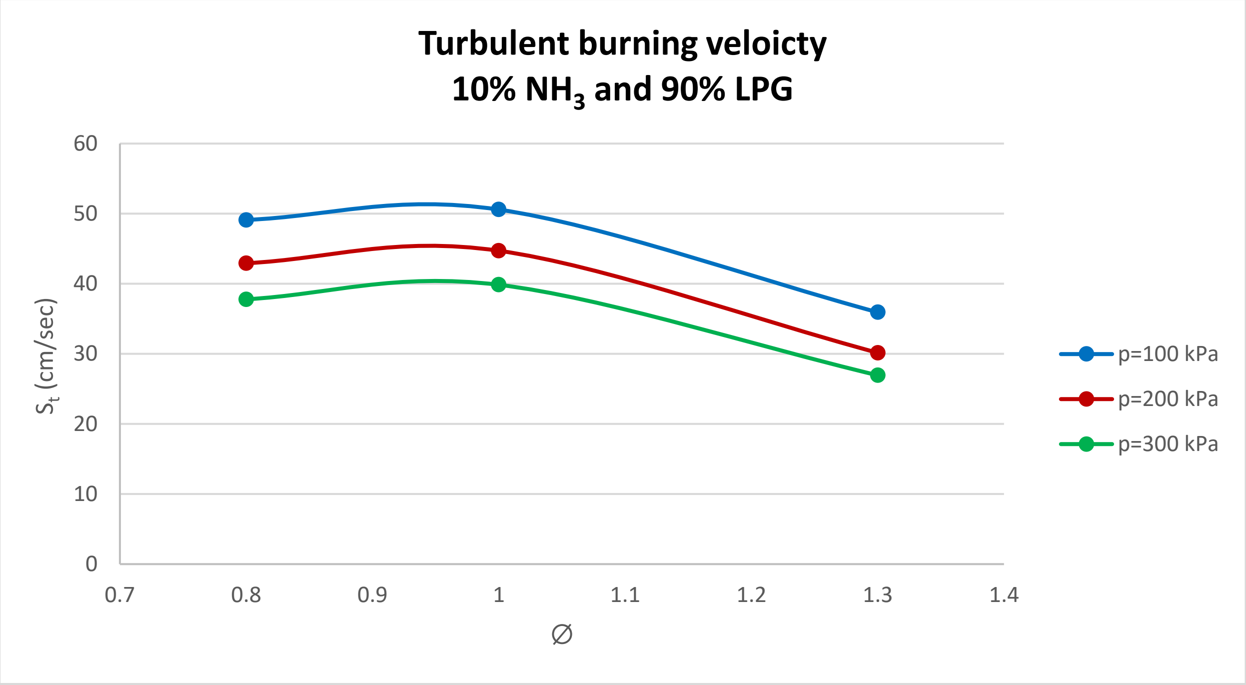


Figure (3) Turbulent burning veloicty S_t with a flame radius for 90% LPG and 10% NH_3 with initial pressure (100, 200 and 300) kPa

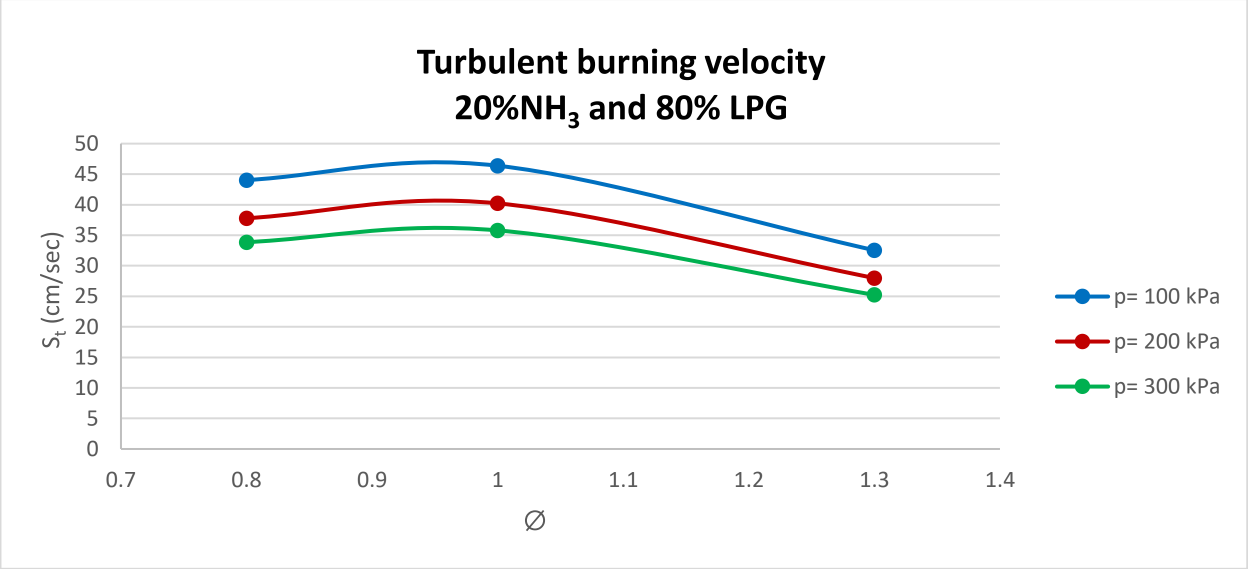


Figure (4) Turbulent burning veloicty S_t with a flame radius for 80% LPG and 20% NH_3 with initial pressure (100, 200 and 300) kPa

