THE STUDY OF DIFFERENT SIZES OF DIY MODEL COMBUSTION CHAMBER

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ABSTRACT

Achieving perfect combustion plays a vital role in the operation of marine diesel engines, as it directly impacts the engine's efficiency, performance, and emissions. Perfect combustion entails the complete burning of fuel, resulting in the production of carbon dioxide and water vapor. Optimization of engine performance, enhance fuel economy, and reduce emissions can be attained by adjusting the fuel injection system in response to pressure variations. To maximize performance and efficiency, careful attention must be given to the design and maintenance of both the combustion chamber and the fuel injection system in a diesel engine. The project aimed to illustrate the actual working pressure in the combustion chamber of an operational direct injection diesel engine. An injector tester was employed to showcase diverse pressure buildups on DIY model combustion chambers of varying sizes. A slowmotion camera was utilized to provide a detailed observation of the processes involved in spray formation and dispersion. The slow-motion footage served as a valuable visual aid, facilitating an understanding of how alterations in pressure and volume affect the atomization of fuel and the subsequent spray pattern. Mathematical approaches were employed to determine the chamber pressure buildup and the spray cone angle. An increase in pressure from 16.71Pa to 36.61Pa within the 150ml DIY model chamber resulted in a wider spray angle, whereas a decrease in pressure from 17.29Pa to 8.07Pa within the 200ml DIY model chamber led to a narrower spray angle.

Keywords: *perfect combustion, pressure variation, DIY model combustion chamber, slow-motion camera, spray pattern.*

1. INTRODUCTION

The combustion chamber played a major role in a diesel engine, as it plays a significant part in the combustion process that generates power, (Hoang, 2020). In a direct injection combustion chamber as shown in Figure 1, fuel was injected directly into the combustion chamber instead of the intake manifold, allowing for better control of the fuel-air mixture and more precise combustion, (Rounce et al., 2013). Unlike spark-ignition engines, which used a spark plug to ignite the air-fuel combination, compression ignition engines depend on the high temperature and pressure generated by compressing the air inside the combustion chamber. In compression ignition engines, the combustion chamber was comprised of multiple components that worked together to provide the proper conditions for combustion. The piston compressed the air, while fuel injectors injected fuel into the combustion chamber. The fuel and compressed air mixed, and the heat created by compression ignited the combination. Other essential components of the combustion chamber included the cylinder head, where the fuel injector and the valves that controlled the flow of air and exhaust gases were located.

The shape and design of the combustion chamber could considerably affect the spray characteristic of the fuel, which in turn could affect the engine's performance, fuel economy, and emissions, (Zhang et al., 2021). The study of the combustion chamber's influence on fuel spray characteristic entailed analyzing the flow of fuel and air within the chamber, as well as the combustion process itself, to discover how modifications in the chamber's design could maximize performance. By understanding how combustion chamber design influenced the engine's performance, researchers and engineers could produce more efficient and powerful diesel engines. Thus, careful consideration had to be taken to the design and maintenance of the combustion chamber of a diesel engine to maintain maximum performance and efficiency.

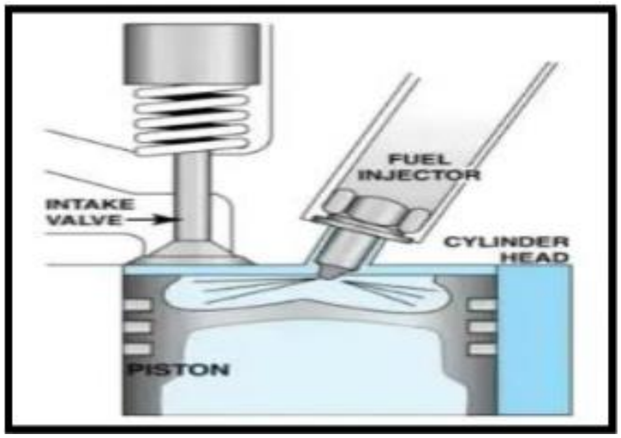

Figure 1: Direct Injection (DI) Combustion Chamber

Diesel engines burn fuel to generate power. Fuel was sprayed into the combustion chamber and ignited by air compression heat as shown in figure 1. Due to combustion chamber pressure fluctuations, the fuel injection system had to deliver the right amount of fuel at the right time. The combustion chamber pressure varied with engine speed, workload, and temperature. The spray's spread and penetration into the engine could affect engine efficiency and emissions. Pressure changes in the combustion chamber affected fuel spray. If the fuel injection system may not respond properly to pressure variations, causing incomplete combustion, increased emissions, reduced power, and engine damage. The combustion chamber pressure changed significantly during the engine cycle. Pressure increased fast during compression, peaking before ignition, (Qiu et al., 2019). When the piston descended, pressure dropped quickly, discharging burnt gases through the exhaust valve. Pressure differences affected fuel spray behavior differently.

