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ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Mechanical Engineering

**INVESTIGATION OF THE EFFECT OF ADDING
NITROGEN ON THE TORQUE GENERATED BY
A FOUR CYLINDER ENGINE**

Mustafa Raheem Jasim AL-MAMOORI

Master's Thesis

Supervisor

Asst. Prof. Dr. Yaser ALAIWI

İstanbul, 2024

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The thesis titled INVESTIGATION OF THE EFFECT OF ADDING NITROGEN ON THE TORQUE GENERATED BY A FOUR- CYLINDER ENGINE WITH IMAGE PROCESSING CONTROL prepared by MUSTAFA RAHEEM JASIM AL-MAMOORI and submitted on 09/01/2024 has been **accepted unanimously** for the degree of Master of Science in Mechanical Engineering.

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Mustafa Raheem Jasim ALMAMOORI

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ABSTRACT

INVESTIGATION OF THE EFFECT OF ADDING NITROGEN ON THE TORQUE GENERATED BY A FOUR- CYLINDER ENGINE

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Date: January / 2024

Pages: 77

The goal of this study is to investigate the impact of adding nitrogen gas (N₂) to diesel engines. It primarily aims to look at the various characteristics of nitrogen gas and how they could affect combustion processes and emissions. The study utilizes computational fluid dynamics (CFD) simulations to analyze the influence of nitrogen gas concentration on the combustion efficiency, emissions, and performance of a compression-ignition diesel engine. The findings demonstrate that the dynamics of combustion are significantly impacted by the addition of nitrogen gas, changing patterns of temperature and pressure. As a result, the cylinder's maximum pressure, rate of heat release, and ignition delay are all variable. Additionally, the research examines the effects of nitrogen gas on emissions, particularly on particulate matter and nitrogen oxide (NO_x) emissions (PM). By lowering peak combustion temperatures and reducing the amount of oxygen available, nitrogen gas has the potential to cut NO_x emissions. However, because nitrogen content affects particulate matter (PM) emissions, both mitigation and exacerbation are possible. This work opens the door for further empirical investigation and technological breakthroughs by highlighting the relevance of nitrogen gas addition as a viable technique for improving the efficiency and cleanliness of diesel engines. This study assesses the impact of nitrogen gas concentration on the velocity of a mixture entering a combustion chamber. The mass flow rate and flow velocity are positively correlated, with the flow reaching its maximum at 7.96 m/s at a mass flow rate of 0.00015 kg/s and 7.85 m/s at 0.00025 kg/s. The crankshaft deforms more rapidly as the engine's rotational speed rises. At 1800 RPM, 2200 RPM, and 2600 RPM, respectively, the deformation values are particularly identified. The deformation and

pressure applied to the crankshaft are affected by nitrogen gas concentrations. The deformation values can be seen at a ratio of 0.1 mole per 1 mole of diesel. The study discovers that when nitrogen gas concentrations increase, temperature drops, since nitrogen gas largely reduces engine temperature. The stress experienced by the crankshaft is proportional to the engine's rotational speed and the concentration of nitrogen gas. Deformation values increase at 1800 RPM and 2200 RPM, indicating fluctuating pressures in the internal combustion chamber due to the correlation between mass flow rate and crankshaft deformation.

Keywords: Adding Nitrogen, Torque, Four-Cylinder Engine, Pressure, CFD.



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ABBREVIATIONS

IC	:	Internal Combustion
CFD	:	Computational Fluid Dynamics
MVEM	:	Mean Value Engine Model
CCEM	:	Cylinder-by-Cylinder Engine Model
DI-IE	:	Direct Ignition - Internal Evaporation
TDC	:	Top Dead Centre
LN ₂	:	Liquid Nitrogen
NO _x	:	Nitrogen Oxides
CO	:	Carbon Monoxide
HC	:	Hydrocarbons
LPG	:	Liquefied Petroleum Gas
PFI	:	Port Fuel Injection
OEMs	:	Original Equipment Manufacturers

LIST OF SYMBOLS

r	:	Spark Radius
r_t	:	Radius of the Representative Shere
t	:	Time
S_t	:	Turbulent Flame Speed
ρ_u	:	Density
l_t	:	Turbulent Length Scale
φ^μ	:	Unburned Composition
$S_t(r)$:	Turbulent Flame Speed Assessed at the Turbulent Length Scale
I_0	:	Function for the Influence of Strain on the Laminar Burning Velocity
t_0	:	Start Time
u	:	Turbulent Velocity Scale
δ	:	Laminar Flame Thickness

1. INTRODUCTION

1.1 OVERVIEW

The use of electronic and software programming in automobiles to improve performance is constantly expanding because of recent advancements in electronics. Better performance can be attained in a variety of areas, including driving prowess, improved safety, decreased emissions due to improved fuel efficiency, etc. To pursue improvements to the internal combustion engine at this time, when fully electric automobiles become a possibility due to advancements in battery technology, it might be unwise. There appears to be lots of opportunity for improvement with an average thermodynamic efficiency of only about 25% [1]. Enhancing specific power and efficiency while decreasing fuel consumption and, consequently, emissions. Additionally, running engines on biofuels or even ammonia produced by the sun or wind might help make them more resource- or carbon-neutral. Engine of Figure 1.1 represents the mechanical maturity of the four-stroke piston engine. The most powerful engines in our cars today, nearly a century later, are identical to this engine. Additionally, their effectiveness has not changed much.

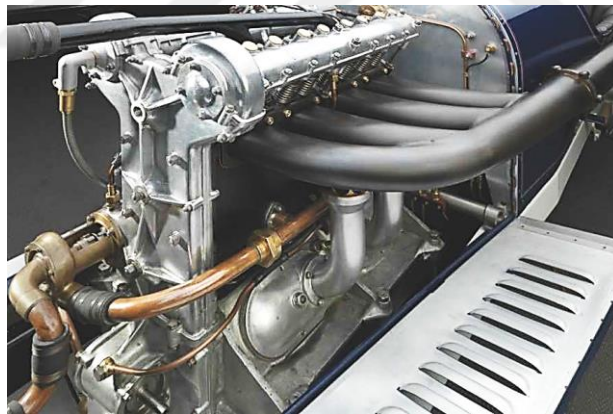


Figure 1.1: The Classic Pattern of Engines from 1913 to 1926 [1].

Demystifying the physics of the engine has been a constant endeavour for more than a century, with some of the finest minds in science and engineering contributing to the cause. By the 1920s, it had been found, understood, and developed to a meaningful degree how engines work in terms of their mechanics, structures, vibrational dynamics, and thermodynamics. However, engine designers have been perplexed a few engines' seeming inability to act as design principles and analytic techniques would have them believe they should. Researchers have created devices that can forecast how an engine's intake and

exhaust systems will function. Figure 1.2a illustrates one straightforward method for simulating the fluid flows in an engine, where three-dimensional CFD is used to represent the flow within a cylinder, as well as the intake and exhaust tubes.

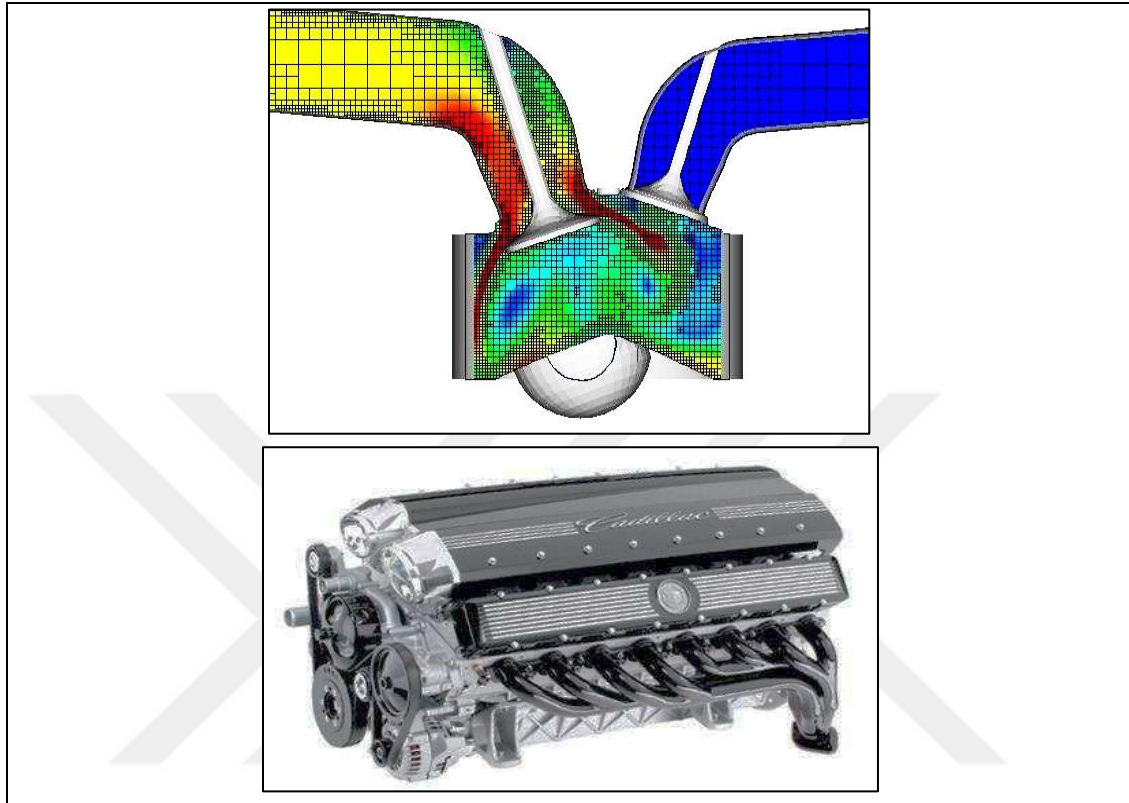


Figure 1.2: CFD Application to Engine Design [1].

This method was employed by Cadillac to create a V16, supposedly with better indication; the actual performance was about as expected. There is currently no "optimal approach" available in published literature for simulating an engine's charge, intake, and exhaust flows. There is a thriving, active sector of research committed to this quest, but the subject remains unsolved. To make an engine simulation a valuable tool and hasten the return of results, some kind of reduced-order approach must be used to characterize the charge inside the cylinder, in particular the intake and exhaust flows.

When aggregate torque from all cylinders is taken into account for control purposes, a Mean Value Engine Model, or MVEM, is usually utilized. However, other aspects, like as misfire detection or backlash brought on by gear motion, require a Cylinder-by-Cylinder Engine Model, or CCEM.

1.2 ENGINES WORKING PRINCIPLE

Using a heat engine, you can convert the heat that results from fuel combustion into useful work. A heat engine is a type of equipment that converts thermal energy into mechanical energy.