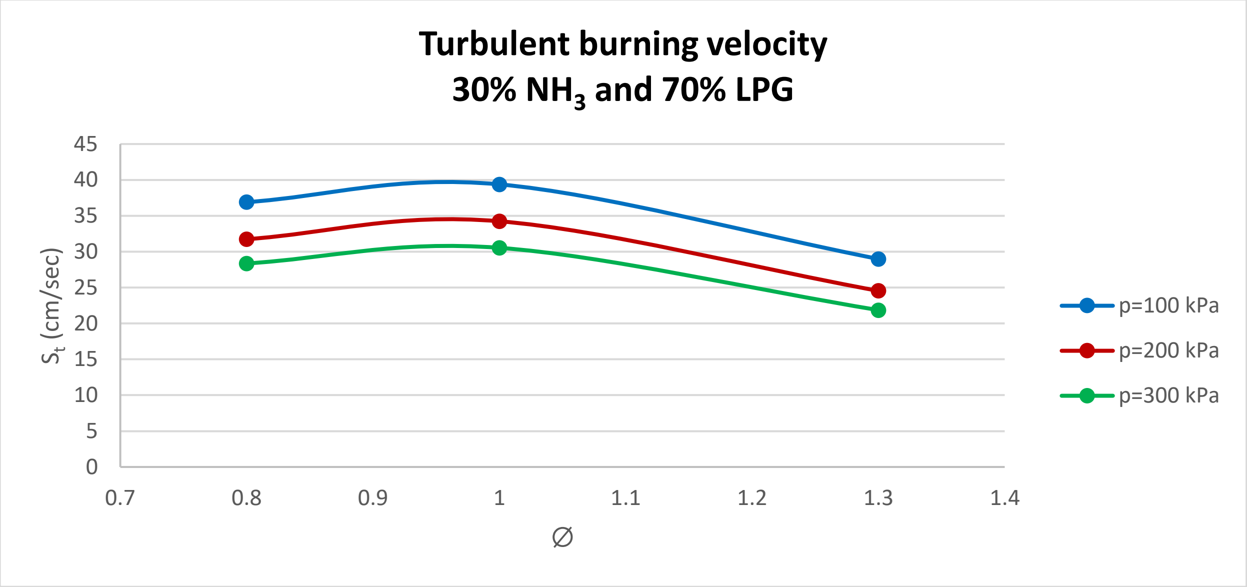


Figure (5) Turbulent burning veloicty S_t with a flame radius for 70% LPG and 30% NH_3 with initial pressure (100, 200 and 300) kPa

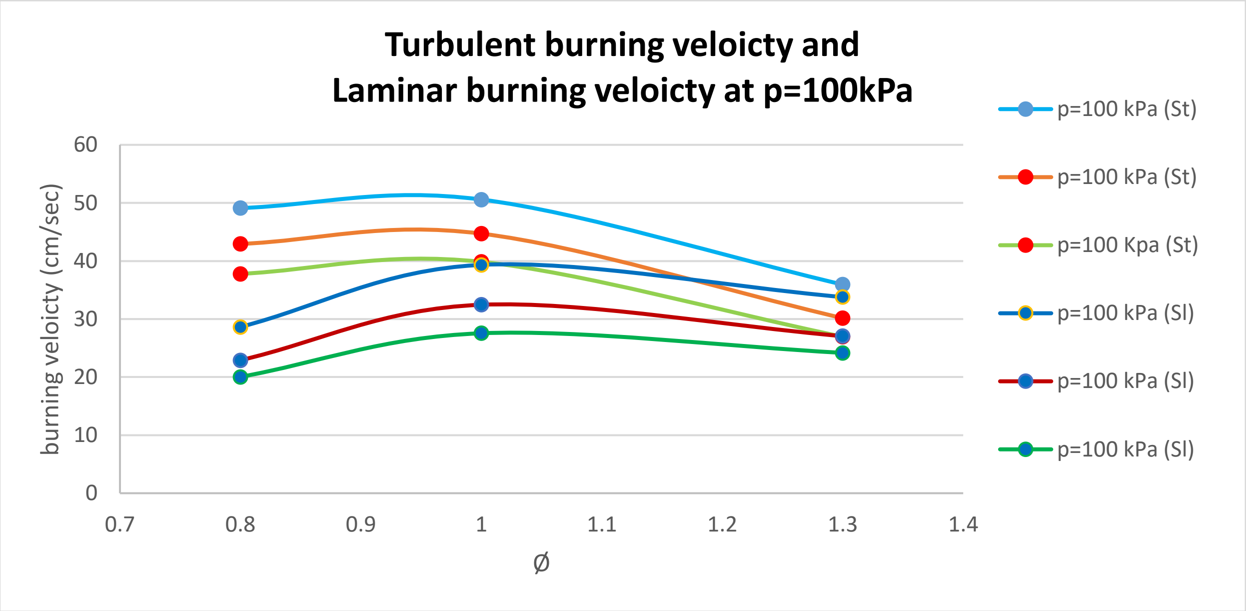


Figure (6) Turbulent burning veloicty S_t with a flame radius for 70% LPG and 30% NH_3 with initial pressure (100, 200 and 300) kPa

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