Fuel spray atomization depended on combustion chamber pressure. A small hole in the injector nozzle allowed high-pressure fuel to enter the combustion chamber quickly. The high pressure and aerodynamic forces and surface tension broke the fuel into tiny droplets when it entered the chamber. Gas pressure affected droplet size and distribution. Higher pressure increased spray width, improving fuel-air mixing, combustion, and emissions. However, high pressure can induce inefficient atomization and incomplete combustion, whereas low pressure can cause inadequate atomization. Pressure changes in the combustion chamber affected how far the fuel spray penetrated before combining with air and vaporizing, (Dobó et al., 2019). Shallow injection could cause incomplete combustion and higher emissions, while deeper injection improved mixing and combustion. High combustion chamber pressure limited spray penetration, while low pressure permitted deeper penetration. Pressure fluctuations in the combustion chamber affected fuel injection angle. Wider spray angles improved fuel and air mixing, whereas narrower angles could cause incomplete combustion. Low pressure focused the spray, limiting the angle, while high pressure distributed it rapidly.

For numerous reasons, the effect of DIY model injection chamber sizes on diesel engine fuel spray characteristics needed to be studied. Fuel spray greatly affected engine performance, efficiency, and emissions. The size, shape, and distribution of fuel droplets affected combustion and engine energy transfer, (Temizer and Cihan, 2021). The effects of DIY model injection chamber diameters on fuel spray characteristics were studied to optimize engine performance. Diesel engines were known for generating PM and NOx, which polluted air and public health. According to MAPPOL Annex VI, better combustion and fewer byproducts could minimize these emissions. This could reduce diesel engine emissions and promote greener transportation. Fuel injection constituted a complex process involving factors such as fuel pressure, injector design, and combustion chamber geometry. The study of how DIY model injection chamber sizes affected fuel spray characteristics intended to better understand how these factors affected fuel injection. This knowledge could help construct accurate fuel spray models and optimize engine performance. Pressure changes in the combustion chamber were studied to better understand combustion's complex physical processes. In a diesel engine, continuous shifts and pressure fluctuations in the combustion chamber affected fuel spray behavior and combustion.

The combustion chamber played a vital role in a marine diesel engine, serving to facilitate the combustion process of the fuel and air mixture. Positioned within the engine, the combustion chamber created a confined space where fuel injection and ignition occurred, regulating combustion, (Dai et al., 2020). The primary objective of the combustion chamber was to establish an operational environment that maximized the efficiency of combustion and the extraction of energy from the fuel. This was achieved through a combination of factors, including the geometric properties, volume, and configuration of the chamber's walls and piston crown. The shape and size of the combustion chamber influenced the airflow, fuel-air mixing, and combustion characteristics of the engine, subsequently impacting its performance in terms of power output, fuel efficiency, and emissions, (Zhou et al., 2019). Managing the combustion process, controlling flame propagation, and reducing pollutant formation, particularly unburned hydrocarbons, and soot, were critical functions within the combustion chamber. In general, the combustion chamber played a crucial role in achieving ideal combustion conditions and enhancing the efficiency and environmental sustainability of a marine diesel engine.

2. RESEARCH METHODOLOGY

This project was issued to achieve the research objectives of the DIY model combustion chamber project, and thus systematic and structured project workflow was implemented, consisting of a series of consecutive procedures. The project comprised several stages, including designing and constructing, setting up instruments and conducting tests, collecting, and analyzing data, and finally, reporting the findings as shown in figure 2. The DIY model combustion chamber project followed a methodical and repetitive approach, initiating with the creation and assembly of various prototypes of combustion chambers with different dimensions. The models underwent measurement and testing to quantify various characteristics throughout the combustion process. To understand how the size of a DIY model combustion chamber affected the effectiveness of fuel injection, the study adhered to a systematic approach with a series of steps. The project commenced with the troubleshooting and maintenance of the fuel injector tester system to ensure optimal fuel injection conditions were met. Subsequently, various sizes of do-ityourself model combustion chambers were constructed. The investigation of spray cone angle and spray penetration was conducted using a slow-motion camera to capture the spray behavior. Finally, a mathematical approach was employed to determine the value of pressure buildup in the DIY chamber and the spray cone angle value. The DIY model combustion chamber project plan was thoroughly prepared and implemented to ensure timely completion and the achievement of research objectives.