When the right amount of fuel and air are available, an engine cylinder that is closed at one end bursts. The pressure of the burning gases rises because of the heat created by this explosion. A close-fitting piston is compelled by this pressure to depressurize the cylinder. A crankshaft rotates and turns a flywheel that is attached to it after a connecting rod transmits the motion of a piston to it. The sequence of events that take place while the engine is running is referred to as its working cycle. The events that take place inside the engine occur in the following order [2].

1.3 OPERATING PROCEDURES FOR LN₂ DIRECT INJECTION

Engine using internal evaporation (DI-IE). In the same way that diesel and gasoline engines do, it starts by taking air from the atmosphere. During second stroke, air is pressed and heated. LN₂ is injected into the engine cylinder at the top dead center (TDC) of the compression stroke to generate power and evaporates quickly when heated air is present. The last and fourth strokes release the exhaust valve, letting air gas and nitrogen escape into the atmosphere. There is no combustion during the engine's strokes; instead, LN₂ evaporates, creating enough pressure in the gas to overcome the friction losses of the engine and enable the intake and compression strokes as well as the engine's output power.

1.3.1 Combustion Process

These processes occur in each engine to produce the power [4].

- a. Fresh air is used to fill the cylinder.
- b. Fresh air must be heated above the temperature required for fuel ignition. The air is compressed to do that.
- c. The heated air volume must receive a controlled injection of fuel at the appropriate time.
- d. The power stroke for the piston is produced by combustion, which releases mechanical energy.
- e. The mechanical energy powers rotational motion and powers systems and components necessary for the cylinder's subsequent cycle.

f. Gases from burning must be expelled.

The engine's performance is dependent upon the many specifications as shown in table 1.1, [5]:

Table 1.1: Main Specifications.

Particulars	Specifications
Model	2.0 L, L4 DOHC 16 Valves
Combustion	Injection
Type	standard unleaded
Bore × Stroke	81 × 97
Number of cylinders	4
Maximum power	108 kW
Compression ratio	12:5:1
Max torque	132 N.m

The development of alternative and renewable energy sources like solar, wind, and hydropower plants is necessary. Because many countries have set a national objective for greater adoption and penetration of solar and wind energy systems. It can be solved more successfully in manufacturing compressed air or liquid nitrogen with their subsequent utilization in automotive cryogenic power systems [6]. Figure 1.3 show an overview of the manufacture and use of LN₂ in clean vehicles.

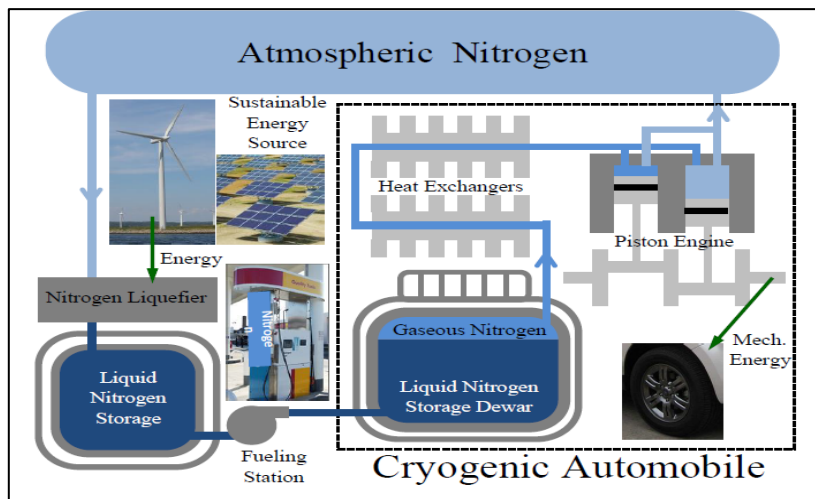


Figure 1.3: An Overview of the Manufacture and use of LN₂ in Clean Vehicles [6].

Additionally, the production of LN₂ using electricity from renewable energy sources can be combined with rural needs for food preservation and quality transportation in frigid conditions.

1.4 ISOTHERMAL EXPANSION ENGINES

Liquid nitrogen is utilized in vehicle propulsion for an open Rankine cycle, powered by ambient heat exchangers to enhance heat transfer during the expansion stroke. The cryogenic propelling system, if sufficient heat input is obtained, could offer greater automobile ranges and lower operating costs than electric vehicles currently being studied for mass production. The viability of resolving this technical problem has been evaluated, and many techniques for obtaining quasi-isothermal expansion are described. A quasi-isothermal reciprocating engine with a heater core can achieve approximately 85% of the performance of an ideal isothermal power cycle, according to heat transfer estimations. A typical example would be a 2-cylinder engine producing 15 kW and 190 N-m torque at 850 RPM and 6 MPa of injection pressure. A zero-emission vehicle may go 140 km on 200 liters of LN₂ with the aid of this power source. As a result, even though this expander concept needs to be refined, it can still provide an effective power source for a zero-emission vehicle [7].

1.5 LIQUID NITROGEN ENGINE CONSUMPTION

The LN₂ engine consumes directly introduced liquid nitrogen at a rate that is substantially higher than a gasoline or diesel engine. Table 1.2 displays the LN₂ consumption in G/m and G/h. The recommended LN₂ engine uses less liquid nitrogen than traditional engines, but requires 30 times more fuel than diesel and gasoline engines, requiring 0.02 g each cycle.

Table 1.2: Consumption of LN₂ Engine [2].

parameter	Value	units
speed	500	[rpm]
cycles	250	[cycles/min]
consumption/C	0.62	[g/cycle]
Con. /M	$0.62 \times 250 = 155$	[g/min]
consumption/H	$155 \times 60 = 9300$	[g/h]

1.6 ENGINE TORQUE AND POWER

The car's services, price, mass, engine torque, and rotation speed are crucial for both technicians and consumers, as they influence its real-world behavior.

These are an engine's two most important qualities. The interests of the technician and the driver in these two values are different, though. In fact, power can potentially be calculated by adding engine speed and torque; clearly, power requires high engine speeds. Beyond the declared power by the manufacturers, there is always a maximum value that is only accessible at the prescribed rotation speed and when the throttle is fully opened. The driver will only have a portion of the advertised power if one or both of these two requirements are not met, much alone both. However, marketers take care to avoid mentioning it. In contrast to maximum power, which can only be attained at moderate rotation speeds, maximum torque is never reached at extremely high rotation speeds (between 1,500 and 1000 rpm for some contemporary diesel cars and between 500 and 1,000 rpm for trucks) [8]. This availability, regardless of the brand or model, may undoubtedly differ from one model to another, notably in terms of engine type, but it abides by the same requirements. Torque and engine rotation speed are more important than power since they have an impact on how the car actually performs when accelerating or trying to tow a load uphill. Diesel engines are designed specifically to offer more generous torque than gasoline ones, which is accessible throughout a larger range and at lower rotation rates.

1.7 TECHNOLOGY OF INJECTION SYSTEMS

Similar technologies are used to turn LPG into fuel for gasoline-powered engines. Currently, the most significant LPG power technology for spark-ignited engines is port fuel injection (PFI). Compared to single-point power systems, LPG provides advantages with gasoline injection at the port. PFI techniques significantly imitate the multi-port electronic control injection systems used in gasoline engines for the past 20 years. In reality, the majority of vehicles with LPG port injection were originally intended to run on gasoline and were later run-on LPG; converted. Original equipment manufacturers (OEMs) offer a wide range of LPG products in both Asian and European markets. Conversions can be of two different types: dedicated, which solely allows the operation of LPG, and bi-fuel, which allows users to switch between LPG and gasoline [9]. LPG installation requires additional fuel injectors in the two-fuel system, whereas LPG injection replaces gasoline injection in dedicated

systems. Because LPG provides less energy per volume individual injectors can work in a sequential PFI system to provide more or less fuel to particular cylinders depending on variations in airflow between the cylinders, which is a significant feature. The reduction of carbon monoxide, NO_x, and hydrocarbons output and improved control of the air-to-fuel ratio in the engine are achieved.

1.8 GASOLINE FUEL

Industrial gasoline is a mixture of many distinct hydrocarbons. It is possible to make gasoline in a variety of ways that meet different engine efficiency needs. As a result, it is unclear what the gasoline's exact molecular structure is. When the temperature is the coldest and there are more unstable compounds present, the output criteria vary greatly between stations because the coldest engine may be used to start (like extra butane). Composition of the refinery differs depending on the kinds of transformers it employs, the raw oils it produces, the elements functionality, when blending the finished product, the refinery uses the desired hydrocarbon flows [9]. Most of the conventional gasoline is composed primarily of thin, relatively light hydrocarbons (often referred to as C4-C12) with 4–12 carbon atoms per molecule. This is a blend of cyclo-alkane, paraffin, and olefin (naphthene). For the oil industry, it is unusual to use paraffin and olefin instead of the more common chemical names alkane and alkene. The AL is used to measure all characteristics of gasoline fuel-Laboratories at Doura Refinery. Table 1.3 show petrol properties.

Table 1.3: Petrol Properties [9].

Stoichiometric AFR	14.98
Density (kg/l)	0.731
Gravimetric LHV (MJ/kg)	43.12
Volumetric LHV (MJ/l)	31.52
Carbon intensity (gCO ₂ /l)	2297.3
Carbon Intensity (gCO ₂ /MJ)	72.88
RON (ASTM D2699)	82
MON (ASTM D2700)	75.0

1.8.1 Properties of Diesel-Gasoline

Diesel and gasoline engines primarily use hydrocarbon-based fuels like gasoline, diesel, natural gas, and LPG, including alkanes, naphthenes, olefins, acetylenes, and aromatics. Comprehensive explanations of their molecular makeup and characteristics have been provided. Furthermore, certain important fuel properties of widely used fossil fuels in internal combustion engines, such as gasoline and diesel, have been evaluated. Hydrocarbon derivative fuels, such as diesel, gasoline, natural gas, and liquefied petroleum gas (LPG), have been researched for use as fuels in internal combustion engines. They discussed and compared the physical and chemical traits of one another. Fuel ignition delay time and self-ignition temperature characteristics are largely determined by both the octane and cetane numbers. Thus, the efficiency of a gasoline or diesel engine is greatly influenced by the octane and cetane ratings, respectively. This has led to an extensive examination and contrast of the benefits and drawbacks of fossil fuels in terms of their physical and chemical characteristics. Investigations have uncovered some of the most significant characteristics of the fuels, which are often used in gasoline and diesel engines [10].

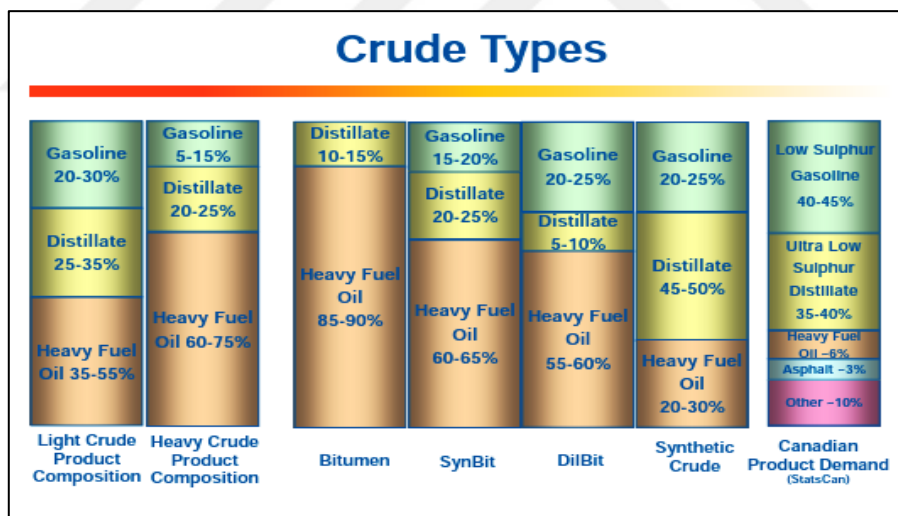


Figure 1.4: Fuel Properties [11].

1.8.2 Driving Performance and Diesel Fuel

Engine type and duty cycle determine the relative relevance of a number of operating factors that affect engine performance (such as a vehicle, a car, a maritime vessel, a stationary generator, etc.). These traits include:

- a. Beginning with ease.
- b. Low sound.

- c. Low abrasion.
- d. Long life of fuel purity
- e. Adequate power
- f. Good fuel efficiency
- g. Operability at low temperatures

Minimal emissions the majority of these traits are largely influenced by engine design. This chapter, however, examines how these traits are impacted by fuel parameters since fuel is the primary subject of this publication. Cold diesel engines are more challenging to start due to leaks and heat loss, making ignition more difficult. Start-assist devices and controls can help, but good ignition quality fuels perform better during cold starts. Modern diesel engines should have a minimum Cetane number of 40, with European engines having a minimum of 51. The quality of ignition affects operation, smoothness, and starting ease. Regardless of Cetane number, starting assistance may be required at below-freezing temperatures [12].

1.9 ENERGY EXTRACTION

The energy therein is removed once the ultimate user receives the energy carriers. In a system such as a fuel cell, the chemical energy of hydrogen may be converted into mechanical or electrical energy by either electrochemical conversion or combustion. Combustion mechanisms for hydrogen-fueled gas turbines and internal combustion engines have both been researched [13]. In a conventional engine, the internal combustion of hydrogen results in extremely high levels of nitrogen oxides, which are bad for the environment due to the high burning temperature. It is possible to reduce nitrogen oxide emissions in a number of methods, however doing so would reduce the engine's efficiency. Given that the current internal combustion low heating value (LHV) efficiency ranges only from 20 to 35 percent, this is noteworthy. Using gas turbines in hydrogen-fueled combustion before pure oxygen is produced from an air separation unit is another way to reduce the production of nitrogen oxides. In order to reduce the turbine input temperature, liquid water is usually used as a mixing fluid in this process. Here, the water is heated in advance using gas turbine exhaust gas. Unlike internal combustion, the burning temperature of these cycles is set by the turbine inlet temperature (TIT), which is presently set at 1300 °C. The preheating and mixing of the three input stream reactants in the combustor accounts for between 40 and 50 percent of the exergy loss in these cycles. With current technology, the total LHV efficiency of these kinds

of cycles is limited to around 50% because of this and the energy needed to produce pure oxygen. But with further developments in material and turbine technology, its efficiency may reach 60% or more. Given that the current internal combustion low heating value (LHV) efficiency ranges only from 20 to 35 percent, this is noteworthy. Using gas turbines in hydrogen-fueled combustion before pure oxygen is produced from an air separation unit is another way to reduce the production of nitrogen oxides. In order to reduce the turbine input temperature, liquid water is usually used as a mixing fluid in this process. Here, the water is heated in advance using gas turbine exhaust gas. Unlike internal combustion, the burning temperature of these cycles is set by the turbine inlet temperature (TIT), which is presently set at 1300 °C. The preheating and mixing of the three input stream reactants in the combustor accounts for between 40 and 50 percent of the exergy loss in these cycles. With current technology, the total LHV efficiency of these kinds of cycles is limited to around 50% because of this and the energy needed to produce pure oxygen. But with further developments in material and turbine technology, its efficiency may reach 60% or more.

1.10 MAKING LIQUID NITROUS OXIDE

The LN₂ "fuel" should be cheaply priced, one hopes. The energy cost of air compression is the main expense in the production of LN₂. Using nitrogen as a feedstock and producing LN₂ from air is essentially the same ideal job since cryogenic separation of nitrogen from other condensable in air usually requires just a very tiny fraction of the total energy. In a contemporary LN₂ plant, the effort needed is 2.0–2.5 times the minimum, or 1540–1920 kJ/kg. [14]. The energy cost would be 2.6 \$/kg-LN₂, which is similar to the cost of broad LN₂ distribution, assuming a 5 kW/h industrial electric rate for interruptible power. The selling of other air components with significant economic value will offset some of the costs associated with producing LN₂.

1.11 PRESSURE IN THE CYLINDER DURING COMBUSTION

Naturally, MATLAB's linear function interpolation function connects each pair of discrete data at a step size 10 times quicker than the company's recommended 0.6 or 0.06 MS. This results in a more continuous and consistent image, as if an infinitesimally tiny step size could have been achieved [13]. Simulations with step sizes of 0.6, 0.06, and 0.006 MS have been performed to demonstrate this. It makes sense that higher resolution would result in better continuity. The pressure curves with the largest step size shows some tiny dents. These dents

are present for curves that were simulated with smaller step sizes as well, but they are invisible to the unaided eye. The dents happen as you cross into the next state from one. The reason is because as one state ends and the next one begins; the same value is set to output. More work may be done to prevent this, either by not implementing in state flow at all or by implementing state flow in a different way given that this is not a computer program bug.

1.12 AIMS OF STUDY

Scientists have created non-fossil fuels that are cleaner, have lower fuel consumption, and greater output efficiency in order to cut down on emissions from internal combustion engines. The significant air pollution that the automotive industry produces are becoming a big global problem over time. One of the important components in the auto industry's endeavour to cut emissions, by using novel flexible fuels rather than fossil fuels. Recently, other countries have started to share this concern about the depletion of oil supplies. Overuse of fossil fuels worsens air pollution and depletes supply. The development of fuels must be the primary focus of automakers. The alternative fuel must also be economically viable, readily available, ecologically benign, and technically feasible.

This study's main goal is to look at the potential advantages of using liquid nitrogen as fuel for car engines. Despite the fact that LN₂ engines have been built in the past, all published designs gasify LN₂ before it reaches the engine, squandering a large portion of the LN₂ energy. As a result, they have proven inefficient and effectively the same as compressed-air engines.

To ensure a thorough analysis, the following objectives have been outlined:

- a. Analyze the LN's behavior in the engine cylinder, taking note of its evaporation and the variations in pressure and temperature throughout a four-stroke cycle.
- b. reduced the rise of greenhouse gasses, such as carbon dioxide, which raises air temperatures and depletes freshwater supplies.
- c. Create a geometry for the engine and explore how adding nitrogen affects the torque produced by a four-cylinder engine using computational techniques like Computational Fluid Dynamics (CFD) software.

2. LITERATURE REVIEW

Conforming to ever-tougher environmental rules and fuel efficiency standards is getting harder for conventional spark and compression ignition (CI) engines. As the general public's understanding of how humans affect the environment and how that impacts climate change has grown, Governments and businesses are under tremendous pressure to decrease their carbon footprints, especially the automobile sector. In response to rules like the European Emission Standards, several studies looking into strategies to reduce exhaust emissions have been carried out abroad. Our primary energy source continues to be fossil fuels. Petroleum has a significant role in the global transportation sector. An analysis found that 53% of the energy utilized for transportation worldwide is used by light-duty vehicles.

Examined diesel engines' usage of hydrogen as a fuel additive. Injection of hydrogen was regulated to have an energy content of 0, 25, and 50% of the total energy of the fuel, with 0% denoting the operation of clean diesel without hydrogen injection. At engine speeds of 750, 900, 1100, 1400, 1750, and eventually 2100 r/min, test circumstances were put under full load. When 25% and 50% of the entire charge energy is hydrogen supplied into the engine, much less smoke is created, but nitrogen oxides are significantly elevated. Although CO₂ and CO gaseous emissions significantly decreased, a minor increase in total unburned hydrocarbons was seen with increasing hydrogen concentration. As the hydrogen percentage increased, the rate of heat release and maximum cylinder gas pressure reached their highest levels [15].

The study examined the effects of incorporating hydrogen as a fuel into compression ignition engines to improve their performance. The engine used had four cylinders, a four-stroke design, a turbocharger, a 17/1 compression ratio compression ignition engine (CI), and 3.908 liters of engine volume. Hydrogen addition to diesel fuel reduced emissions, improved engine torque, power, thermal efficiency, and NO_x levels. At 2250 rpm and 7.5 percent hydrogen addition, engine output improved by 17%, torque increased by 8.3%, and brake thermal efficiency reached 2.5% at 1750 minutes, which is a 40.4 percent increase over the SDI value of 33 percent. The lowest, HC, NO_x, CO₂ and CO emission amount were recorded at speeds of 2250 min⁻¹, 2.5 percent hydrogen addition ratio, 0.013, 2500 min⁻¹, 7.5 percent hydrogen addition ratio, 7.4 percent, 1250 min⁻¹, 2.5 percent ratio for hydrogen addition, 10

ppm, and 1000 min⁻¹, 7.5% hydrogen addition ratio, 1092 ppm when compared to standard diesel operation [16].

The study investigated the impact of NO₂ on the combustion properties of n-butanol/biodiesel in a single-cylinder engine. Results showed that adding NO₂ accelerated heat release and increased peak in-cylinder pressure. It also led to earlier biodiesel and n-butanol consumption, and increased OH radical production. The study also examined reaction rate and flux, revealing that NO₂ addition may increase CH₃ radical consumption [17].

Measured agriculture diesel engines' variations in torque, power, and fuel consumption using minerals and vegetable fuels. The study reveals that adding biodiesel to mineral diesel reduces torque and power, increases specific fuel consumption, and maintains hourly consumption at a steady level. This loss of torque and power is especially noticeable in the Diesel S10. Adding 10% biodiesel to mineral diesel results in an increase in consumption of 3.6 g kWh⁻¹ of specific fuel, a maximum torque loss of 0.6 percent, and a maximum power reduction of 0.3 percent (1.3 percent) [18].

The four-stroke, naturally aspirated, single-cylinder, spark ignition engine was powered using clean gasoline fuel. At full load and a steady engine speed of 2400 r/min, values for in-cylinder pressure, performance, and emissions were measured. Different proportions of ethanol addition (2.5, 5, 10, 15, and 20 percent) to gasoline were analyzed and compared with clean gasoline-fueled scenarios. The data showed that adding more ethanol caused an increase in NO_x emissions. Emissions of CO and all hydrocarbons decreased [19].