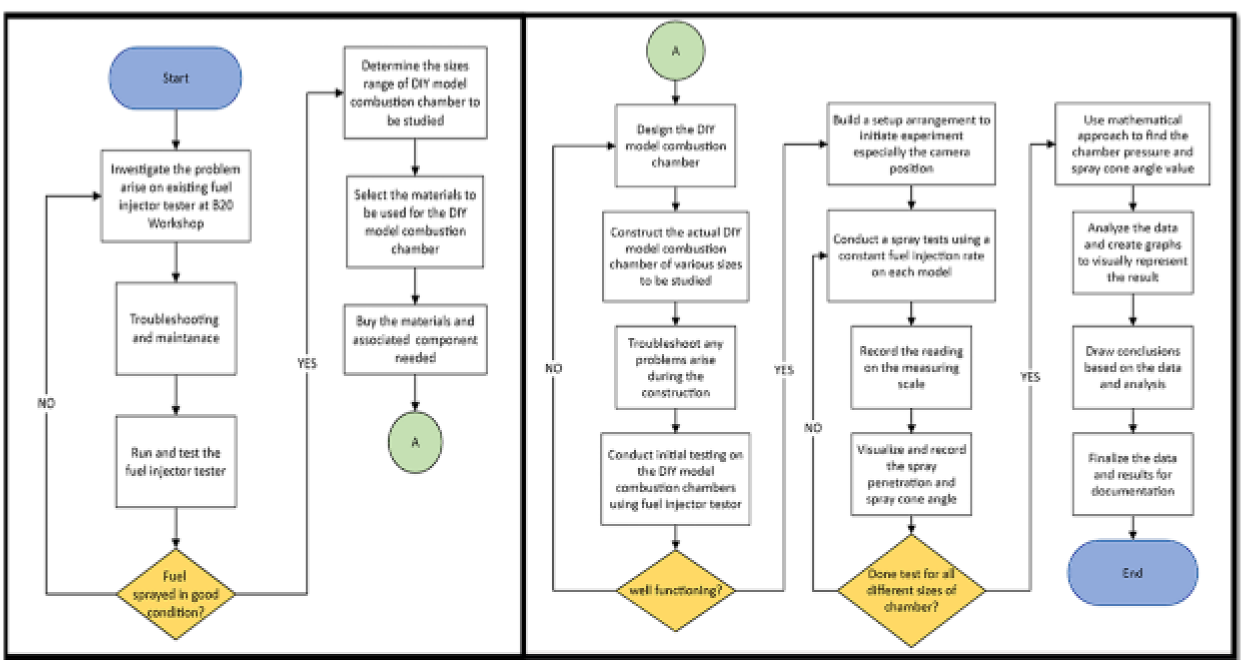

Figure 2: Flowchart of Overall DIY Model Combustion Chamber Project

2.1 Troubleshooting of Fuel Injector Tester System

Troubleshooting and maintenance of a fuel injector tester involved a systematic procedure for identifying and resolving issues with the tester's operation and accuracy. In such instances, the process included inspecting the tester for physical damage, checking and calibrating pressure gauges, and examining potential obstructions in the fuel flow. Diagnostic tests were also conducted to identify potential problems with the injector tester, such as leaks or irregular fuel delivery. Regular maintenance activities, such as cleaning, lubricating moving parts, and replacing worn-out components, were performed to ensure the tester's functionality and extend its lifespan. By carrying out troubleshooting and maintenance on the fuel injector tester, researchers ensured reliable and precise testing of fuel injectors. This contributed to the accurate assessment and optimization of injector performance in combustion chambers.

2.2 DIY Model Combustion Chamber Construction

Creating DIY model combustion chambers involved carefully choosing materials, using specialized equipment, and applying precise techniques. Polypropylene was selected for its strength, impact resistance, and moisture resistance. Construction required tools like a hack saw and cordless drill, with a focus on maintaining uniformity and precision. A controlled environment ensured accuracy, preventing errors during construction. Regular calibration and maintenance of tools were crucial for accurate measurements. Quality assurance protocols, including non-destructive testing, enhanced the effectiveness of self-constructed combustion chambers. The accuracy was validated through iterative testing against recognized standards.

In the marking process as shown in figure 3(a), key reference points were marked on the material, facilitating subsequent cutting and assembly operations. Careful alignment of markings ensured precise fabrication and assembly. Figure 3(b) illustrates the cutting process involved removing unwanted material from the syringe hub, ensuring safety and accuracy. Drilling played a crucial role, creating accurate holes for various parts as shown in figure 3(c). Proper alignment and the use of cooling lubricants-maintained effectiveness and structural integrity. The final step involved examining the chamber to confirm the desired dimensions and alignment were achieved.