Pollutant emissions from spark ignition (SI) engines have been studied. Gasolines with this ingredient have higher octane ratings. Three different kinds of spark plugs were used for this research, and the engine's spark plugs were also changed. Fuel was also adjusted, and additives were used. These include Platinum⁺⁴ spark plugs, dual electrode spark plugs, and spark plugs with a single electrode. The findings demonstrated that each three-spark plug type's braking torque and an additive was added to gasoline to boost power. The study revealed that adding an additive to gasoline led to an increase in nitrogen oxide and carbon dioxide emissions [20].

In response to rules like the European Emission Standards, numerous studies looking at methods to reduce exhaust emissions have been carried out globally. Our primary energy

source continues to be fossil fuels. Petroleum has a significant role in the global transportation sector. According to a study, light-duty cars consume 53% of the energy required for transportation globally. A liquid fuel without harmful exhaust could aid in lowering air pollution in urban areas.

The goal was to develop an emissions-free DI-IE LN₂ engine by simulating the usage of liquid nitrogen (LN₂) in a four-stroke engine using the AVL Boost platform. This research investigates related difficulties and engine performance utilizing directly introduced LN (temperature, inlet, in-cylinder, and outlet pressure, conditions for LN₂ evaporation, etc.). The program AVL Boost was created specially to handle the simulations because of the special nature of modelling using LN. The simulation results demonstrated that the in-cylinder pressure for the power stroke is generated by aspirated air with appropriate enthalpy, allowing LN₂ to expand and evaporate. The LN engine's stated efficiency was around four times greater (56–62 percent), and its IMEP was equivalent to that of internal combustion engines. The required LN₂ was produced using the air separation technique with a 44 percent efficiency, resulting in a 31 percent total efficiency [21].

A study on spark-ignited engines using liquefied petroleum gas (LPG) and gasoline fuels at 2500 rpm revealed that increased piston face temperature decreases braking power and effective torque. LPG produced less torque and carbon monoxide and NO_x emissions, while unburned hydrocarbon emissions decreased. LPG also produced less exhaust gas emissions [22].

The study assessed the BMEP and NO emissions of a heavy-duty diesel engine using a combustion model. The model's performance was evaluated in steady-state and transient conditions, with a range of 0.3 bar to 110 ppm. The model's accuracy remained unaffected even with a reduced calibration dataset [23].

The study investigated the impact of ammonia port injection on ethanol/gasoline dual-fuel engine performance, knock, and NO_x emissions. Results showed a 50% decrease in NO_x emissions, but increased BSFC, CO, and HC emissions. Additionally, ammonia reduced the minimum octane number required for knock. If ammonia is added to a biofuel engine, it may perform better and release fewer NO_x emissions, but it may also create greater BSFC, CO, and HC emissions [24].

Studies show that cryogenics can be used as energy storage for zero emission vehicles by liquefying working fluids from closed Rankine power cycles with liquid nitrogen. These systems can produce specific energy of over 400 kJ/kg-LN₂ without isothermal expanders. The optimal use of LN₂ and CH₄ occurs at extremely low injection pressures (1.0 MPa) [25].

The amount of sulfur in the fuel has been discovered to be correlated with the rate of wear in diesel engines. The amount of nitrogen and naphthenic acid has minimal impact on the rate of wear. Tests on wear conducted at 100 and 160 F revealed that the lower temperature caused significantly more wear. According to the reasoning, condensation of moisture in the presence of carbon dioxide at lower temperatures results in the creation of carbonic acid, which has corrosive properties. Iron concentration in crankcase oil was chemically analyzed to evaluate wear in the authors' tests [26].

A methodology explores the impact of real-life factors on tractors' emissions. Tests revealed that ten farm tractors, including Massey Ferguson 6499, emitted 60.1% of total NO_x gases during real-life operating times, with the most significant NO_x emissions occurring in cyclic fuel injection mode [27].

The study examines the impact of intake oxygen concentration on engine combustion features and emission characteristics in a single-cylinder, naturally aspirated, air-cooled diesel engine. Results show a quadratic polynomial relationship between oxygen concentration and four pollutants, with oxygen affecting in-cylinder pressure and NO_x and HC emissions more sensitively at low loads [28].

Diesel engine emissions pose a significant environmental threat, and selective catalytic reduction (SCR) is used to reduce NO_x emissions. A two-cylinder engine underwent hydrogen-assisted SCR, while a four-stroke twin-cylinder engine underwent SCR with hydrogen injection and chromium-plated V₂O₅ catalyst. Experiments showed NO_x emission decreased by 68.64% at 1500 rpm and 53.62 percent at 1800 rpm, with higher smoke emissions [29].

The study examined the impact of diesel oil temperature on NO_x emissions in a 9.5 kW multi-fuel compression-ignition engine. Results showed that increased engine load reduced specific NO_x emissions, but only when at 75% torque. Preheating diesel oil was found ineffective for reducing NO_x emissions [30].

after analyzing the primary statistical traits influencing engine torque using correlation analysis technologies. It is predicted that there will be an RMSE of 4.6186 between the engine torque forecast value and actual value, and the torque prediction R2 is more than 1.00. The forecast R2 for NO_x emissions is 0.99, while the actual and expected values for NO_x emissions deviate by 67.599. Using fresh WHTC data, the model's prediction accuracy was 99.60 percent. The model's relative accuracy is shown by the 72.38 RMSE between the expected and actual NO_x emission levels and the 99.2 percent prediction accuracy. There is a positive association between engine torque and ambient temperature when the effect of ambient temperature on engine torque is assessed [31].

A real-time combustion model was used to simulate brake BMEP and NO_x emissions from a 11.0 L FPT Cursor 11 diesel engine. The model's accuracy was significantly impacted by a reduction in the calibration dataset. The model demonstrated real-time capabilities on a rapid prototyping device. Average error during steady-state operation was found to be between 0.28 and 0.32 bars for BMEP prediction and between 80 and 110 ppm for NO_x simulation, with the use of ECU-derived input parameters causing the most error. In transient operation, the accuracy levels were equivalent [32].

LDCR common rail injection systems balance economy, low nitric oxide generation, combustion noise, and soot emissions by providing high torque at low engine speeds and reducing noise and emissions. This is primarily due to the LDCR injectors' rapid nozzle response and control valve activation. Studies on single-cylinder engines demonstrate how this FIE may enhance HSDI engine combustion system performance and refinement while retaining low exhaust emissions and great fuel efficiency. The LDCR FIE enhanced the specific output in multicylinder engines to 53 kW per liter, preserving refinement with sufficient technical margin [33].

A model-based controller for engine torque and NO_x emissions was developed and tested on an FPT F1C 3.0 L diesel engine through offline simulations and rapid prototyping. In order to increase predictability of NO_x, new NO_x has been built with reference to the existing one. The controller's fundamental operation under transient situations, over a variety of load ramps, has been proven by experimental testing. The study found that average RMSE values for NO_x emissions and brake mean effective pressure were 55-90 ppm and 0.25-0.39

bar during load ramp tests, respectively. The lower accuracy in NO_x emissions management at low engine speed was due to engine temperature condition [34].

The nitrogen oxide (NO_x) emissions that are produced during the type approval procedure frequently exceed those that are measured during laboratory-based testing. A study analyzing Euro 6 diesel passenger car emissions from a test route involving urban and highway sectors found that average NO_x emissions are 4.5 times the Euro 6 limit, with the urban portion experiencing higher emissions. The study found that by eliminating the top 5 most polluting vehicles, average emissions were significantly reduced [35].

The study forecasts passenger car demand, use, and CO₂ emissions for 11 geographical areas using data from global sources. The demand for vehicles is predicted using single equation models and utility maximization. Forecasts suggest that fuel consumption and related CO₂ emissions will likely increase, but there is a chance that this will be mitigated by technical improvements in fuel efficiency standards. In industrializing nations like China, demand and use dynamics for automobiles will be observed in the future, with regional variations given particular weight. In the future, multi-modal transportation systems might offer a workable solution to the needs and demands of people for mobility [36].

Studied a four-cylinder engine performs after being switched from port injection to direct injection. It has been used to substitute hydrogenated compressed natural gas for gasoline (HCNG). CNG, which makes up 10% of the total mass fraction, is the initial fuel injection. HCNG is used as the remaining 90% of the fuel and is directly injected into each cylinder. At 160 BTDC, the CNG was first injected over a 20-second stroke. 50 strokes of HCNG fuel from the (0 percent e40 percent) stage were injected at 130 BTDC. A 30% HCNG blend enhances braking power, thermal efficiency, and in-cylinder pressure by 8-13.64%, reduces specific fuel consumption by 6.2-18%, and reduces carbon monoxide and unburned hydrocarbons by up to 14%. [37].

Internal combustion engines are a necessary component of modern life, particularly in the fields of transportation and agriculture. However, there is a growing tendency toward alternate energy sources as a result of the depletion of petroleum resources and environmental issues. In this sense, the use of hydrogen as one of the renewable energy sources is anticipated to provide a solution to the issues previously described. The study examined the performance and exhaust emission parameters of a compression ignition

engine at different engine speeds using hydrogen as an extra fuel. Results showed decreased emissions, improved engine torque, power, thermal efficiency, NO_x, and exhaust gas temperatures, with the lowest CO, CO₂, HC, and NO_x emission values [38].

The maximum range of potential engine operating circumstances is indicated by an exterior speed characteristic. Therefore, with its aid, it is possible to evaluate the extreme values of the engine's characteristics and indicators when it is operating at a particular crankshaft speed. The largest mechanical and thermal demands are placed on engine components at external speed, and diesel engine exhaust smoke is likewise at its highest level at this speed. When checking the engine on the test bench, get the external speed characteristics. This option isn't always available, especially not during the design phase. The engine performance is evaluated during the cycle in two distinct modes: rated power and maximum torque. Therefore, it's crucial to consider the calculated exterior speed characteristics while justifying the key engine design indicators and parameters [39].

The study used GT-Power software to simulate down speeding for improving fuel efficiency in internal combustion engines. Results showed a 3.38% improvement, attributed to friction reduction, reduced heat transfer, and increased fuel conversion efficiency. However, validation was hindered by the need for new engine designs [40].

This study examines inertial-torque properties of inline internal combustion engines, revealing that imbalance is most severe for engines with two pistons, and significant reduction can be achieved with four or more pistons [41].

- a. The torque imbalance in a single piston internal combustion engine occurs at four different frequencies of the crank-rotation.
- b. Two-piston engines have the largest torque imbalance, followed by three-piston and single-piston engines, which display the next-largest imbalance, which is not monotonic.
- c. This work describes the inertial-torque imbalance produced by an internal combustion engine with 1, 2, or 3 pistons, illustrating how torque imbalance grows with crank speed x .
- d. The torque imbalance can be significantly reduced by using four or more pistons in the design, and when eight pistons are used, the mismatch almost disappears.
- e. The conventional mass approximation, as depicted in Fig. 4, effectively represents the variance of the actual torque imbalance compared to its mean.

This paper tackles torque balancing control for multi-cylinder SI engines using average torque in ignition-event scale and individual spark advances. A linear discrete time model and an estimation algorithm are proposed, with experimental validation on a commercial car-used six-cylinder gasoline engine [42].

A study on engine combustion noise found that increasing the rotational speed and rail pressure can increase the idling noise of diesel engines by 1.4dB and 1.4dB respectively, thereby reducing pollution and providing a reference for optimizing engine noise [43].

This paper presents a design concept for slider-crank mechanisms that enables simultaneous shaking force/shaking moment balancing and torque compensation, using a cam mechanism and a contact-maintaining spring for torque minimization [44].

This dissertation analyzes the dynamic dynamics of an inline internal combustion engine, examining inertial-torque characteristics, foundation forces, and mass approximation goodness. It identifies the largest torque imbalances in 2-piston, 3-piston, single-piston, and 3-e-piston engines, and demonstrates mass approximations accurately capture these variability [45].

The paper introduces a variable inertia flywheel (VIF) to enhance the speed stability of diesel generators against loading impact. It uses engine angular acceleration as input and reduces loading pulse impact. The VIF is passive and doesn't require a driving mechanism [46].

Examined the differences between U.S and EU emission regulations are crucial because this article takes into account both the currently used combustion-based technologies and emerging ones. The foundation for the original automobile regulations should be considered first when comparing because it is well known that they were the result of various points of view. Both markets sought to lower car emissions, but in 1970, the EU placed a higher priority on member state coherence and worked to prevent them from taking unilateral actions that would have disrupted the fledgling internal European market. In those early days, issues about air quality were secondary to concerns about vehicle safety and fuel efficiency. For dynamometer testing, however, an urban driving cycle with a peak speed of 50 km/h, gentle accelerations, and modest engine loads was developed [47].

EU regulations are stricter when considering greenhouse gas emissions. A model predicts engine torque and NO_x emissions using regression and correlation analysis. The model has

a high prediction accuracy of 99.60 percent, with an R^2 greater than 1.00 and a RMSE between predicted and measured torque. The model's relative performance is shown by the 72.38 RMSE between expected and actual NO_x emission levels and the prediction accuracy of 99.2%. A positive association between engine torque and ambient temperature is discovered when the effect of ambient temperature on engine torque is assessed. Remember that the German auto industry forced the EU to delay this goal by one year after it set the most aggressive fleet average CO₂ emission target of 95 g/km by 2020 [48].

Fuel taxes are often less expensive overseas than they are in the EU. Europe now has a greater need for fuel-efficient vehicles, which brings up diesel technology. Due to diesel's historically better fuel economy, this is the case. This pattern persisted up until the dawn of the 2010s, when direct injection gasoline technology was able to match diesel fuel economy. However, this has resulted in significant investments in diesel technology as well as higher expenses in order to ensure that diesel automobiles continue to adhere to the environmental criteria. Modern diesel vehicles use advanced auxiliary emission control devices (AECD) to remove NO_x and PM from exhaust gases, typically costing €2,000 [49].

Catalytic systems were introduced to reduce emissions of engine exhaust gases and photochemical reactions, leading to improved air quality. Platinum-based oxidation catalysts were used to lower carbon monoxide and hydrocarbon emissions. Three-way catalysts were used to simultaneously convert all three pollutants to harmless compounds. Diesel engines emit more PM, posing health risks. Selective catalytic reduction and NO_x-trapping with periodic reductive regeneration are being explored for lean-NO_x control [50].

The European Commission is reviewing test procedures for effective emission control in light-duty cars. Tests using chassis dynamometer testing and on-road emissions measurements reveal potential differences between real driving emissions and test cycles [51].

The study analyzes 12 light-duty diesel and gasoline vehicles, revealing significantly higher NO_x emissions than Euro 3-5 emission limits. Gasoline vehicles often satisfy the Euro 3-5 pollution regulations for NO_x, CO, and THC emissions on the road. Nitrogen dioxide, or NO₂, accounts for up to 60% of total NO_x emissions from diesel cars. PEMS equipment is reliable and offers precise readings of the emissions. Current transport emission models and inventories may be updated using the PEMS study's findings. Combining PEMS on-road

emissions testing with laboratory emissions testing may boost light-duty vehicle compliance with emission limits [52].

The proportion of NO₂ (f-NO₂) in vehicle exhaust has significantly changed as a consequence of the Euro classes. Diesel cars with engines larger than 2.0 liters produce more NO₂ than those with smaller engines, sometimes by a factor of 40-60 (Euro 3 and Euro 4/5). The f-NO₂ levels of Euro 4 and Euro 5 diesel cars vary regularly depending on the manufacturer. Further study is needed to understand the effects of specific manufacturer emission control systems. The pollution control system and bus manufacturer have an impact on the NO₂/NO_x ratio of TfL buses. Diesel particulate filters (DPF)-equipped vehicles typically have ratios of 15-20%, while NO₂ responses to SCR technology range from almost none for Euro IV to >30% for improved environmental cars (EEV). London taxis behave like diesel cars due to the larger amount of NO_x produced as NO₂. The lower NO₂/NO_x ratio seen for different vehicle types has affected recent NO₂ ambient trends at roadside sites in London [53].

A generator with a diesel engine reduced emissions by 10.34%, 24.77%, and 41.05% using H₂/O₂ gas mixture, with a maximum reduction of 56% at 115.4% load, powered by a battery/alternator [54].

The study examines the combustion and emissions of a turbocharged diesel engine in a composite combustion mode, revealing that with certain premixing of DME with intake air, the cylinder pressure and pressure rise rate increase [55].

Experimental tests showed that ethanol-diesel blends outperform diesel engines under different atmospheric pressures. Higher HC and CO emissions increase with engine speeds and loads, while smoke emissions decrease with ethanol content. Atmospheric pressure significantly impacts equivalent specific fuel consumption. NO_x and smoke emissions decrease with ethanol-diesel blends [56].

The study explores the use of Brown's gas in compression ignition engines to reduce environmental pollution, revealing a 37.5% reduction in CO and HC emissions, while increasing CO₂ and NO_x emissions [57].

The World Energy Council's 2019 scenarios predict a significant transformation in the energy sector, with global electricity consumption doubling over the next 40 years, primarily

driven by renewable energy, and a decoupling of economic growth and energy consumption. To protect the climate, renewable energy, increased energy efficiency, and carbon capture and use are essential strategies. International cooperation and open markets are also essential factors. All scenarios show a strong rise in power generation that exceeds primary energy consumption [58].

The U.S. Energy Information Administration's 2016 Reference case predicts that OECD countries' transportation energy consumption will remain stable over the next 25 years, while non-OECD countries will grow to higher levels by early 2020s. The study uses the International Transportation Energy Demand Determinants (ITEDDD) model to examine potential energy impacts associated with uncertainties such as consumer preference, vehicle ownership rates, government policy, and growth in non-regulated markets [59].

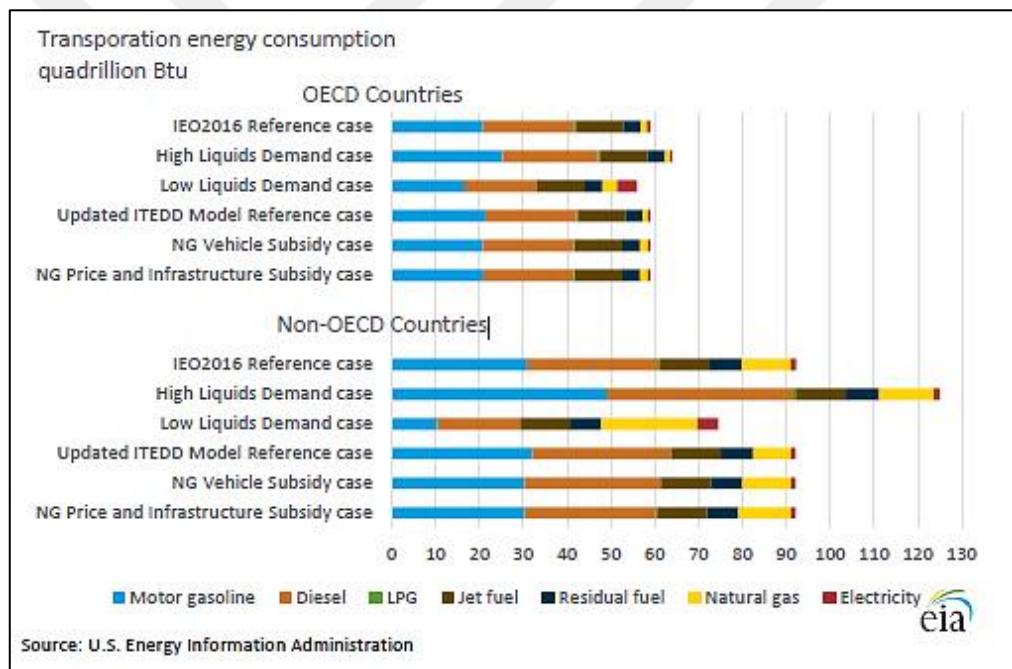


Figure 2.1: By OECD and Non-OECD Countries, Global Transportation Energy Consumption in 2040 [59].

Rapid growth in passenger and freight travel is possible, but challenges like air pollution, traffic casualties, oil depletion, and climate change may limit it. Technical solutions, such as goods kilometre tax and food miles, could help reduce travel demand [60].

Many studies have been done previously on improving the efficiency of diesel engines, including the addition of many improved materials such as hydrogen, NO₂, clean gasoline, ammonia, LN₂, NO, NOX, in addition to that there are researchers who worked on changing

the engine design or changing the spark plug, and the goal is the same to improve Efficiency and reducing emissions, and so far, modernization is underway and work is being done to obtain the ideal condition for the engine to work. According to the obtained results, indicate that the most important factors affecting the additions to the previous materials are the mixing ratios, as diesel fuel is greatly affected when raising or decreasing these proportions even if the ratios are few.