(a) (b) (c)

Figure 3: (a) Marking process (b) Cutting process and (c) Drilling Process

2.3 Experimental Setup

Experimental setups provide an opportunity for conducting practical investigations, gathering empirical data, and conducting analyses, thereby enhancing comprehension of combustion mechanisms within a regulated and adaptable environment, (Liu and Dumitrescu, 2018). The initial phase of the methodology involved the careful selection of an appropriate slow-motion camera system. Several factors, including frame rate, resolution, and light sensitivity, were considered to ensure that the camera system aligned with the research objectives. The selected camera model offered a high frame rate, providing the capability to capture rapid spray dynamics in fine detail. Moreover, its high resolution ensured the detailed imaging of even the smallest droplets, while its light sensitivity allowed for reliable data capture under varying lighting conditions, (Vollmer and Möllmann, 2011). Furthermore, the methodology included the selection of a suitable nozzle, known for its consistent spray characteristics, eliminating unnecessary variables to focus on the effects of other key parameters. The experiments were conducted within a controlled laboratory environment, equipped with the necessary infrastructure and safety measures for conducting spray pattern analysis experiments safely. The camera was placed 30 centimetre parallel to the DIY model combustion chamber along with the fuel injector tester system itself as shown in figure 4.

Figure 4: Setup Plan Arrangement

3. RESULT AND DISCUSSION

In this study, two distinct DIY model combustion chambers, utilizing a 150ml syringe and a 200ml syringe as the primary material for their construction, were successfully constructed. Some modifications were made on the syringe hub to fit with the fuel injector nozzles. The selection of syringes as the basis for our combustion chambers was deliberate and based on several considerations. The volumes of the chambers were altered by adjusting the piston positions, creating different chamber volumes. The volume was calculated using the formula for the volume of a cylinder (π×r2×h), while the force acting on the piston surface was determined using the pressure formula (P=F/A), with force values obtained from a measuring scale and the area calculated based on the circular shape of the piston's top surface (π×r2). A multiple-hole nozzle (4 Holes) type was employed for fuel injection at a constant pressure of 180 bar.

Table 1. Parameter and reading for 150ml DIY syringe chamber experiment.

Parameter and Reading for 150ml DIY Syringe Chamber Experiments					
Piston Height from nozzle (cm)	Syringe Piston Radius (cm)	Fuel Injection Pressure (Bar)	Chamber Volume (m3) (×10^-5)	Measuring Scale Reading (g)	Pressure Build-Up (Pa)
1.3	2	180	1.63	4.7	36.61
1.7	2	180	2.14	2.9	22.28
2.3	2	180	2.89	2.1	16.71

Table 1 depicts data from an experiment involving a 150ml DIY Syringe Chamber, designed to investigate the impact of different chamber volumes on chamber pressure. In this setup, a syringe piston with a fixed radius of 2 cm is variably positioned at different heights from the nozzle (1.3 cm, 1.7 cm, and 2.3 cm), while fuel is consistently injected at a pressure of 180 Bar. The experiment records the resulting chamber volume in cubic meters (scaled down for practicality), the mass in grams as indicated by a measuring scale, and the measurement of pressure build up in pascals by using formula P=F/A. The data suggests that an increase in piston height leads to a larger chamber volume and a decrease in both the measured mass and pressure build-up, implying an inverse relationship between the piston height (different volumes) and the pressure within the chamber.

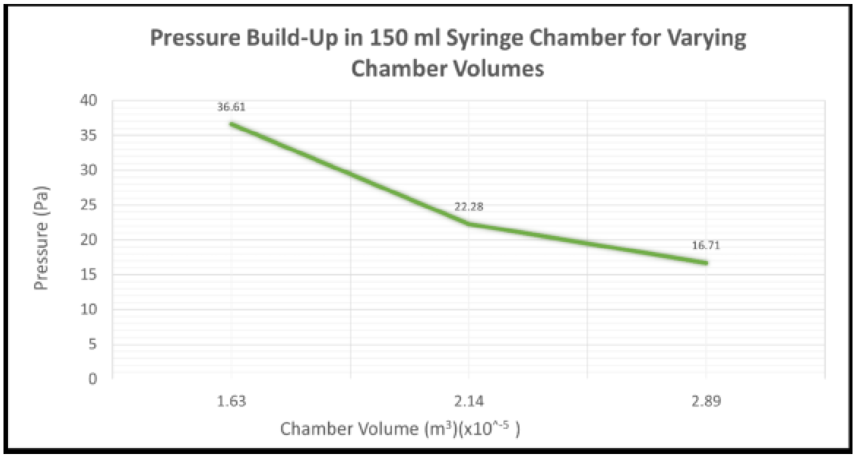

Figure 5: Line Graph Chamber Volume (m3) versus Pressure (Pa) for 150ml syringe chamber