Due to the need to abide by ever-stricter regulations governing CO and pollutant emissions, the automobile sector is being compelled to develop cutting-edge technology. Nowadays, internal combustion engines play a big role in society. Numerous internal combustion engine types are extensively used in many industries, including the petroleum industry, aviation, power generation, and other fields in addition to the automobile industry. Research focuses on optimizing internal combustion engine design and creating new fuels with high efficiency and minimal emissions due to limited fossil fuel supply and emission regulations. The power stroke is created by the rapid evaporation of LN₂, which is immediately injected as a liquid into the four-stroke cylinder and heated by the compressed inspired air charge. This is engine's distinctive feature. The key insight is that this may be done in a DI- LN₂ cycle with enough enthalpy from the LN form (DI- LN₂) to do meaningful external work. Some details concerning the characteristics of such an engine may be deduced. The manufacture of LN₂ is already a significant, well-established industry that might grow much more to meet the demands of the new market. Compressors should be powered by renewable energy sources like solar, wind, or waste, and any modifications can be studied, optimized, and analyzed using engine-specific simulation software. Even when simulation is unable to account for all impacts and losses, it can nevertheless produce predictions of production and consumption that are extremely accurate. Before going to the experimental stage, industry and research now heavily rely on simulation data. Modern engineering places a high importance on simulations since they facilitate the design of experiments, reduce costs, and free up time and resources before hardware testing. In order to better understand how LN behaved in the engine cylinder, including how it evaporated and how temperature and pressure changed over the duration of a four-stroke cycle, these simulations were performed.

3. METHODOLOGY

3.1 INTRODUCTION

Internal combustion engine behaviour, performance, and structural integrity may be thoroughly studied utilizing IC Engine simulation using ANSYS Fluent and ANSYS Mechanical (Static Structural) software. These two software modules, which are a component of the ANSYS package, IC engine fluent, cater to many areas of engine simulation by integrating structural evaluation and fluid dynamics analysis to provide a comprehensive knowledge of engine operation and interactions with the environment. The complicated fluid movement, heat transport, combustion, and structural stresses found in internal combustion engines make them complex systems.

3.2 IC ENGINE FLUENT

Internal combustion engine fluid dynamics and combustion processes may be simulated using IC Engine Fluent, a specialist computational tool included in the ANSYS software. It gives engineers and scientists a thorough platform to evaluate and improve the performance, emissions, and efficacy of numerous internal combustion engine types utilized in industrial, automotive, and aerospace applications. Complex systems known as internal combustion engines use the burning of fuel in a small area to generate mechanical work. These engines' pressure, velocity, and temperature are largely determined by the fluid dynamics inside them.

3.2.1 Geometry Modelling

Users of IC Engine Fluent may design intricate 3D geometries of various engine parts, including cylinders, pistons, valves, and combustion chambers. The accuracy of the simulation results is guaranteed by the geometry model ling's accuracy. Whereas, as shown in figure 3.1, the dimensions of the combustion chamber were created in consideration of earlier study about piston diameter, crankshaft length, and other factors.

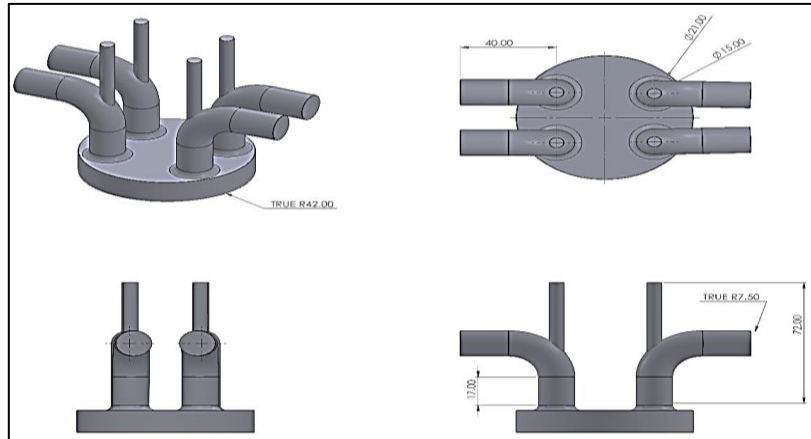


Figure 3.1: Internal Combustion Design.

Slice	InputManager2
Decomposition Position	IVC
Decomposition Angle	570 °
Sector Decomposition Type	Complete Geometry
Cylinder Liner Faces	1 Face
Sector Angle	60 °
Validate Compression Ratio	Yes
Compression Ratio	21
Crevice H/T Ratio	3
Spark Points (Optional)	Not selected
IC Valves Data 1 (RMB)	
Valve Bodies	4 Bodies
Valve Seat Faces	4 Faces
IC Injection 1 (RMB)	
Spray Location Option	Height and Radius
Spray Location, Height	0.02 mm
Spray Location, Radius	0.02 mm
Spray Direction Option	Spray Angle
Spray Angle	70 °
IC Advanced Options (RMB)	

Figure 3.2: Input Manager [61].

After entering the required information as shown in Figure 3.2, the input manager converts the model of the internal combustion chamber into a geometry that can be simulated to extract the results as in Figure 3.3.

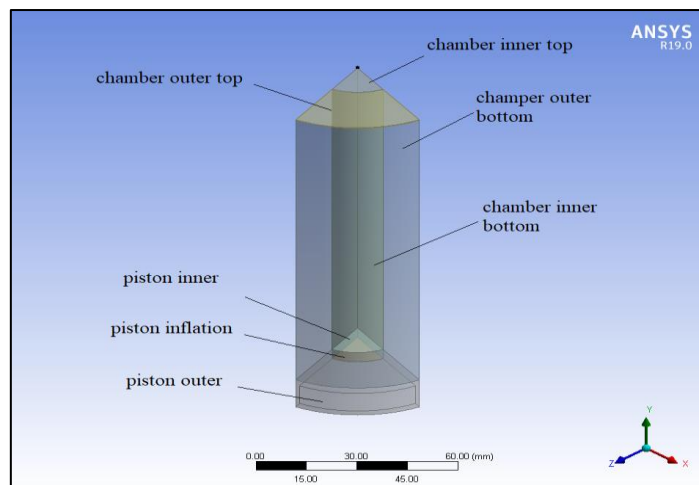


Figure 3.3: IC Engine Domain.

Where the data such as crankshaft length 165 mm and minimum lift 0.2 mm and the input option for inlet valve closed (IVC) and exhaust valve open (EVO) is entering direct values , the inlet valve closed 570 degree and exhaust valve open 833 degree.

3.2.2 Mesh Generation

In general, the structured Hexahedron grids were selected for the present study because structured grids perform well for complex geometries.

ANSYS facilitates the development of solid geometry meshes, three-dimensional models, and fluent IC engines. In this investigation, 2062218 cells were extracted; for a breakdown, refer to figure (3.4) and table (3.1).

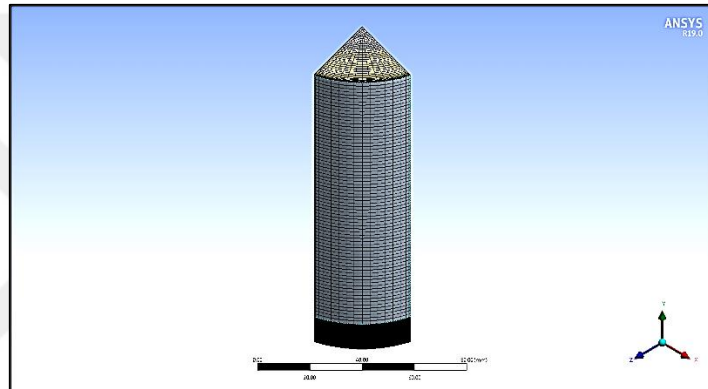


Figure 3.4: Mesh Generated.

As it terminates when the output results approach stability and the element size is set to 0.001 m, a mesh independence must be created to clearly show changes when the element count and output results are changed. This will ensure accurate and trustworthy results.

Table 3.1: Mesh Independency.

Case	Element	Max. temperature (K)
1	1405636	961
2	1612356	949
3	1805436	946
4	2062218	945

3.2.3 Physics Setup

ANSYS Fluent is often used for fluid flow simulations, which is relevant for IC engine simulations. Set up the physics by specifying the appropriate boundary conditions, material properties, and modelling assumptions. For an IC engine simulation, we will need to define

the fluid properties, combustion model, turbulence model, heat transfer, and other relevant parameters.

Figure 3.5: Physics Setup.

3.2.4 Boundary Conditions

Boundary conditions are crucial for setting up a realistic and accurate simulation of an internal combustion engine using ANSYS Fluent. They define the interaction of the engine with its surroundings and play a pivotal role in capturing the engine's behaviour.

Table 3.2: Boundary Conditions.

Name	Type	Value
ice-sector-top-faces	Wall temperature	602 K
ice-piston	Wall temperature	645 K
ice-cyl-piston	Wall temperature	567 K
ice-cyl-chamber-top	Wall temperature	567 K
ice-cyl-chamber-bottom	Wall temperature	567 K

Where the engine speed will be changed from 1800 to 2600 RPM, as well as the flow rate from 0.00015 to 0.00025 kg/s. As for adding nitrogen concentrations, the molar concentrations of nitrogen are added to the same reaction equation 0.1 moles, 0.3 moles and 0.5 moles per 1 mole of diesel as shown figure 3.6.

Figure 3.6: Reaction Parameters.

3.2.5 Combustion Modelling

Continuity equation:

$$\nabla \cdot \vec{V} = 0 \quad (3.1)$$

Momentum equation:

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \nabla \vec{V} = \frac{1}{\rho} \left(-\nabla P + \mu \nabla^2 \vec{V} + \rho \vec{g} \beta (T - T_{\text{ref}}) \right) + S_m \quad (3.2)$$

Energy equation:

$$\frac{\partial h_{\text{sens}}}{\partial t} + \frac{\partial h_{\text{lat}}}{\partial t} + \nabla \cdot (\vec{V} h_{\text{sens}}) = \nabla \cdot \left(\frac{k}{\rho c_p} \nabla h_{\text{sens}} \right) \quad (3.3)$$

The spark is often under-resolved on the CFD mesh because the initial spark size is typically modest in comparison to the cell size. Modelling the spark by burning a few cells close to the spark position reveals considerable grid and time-step sensitivity, and flame speed and flame brush diffusion may be inaccurate owing to the poor space and time resolution. Additionally, ignition happens too soon when the initial spark is lower than the size of the cell.

The ANSYS IC engine fluent calculates a sub-grid equation for the spark evolution to lessen this sensitivity. It is believed that the flame front of the spark is infinitely thin and completely spherical. Spark radius, r , increases with time, t [62],

$$\frac{dr}{dt} = \frac{\rho_u}{\rho_b} S_t \quad (3.4)$$

where S_t is the turbulent flame speed, ρ_u is the density of the burned fluid behind the flame, and ρ_b is the density of the unburned fluid in front of the flame front.

Through a representative volume of CFD cells, the sub-grid spark model is translated to the CFD grid. The local turbulent length scale at the spark site is estimated as the fixed diameter of this spherical container. However, the radius of the representative sphere, r_t , is determined as follows to make sure that it is neither too big (in relation to the size of the combustor) nor too tiny (in relation to the size of the cell),

$$r_t = \max \left(r_0 + 34,3 r_0, \min \left(\frac{1}{2} l_t, r_0 + 10\Delta \right) \right) \quad (3.5)$$

where Δ is the cell length scale, l_t is the turbulent length scale, and r_0 is the initial spark radius that the user specifies [62].