The examination of chamber volume's impact on pressure in a 150ml syringe revealed an inverse relationship as shown in figure 5. The smallest volume led to higher pressure (36.61 Pa) due to limited fuel and air expansion and increased compression, fostering intense combustion. Conversely, the largest volume resulted in lower pressure (16.71 Pa) as the expanded space reduced compression, creating a less intense combustion environment. Compression dynamics played a pivotal role, with smaller volumes causing intense compression and higher pressure, while larger volumes reduced compression, yielding lower pressure. This highlights the crucial role of chamber volume in shaping pressure dynamics, emphasizing how limited volume encourages compression and elevated pressure, while increased volume permits expansion and decreased pressure.

Table 2. Parameter and reading for 200ml DIY syringe chamber experiment

Parameter and Reading for 200ml DIY Syringe Chamber Experiments					
Height from nozzle (cm)	Piston Radius (cm)	Injection Pressure (Bar)	Chamber Volume (m3) (×10^-5)	Measuring Scale Reading (g)	Pressure Build-Up (Pa)
1.3	2.35	180	2.26	3.04	17.29
1.7	2.35	180	2.95	2.02	11.53
2.3	2.35	180	3.99	1.43	8.07

Table 2 presents a dataset from an experiment conducted using a 200ml DIY Syringe Chamber, focusing on the relationship between the syringe piston height from the nozzle and various other parameters within the system. The syringe piston radius is consistently maintained at 2.35 cm across all tests. Fuel is injected into the chamber at a uniform pressure of 180 Bar for each of the three trials, which vary by the height of the piston from the nozzle (1.3 cm, 1.7 cm, and 2.3 cm). As the height from the nozzle increases, there's a noticeable increase in the chamber volume from 2.26×10^-5 m3 to 3.99×10^-5 m3, suggesting a direct relationship between piston height and available volume. The measuring scale reading, indicating the spray forces applied to the top surface of the syringe piston, decreases from 3.04 g to 1.43 g, while the pressure build-up inside the chamber decreases from 17.29 Pa to 8.07 Pa. This pattern reinforces the hypothesis that as the piston is retracted, allowing for a greater volume, the pressure within the chamber is reduced, which is a fundamental principle in fluid dynamics.

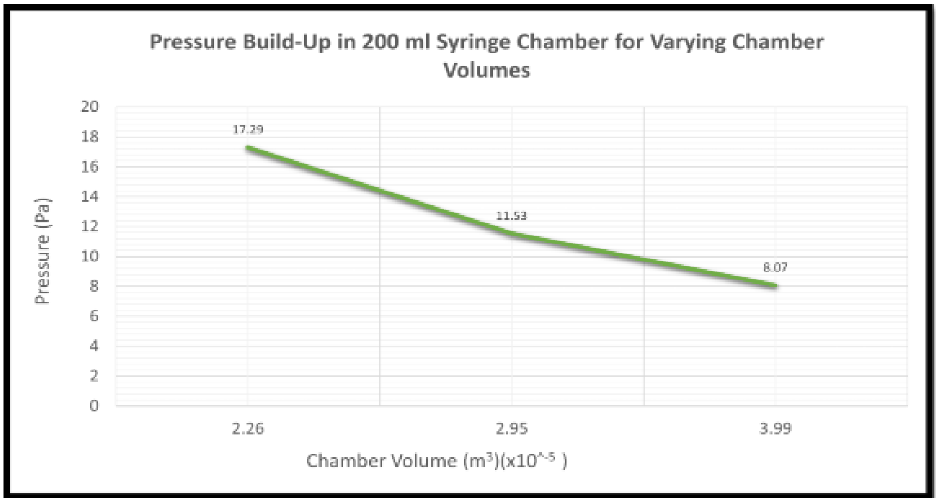

Figure 6: Line Graph Chamber Volume (m3) versus Pressure (Pa) for 200ml syringe chamber.

In the examination of the relationship between chamber volume and pressure in a 200ml syringe as shown in figure 6, distinct patterns were observed. Utilizing the smallest volume led to elevated pressure (17.29 Pa) due to limited space for fuel and air expansion, requiring intense compression and fostering intensified combustion. Conversely, the largest volume resulted in lower pressure (8.07 Pa) as the spacious chamber allowed for greater expansion, reducing compression, and leading to a less confined combustion environment. The inverse relationship between volume and pressure highlights the crucial roles of confinement and compression in shaping combustion dynamics within the syringe. Regarding compression, the experiment revealed that smaller volumes induce intense compression and higher pressure, while larger volumes permit reduced compression and lower pressure levels.

3.1 Spray Cone Angle Results For 150ml and 200ml Syringe Chamber Experiments

This section provides an in-depth examination of the experimental findings derived from the exploration of the impacts of diverse chamber volumes in DIY model combustion chambers on spray cone angles. The study involved two sets of syringe chambers, specifically 150ml and 200ml, each with varying volumes. The challenges associated with measuring spray penetration in smaller chamber sizes are also addressed. The spray cone angle emerges as a pivotal factor in fuel injection systems, directly influencing fuel distribution within the combustion chamber and thereby impacting combustion efficiency, engine performance, and emissions. The application of the cosine rule to experiment images facilitated the computation of spray cone angles. Contrary to initial expectations, the results revealed an inverse correlation between chamber volume and spray cone angle.

Table 3: Spray cone angle result for 150ml DIY syringe chamber

Spray Cone Angle Result for 150 ml DIY Syringe Chamber Experiments					
Chamber Volume (m3) (×10^-5)	Pressure Build-Up (Pa)	Triangle length side a (cm)	Triangle length side b (cm)	Triangle length side c (cm)	Spray cone angle (degree◦)
1.63	36.61	5.7	5.2	0.7	5.16
2.14	22.28	5.8	5.2	0.7	3.76
2.89	16.71	6.15	5.4	0.8	2.77

Table 3 displays results from an experiment with a 150 ml DIY Syringe Chamber, aiming to investigate how changes in chamber volume and pressure affect the spray cone angle with the pressure build-up measured in pascals and corresponding to volumes of 1.63×10^-5 m3 , 2.14×10^-5 m3 , and 2.89×10^-5 m3 . The data includes measurements of three sides of a triangle using cosine rule with reference to the images display by the slow-motion camera. It changes slightly with each test, likely impacting the spray cone angle, which is reported in degrees. As the chamber volume increases, the pressure decreases, and the spray cone angle becomes narrower, dropping from 5.16 degrees to 2.77 degrees. This suggests a direct relationship between the volume of the chamber, the pressure within it, and the dispersal characteristics of the spray.

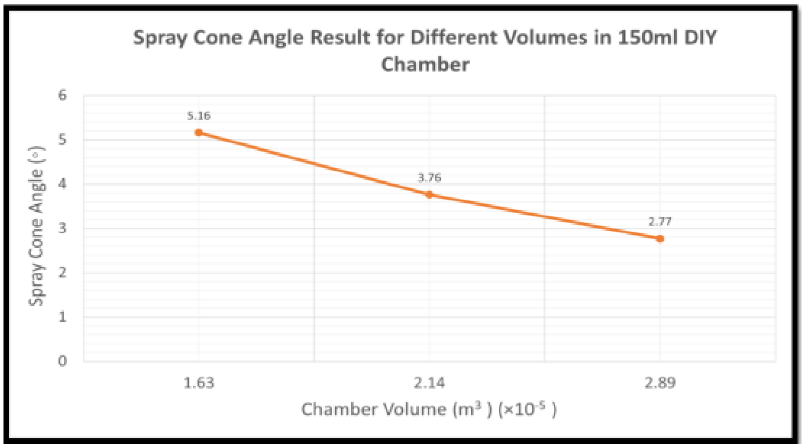

Figure 7: Line Graph Chamber Volume (m3) versus Spray Cone Angle (◦) for 150ml syringe chamber

Figure 7 presents a line graph titled "Spray Cone Angle Result for Different Volumes in 150ml DIY Chamber," which visualizes the relationship between the chamber volume and the spray cone angle from the previously discussed experiment. The horizontal axis represents the chamber volume in cubic meters (multiplied by 10^ -5), and the vertical axis represents the spray cone angle in degrees. The graph shows a clear downward trend, where an increase in chamber volume from 1.63 to 2.89 (×10^-5 m³) correlates with a decrease in the spray cone angle from 5.16 degrees to 2.77 degrees. This trend confirms the inverse relationship previously inferred: as the volume within the syringe chamber increases, the pressure decreases, resulting in a narrower spray cone angle, which is crucial for applications requiring precise control over spray dispersion.