An alternative is to use the spark-model text interface to provide r_t as a fixed value.

, $l-t$. is used to define the representative volume because, once the spark diameter reaches this size, the flame speed is affected by all of the turbulent scales present. The spark radius will increase until the desired length scale is reached, even if the simulation period runs longer than the user-specified time limit. It should be noted that the period supplied is solely utilized to determine the rate of spark energy input and the moment at which this input stops. Ansys Fluent turns off the spark flame speed model at this point, modelling the flame speed across the domain using the flame speed model you chose in the Species dialog box. The typical spherical volume's temperature and species composition, indicated by, are determined as follows [62]:

$$\varphi = c\varphi^b + (1 - c)\varphi^\mu \quad (3.6)$$

where φ^μ the unburned composition is represented by and the equilibrium burnt composition by φ^b . These musical arrangements are constant in time and consistent in space.

Spark energy is not needed to ignite the mixture because the thermo-chemical condition behind the spark flame front is instantly equilibrated as the spark propagates. All combustion models start off with the spark energy set to zero and the burned temperature as the equilibrium temperature. The temperature behind the spark, however, may be changed via the user interface to a positive number, in which case the equilibrium temperature will be greater [62].

The Turbulent Curvature model is used to calculate the turbulent flame speed as follows:

$$S_t = \max\left(S_l - \frac{2D}{r}, S_t(r) - \frac{2D_t}{r}\right) \quad (3.7)$$

where D is the laminar diffusivity, r is the current spark radius, and $D-t$ is the turbulent diffusivity. The laminar flame speed is, $d-d$. The turbulent flame speed measured at the turbulent length scale of the spark radius is denoted by, $d-t$. (r). D and, $D-t$. are assessed where the spark occurs. Because scales larger than the spark radius convect the spark but do not increase its area or flame speed, only turbulent length scales up to the spark radius r may have an effect on the turbulent flame speed of the spark. The flame speed model used for the primary combustion is the same flame speed model used for the premixed and partly premixed versions. The Zimont flame speed model is by default used to Species Transport instances. S_t and D are included in the interface for the species transport models as extra material inputs [62].

Keep in mind that the flame curvature has the effect of reducing the speed of both laminar and turbulent flames. Since the user inputs the initial spark radius r_0 , reducing r_0 slows the spark propagation and lengthens the burning period. The Turbulent Length model is used to calculate the turbulent flame speed as follows:

$$S_t = \max(S_l S_t(r)) \quad (3.8)$$

In other words, the Turbulent Length model disregards how flame curvature affects flame speed. The Herweg and Maly model is used to compute the turbulent flame velocity [62].

$$S_\varepsilon = \max\left(S_l, S_l \left(I_0 + I_0^{\frac{1}{2}} \left(\frac{u}{u+S_l} \right)^{\frac{1}{2}} \left[1 - \exp\left(-\frac{r}{l_t}\right) \right]^{\frac{1}{2}} \left[1 - \exp\left(-\frac{t-t_0}{\tau_s}\right) \right]^{\frac{1}{2}} \left(\frac{u}{S_l} \right)^{\frac{5}{6}} \right)\right) \quad (3.9)$$

Where, [2] I_0 is a function for the influence of strain on the laminar burning velocity.

$$I_0 = \max\left(0, 1 - \left(\frac{\delta}{15l_t}\right)^{\frac{1}{2}} \left(\frac{u}{S_l}\right)^{\frac{3}{2}} - 2\frac{\delta}{\Gamma} \frac{\rho_u}{\rho_b}\right) \quad (3.10)$$

Where,

t = current time

t_0 = start time

u = turbulent velocity scale

$$\tau_s = \frac{l_t}{u + S_l}$$

$$\delta = \text{laminar flame thickness} = \frac{D}{S_l}$$

3.2.6 ANSYS Package

Two modules are used to handle the stream conditions:

- a. Pre-processor, a software structure that creates the calculation and matrix as in the accompanying, is the most important module.
 - i. Modelling of calculation.
 - ii. Mesh number.
 - iii. Boundary condition.
- b. The second module, called the Solution module, settles the violent stream model and the Navier-Stokes conditions, which include flow rate, force, and energy conditions.

3.2.7 Problem Solution

A portion of the control was based on an approach that included the following developments, which may be applied to the arrangement:

- a. A network is created on the field.
- b. A set of mathematical conditions, such as pressure, velocity, and preserved scalars, is constructed by combining the administering conditions on each control volume.
- c. Iteratively, the discretized equations are solved using linearization.

3.2.8 Solution Parameters

The solution parameters include the following:

3.2.8.1 Precision solver type

Accuracy solutions are often identified by a process known as "single and two folding." A PC with infinite precision, residuals would vanish as the configuration comes together. A real PC, the leftovers decay to a minimal value ("adjust") and ultimately change ("level out").

3.2.8.2 Iterations number

This is the maximum number of iterations completed prior to the solver stopping. Where the two processors will be connected for the purpose of simulation as shown in Figure 3.7.

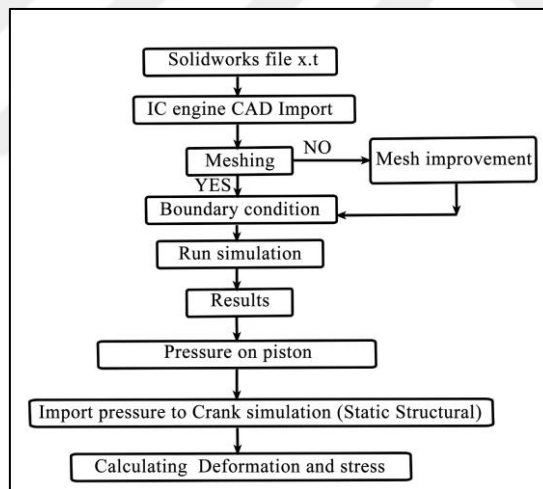


Figure 3.7: Flow Chart of CFD.

3.2.9 Convergence Criteria

It should be emphasized that the flow conditions of the internal combustion process parameters are regulated according to the CFD approach in order to be properly recognized and simulated. When the order of the materials involved in the reaction remains within the accuracy of the specified mixing models, a complete simulation is obtained without errors. The error residuals, which compare the positive aspects of a variable at two continuous concentrations, are considered. For all flow conditions mentioned previously, the ranking is

assumed to be uniform when the error percentage is less than the outcome difference value of 10^{-6} .

3.3 CRANKSHAFT SIMULATION (STATIC STRUCTURAL)

The crankshaft was designed with the required dimensions from the [63] reference, matching the simulated combustion chamber composition as shown in figure 3.8.

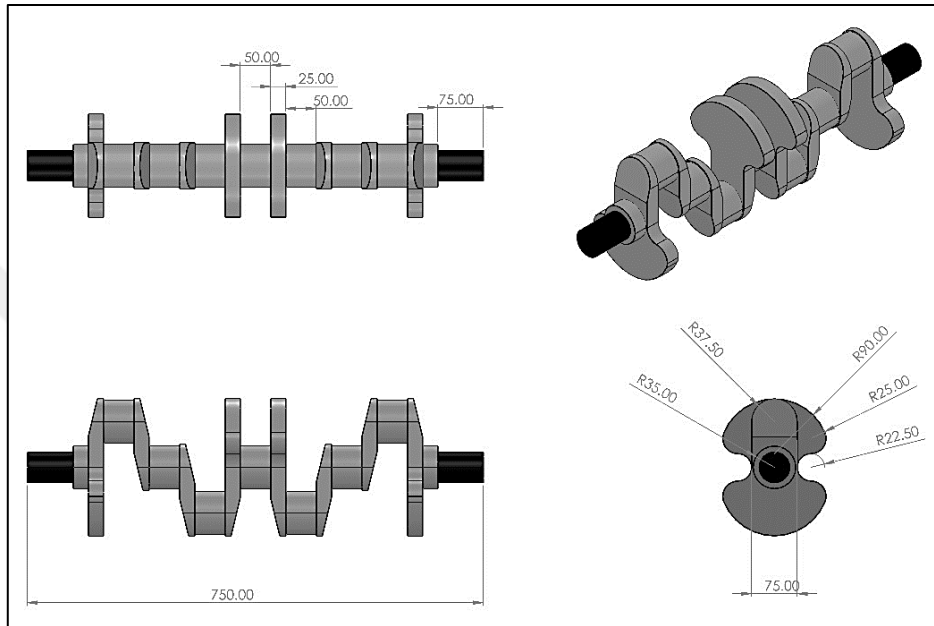


Figure 3.8: Crankshaft Design.

After the design process, the crankshaft is simulated with the static structural program, the stresses obtained through the IC engine program are placed in the various cases that have been studied, and the stresses are applied vertically on the crankshaft according to the angle to be analysed to obtain accurate and clear results as shown in Figure 3.9.

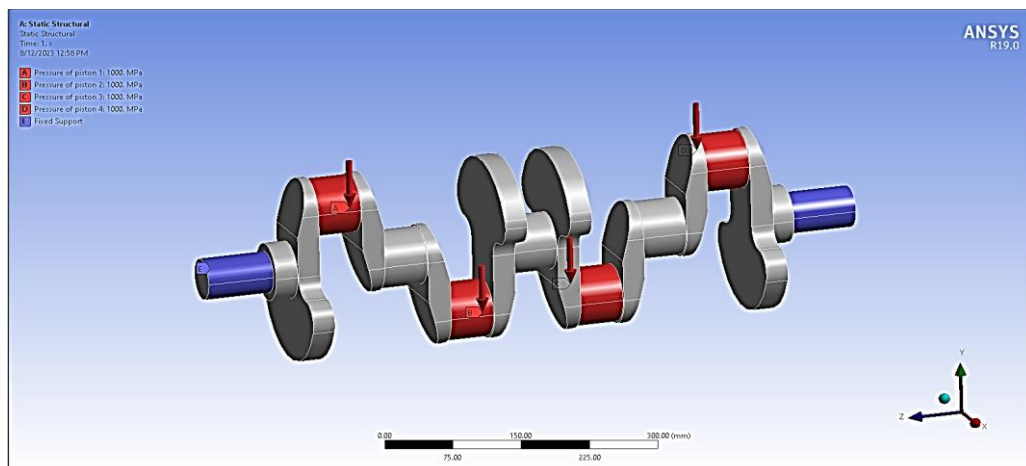


Figure 3.9: Load Applied.

4. RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter will give a thorough analysis of the outcomes of the simulation program. The analysis will be separated into two primary areas of inquiry based on these findings: the investigation of engine rotation speed and fuel mixture flow rate, and the investigation of the impact of the higher nitrogen ratio on internal combustion engine performance. In the second stage, the crankshaft is simulated together with the stresses added as a result of the internal penetration simulation software so that the impacts on it may be examined.