Table 4. Spray cone angle result for 200ml DIY syringe chamber

Spray Cone Angle Results for 200 ml DIY Syringe Chamber Experiments					
Chamber Volume (m3) (×10^-5)	Pressure Build-Up (Pa)	Triangle length side a (cm)	Triangle length side b (cm)	Triangle length side c (cm)	Spray cone angle (degree◦)
2.26	17.29	3.35	3	0.4	3.50
2.95	11.53	6.1	5.8	0.35	1.74
3.99	8.07	7.7	7.4	0.35	1.37

Table 4 displays results from an experiment with a 150 ml DIY Syringe Chamber, aiming to investigate how changes in chamber volume and pressure affect the spray cone angle with the pressure build-up measured in pascals and corresponding to volumes of 2.26×10^-5 m3 , 2.95×10^-5 m3 , and 3.99×10^-5 m3 . The data includes measurements of three sides of a triangle of the cone spray using cosine rule with reference to the images display by the slow-motion camera. It changes slightly with each test, likely impacting the spray cone angle, which is reported in degrees. As the chamber volume increases, the pressure decreases, and the spray cone angle becomes narrower, dropping from 3.50 degrees to 1.37 degrees. This suggests a direct relationship between the volume of the chamber, the pressure within it, and the dispersal characteristics of the spray.

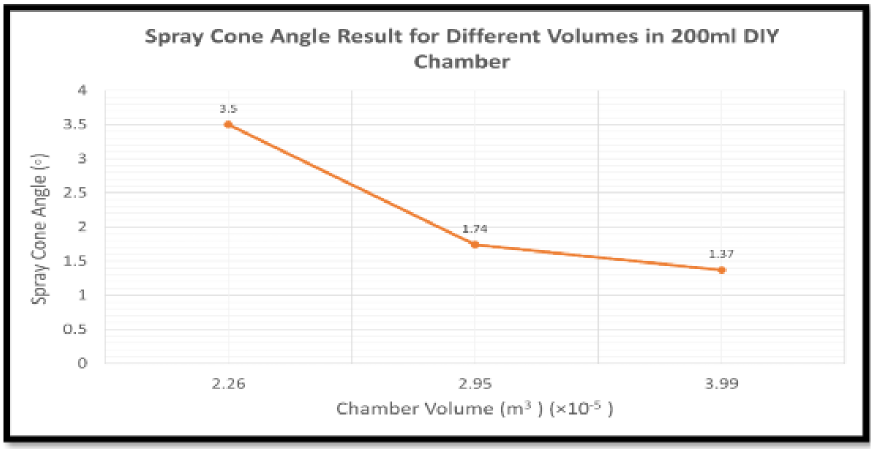

Figure 8: Line Graph Chamber Volume (m3) versus Spray Cone Angle (◦) for 200ml syringe chamber

The graph from figure 8 plots three points corresponding to the three sets of experimental data, showing a clear descending linear relationship. As the chamber volume increases from 2.26 to 3.99 (multiplied by 10^-5 m3), the spray cone angle decreases from 3.5 degrees to 1.37 degrees, indicating that a larger chamber volume, which corresponds to a lower pressure, produces a narrower spray cone. This trend is consistent with fluid dynamics principles, where an increase in chamber volume reduces the pressure and alters the spray characteristics.

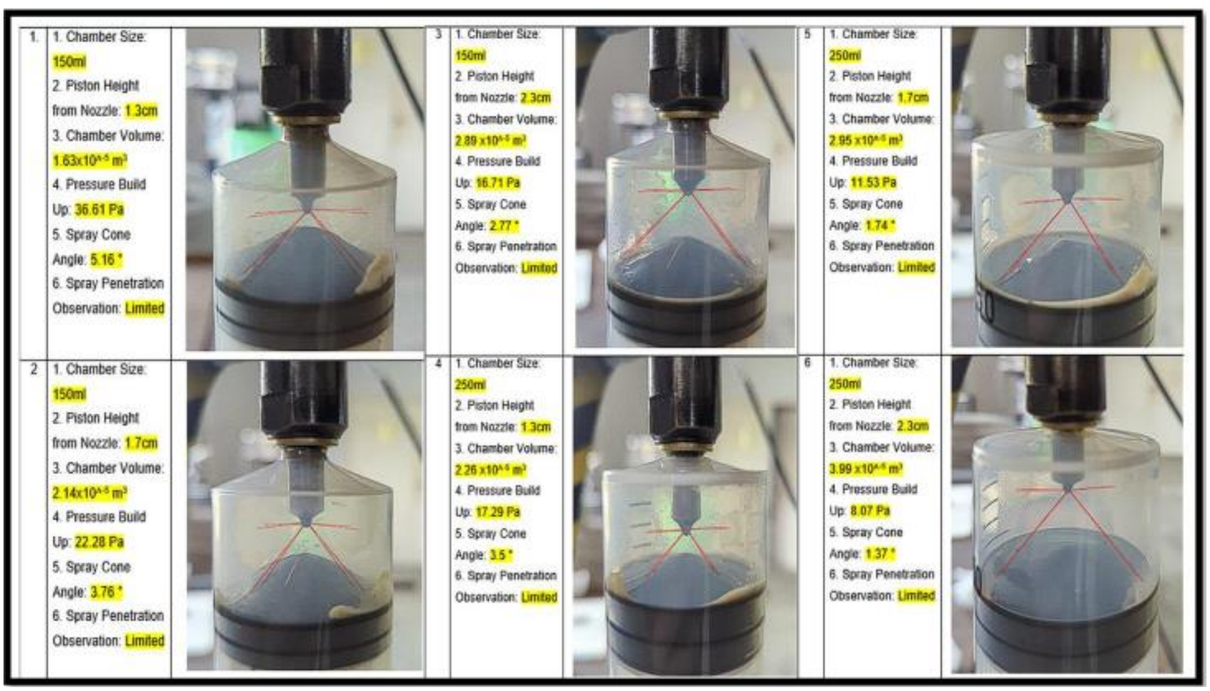

Figure 9: Result on Spray Cone Angle Images

From figure 9, we can clearly observe the data were consistently demonstrates a pattern where an increase in chamber volume corresponds to a decrease in the spray cone angle. This phenomenon can be elucidated by examining the fluid dynamics of the spray process. In larger chambers, there is more room for the fuel to disperse, resulting in a broader spray pattern but at a more compressed angle. This signifies the inverse relationship between chamber volume and spray cone angle. The pivotal factor in this trend is the decrease in pressure build-up with an increase in chamber volume. Smaller chambers exhibit higher pressure build-up, causing a more forceful ejection of fuel at a wider angle. Conversely, larger chambers experience reduced pressure, leading to less forceful ejection and a narrower spray angle. This relationship is evident in the observed decline in pressure build-up from 36.61 Pa to 16.71 Pa in 150ml chambers and from 17.29 Pa to 8.07 Pa in 200ml chambers as volume increases. The challenge of accurately measuring spray penetration arises from the limited size of the DIY chambers. In such confined spaces, the fuel spray contacts the walls before fully developing into a mist, impeding an accurate evaluation of penetration depth. This limitation underscores the difficulties in replicating real-world conditions in small-scale models and emphasizes the importance of considering scale in experimental design.

4. CONCLUSION

This research project primarily centered on the creation of various sizes of DIY model combustion chambers and examining the impact of varied chamber pressures on spray penetration and spray cone angle in marine compression ignition diesel engines. Despite challenges in measuring spray penetration due to the chambers' compact size, the study successfully yielded insights into the correlation between chamber volume and spray cone angle. The results revealed a consistent pattern: an increase in chamber volume led to a decrease in pressure, resulting in a reduction in the spray cone angle, (Kane et al., 2016). This observation aligns with the fundamental principles of fluid dynamics and combustion theory. The incorporation of a slow-motion camera significantly improved the comprehension of these dynamics in the project. This technology enabled a detailed observation of the spray formation and dispersion processes, capturing transient behaviors imperceptible to the naked eye. The slowmotion footage served as a valuable visual tool in understanding how variations in pressure and volume affect fuel atomization and subsequent spray patterns. This advanced visualization played a crucial role in overcoming measurement limitations, offering a fresh perspective on analyzing spray behaviors.

4.1 Implications and Recommendations for Future Research

The findings from this study have far-reaching implications for the advancement and refinement of marine diesel engine design, with the correlation between chamber dimensions and spray characteristics standing out as a crucial factor in boosting engine efficiency and curbing emissions. The significance of precise engineering in the development of combustion chambers and fuel injection systems to optimize fuel atomization and combustion processes cannot be overstated. Future research endeavors should broaden their scope by delving into alternative measurement approaches to overcome limitations in gauging spray penetration. This could involve exploring larger scale models or incorporating more sophisticated measurement technologies. Additionally, investigating the impact of diverse nozzle designs and varying injection pressures on fuel spray dynamics holds promise for further optimizing combustion processes. Simultaneously, the integration of computational fluid dynamics (CFD) simulations alongside experimental studies can provide a more comprehensive understanding of fuel spray processes across various chamber volumes. To deepen insights into transient fuel spray behaviors, researchers should consider not only the continued use of slow-motion camera technology but also the exploration of more advanced imaging techniques. These innovative visualization tools can offer valuable perspectives that may not be captured through traditional measurement methods, contributing to a holistic understanding of combustion dynamics in marine diesel engines.

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