4.2 THE EFFECT OF ENGINE ROTATIONAL SPEED ON IC ENGINE

The effect of engine rotational speed on internal combustion engine (IC engine) modeling is important in the realm of automotive engineering and powertrain development. In many different applications, internal combustion engines are used in automobiles, trucks, motorbikes, and other types of vehicles. Simulation is necessary to comprehend and enhance the emissions characteristics, efficiency, and performance of internal combustion (IC) engines. Revolutions per minute (RPM), a commonly used abbreviation for an engine's rotational speed, is a crucial factor that profoundly affects an internal combustion (IC) engine's (behavior and attributes). Complex mathematical models are used in the modeling of internal combustion engines (IC engines) to take into account a wide variety of variables, including combustion processes, fluid dynamics, thermodynamics, and mechanical interactions that take place inside the engine. Simulations are used for a variety of tasks, including design, analysis, and testing. They are essential for estimating engine performance under various operational conditions. An engine's rotational speed has a direct impact on how it behaves dynamically. Variable speeds are produced by the piston's reciprocating motion and the crankshaft's rotating motion, which are impacted by variations in revolutions per minute (RPM). As a result, these modifications have an impact on the engine's airflow, fuel injection, and combustion properties. Simulation models must completely reflect the dynamic implications in order to produce realistic results. Power output, torque, and fuel economy are just a few of the performance parameters that are significantly impacted by an engine's revolutions per minute (RPM). To forecast the fluctuations in these traits as the engine speed varies, simulation techniques are used. Using this information, engineers may modify the engine's operating conditions to meet particular needs, such as maximizing high-

speed performance or improving fuel economy. Exhaust emissions are also influenced by the engine's speed of rotation. Variations in RPM have an impact on combustion efficiency as well as the emissions of particulate matter (PM) and nitrogen oxides (NO_x). For the purpose of improving emission control techniques and guaranteeing adherence to environmental regulations, simulation models are crucial. These models offer an assessment of emissions levels at various engine speeds. The mechanical forces that the engine's various parts, such as the pistons, connecting rods, and crankshafts, are subject to directly depend on the rotational velocity of the engine. Simulations are used to forecast the fatigue life of the engine's components under various operating situations in order to guarantee the engine's long-term durability and dependability. In real-world situations, engines don't run continuously. The abrupt variations in revolutions per minute (RPM) that occur during transient events like acceleration and deceleration must be accounted for through simulations. In order to optimize drivability and vehicle performance, it is imperative to have a comprehensive understanding of the engine's behavior throughout these variations. Contemporary engines are equipped with sophisticated electronic control systems that adjust engine speed-dependent attributes, such as fuel injection timing and ignition timing. The development and optimization of these control algorithms necessitate the utilization of simulation techniques.

In conclusion, engine rotational speed is a crucial factor that profoundly affects how internal combustion engines behave and function. Engineers may thoroughly examine and improve engines using simulations in order to ensure that they satisfy the demands for performance, efficiency, emissions, and durability for a variety of applications in the automotive and industrial sectors.

The temperature within an internal combustion engine (IC engine) is significantly influenced by the engine rotational speed, which is frequently expressed in revolutions per minute (RPM). Several variables, including engine design, load, and cooling system effectiveness, influence the relationship between engine speed and temperature. As engine speed rises, combustion events happen more often. The combustion chamber's temperature rises as a result of this. In general, higher RPM led to more frequent power strokes, which raise the temperature of the cylinder from the quick burning of air and fuel. Engine speed has an impact on the temperature of the exhaust gases that leave the engine. Because combustion events happen more frequently at higher RPMs, exhaust gases tend to be hotter at these

speeds. Elevated exhaust gas temperature can impact the design of the exhaust system, turbocharger efficiency, and emissions regulation.

The impact of varying engine rotation speeds on the temperature readings at the TDC, or combustion zone, is seen in Figure 4.1. The graphic indicates that as the engine rotation speed increases, the temperature value drops. because the internal combustion chamber's design and the engine's rotation speed are incompatible with the piston movement. Conversely, the engine speed at 1800 RPM produced a temperature of 945 K in the combustion chamber, 2200 RPM produced 864 K, and 2600 RPM produced 709 K.

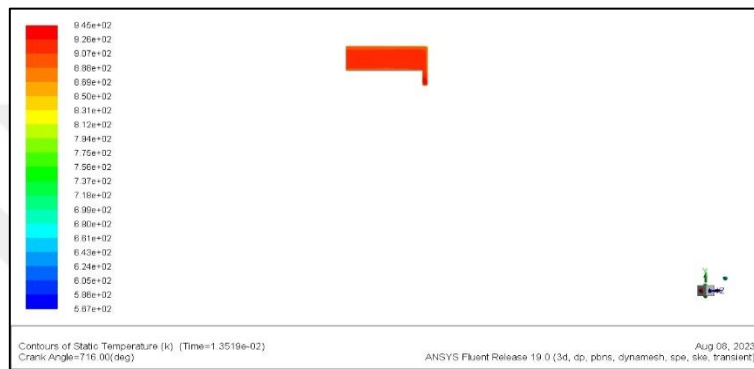


Figure 4.1: Temperature Contour at TDC at 1800 RPM.

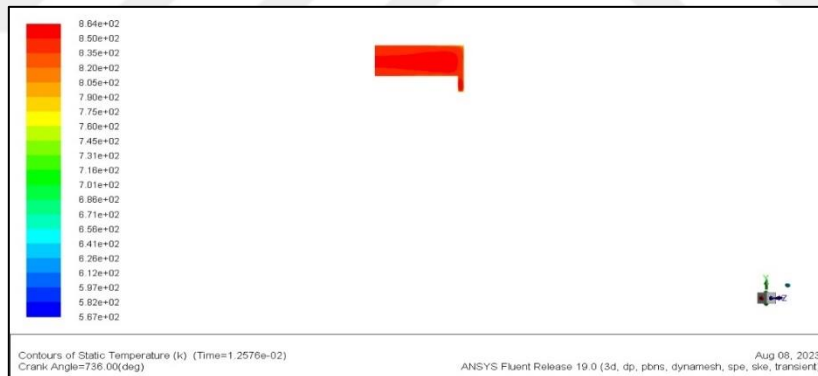


Figure 4.2: Temperature Contour at TDC at 2200 RPM.

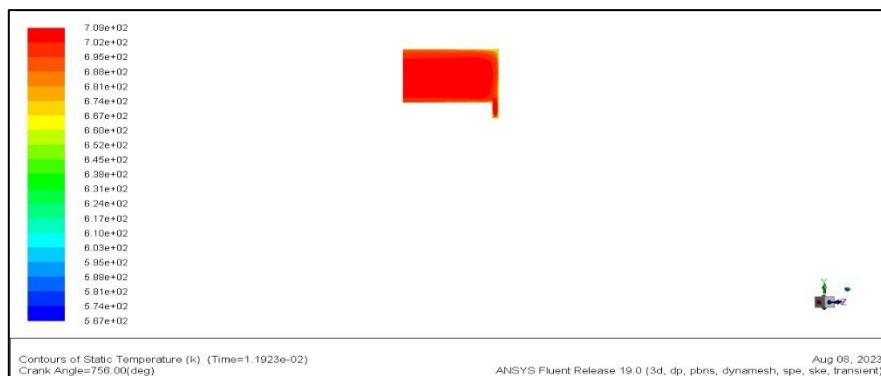


Figure 4.3: Temperature Contour at TDC at 2600 RPM.

The rotational speed of an internal combustion engine (IC engine) has a significant influence on the fuel velocity, which is generally measured in revolutions per minute (RPM). There are several factors that influence the relationship between engine speed and fuel velocity, two of which are the fuel injection system and the combustion process. The determination of fuel injection timing is influenced by the engine's rotational speed, which is a crucial variable. In most contemporary internal combustion engines, fuel is introduced into the combustion chamber at precise intervals within the engine cycle, such as during the intake stroke or immediately prior to the compression stroke. The timing of fuel injection is often adjusted in response to variations in engine speed and load. In order to achieve the appropriate air-fuel ratio at elevated RPMs, it becomes necessary to expedite the fuel injection process through shorter-duration injection events. Fuel injectors have flow rate characteristics that are subject to variation based on the rotational speed of the engine. While certain fuel injectors may be designed to deliver fuel consistently across a wide range of revolutions per minute (RPMs), others may exhibit characteristics that are specific to a particular speed. The response time and atomization capacity of the injector can have an impact on the velocity and distribution of fuel inside the combustion chamber. The rate at which air is sucked into the engine's intake system is directly influenced by the engine's velocity as well as the aerodynamic properties of the airflow. The rate of input into the engine rises as the revolutions per minute (RPM) rise, potentially altering how quickly fuel is fed into the intake airstream. The air and fuel velocities must interact dynamically in order to achieve the highest levels of mixing and combustion efficiency. Several methods, including as intake manifold design, valve timing, and piston shape, are available to engine designers to create turbulence and swirl in the intake air. Even while operating at high engine speeds, these features have the potential to enhance fuel and air mixing, hence improving combustion efficiency. The velocity of fuel can also be influenced by the choice of fuel injection technology, specifically the distinction between direct injection and port injection. Comparing direct injection systems—which provide fuel directly to the combustion chamber—with port injection systems, which supply fuel to the intake ports, it can be argued that the latter may be better equipped to sustain elevated fuel velocities during high revolutions per minute (RPMs).

Figures 4.4 to 4.6 represents the speed of the mixture flowing into the combustion chamber, as it is seen that as the engine's rotational speed rises, so does the value of the mixture's

movement speed. This is because more mixture is able to reach the combustion chamber due to the engine's rotational value. The mixture's flow velocity was 7.86 m/s at 1800 RPM, 9.69 m/s at 2200 RPM, and 11.6 m/s at 2600 RPM depending on the engine speed.

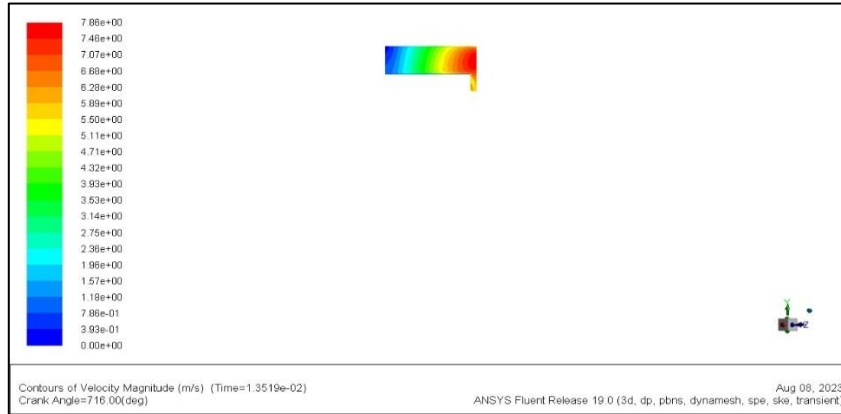


Figure 4.4: Velocity Contour at TDC at 1800 RPM.

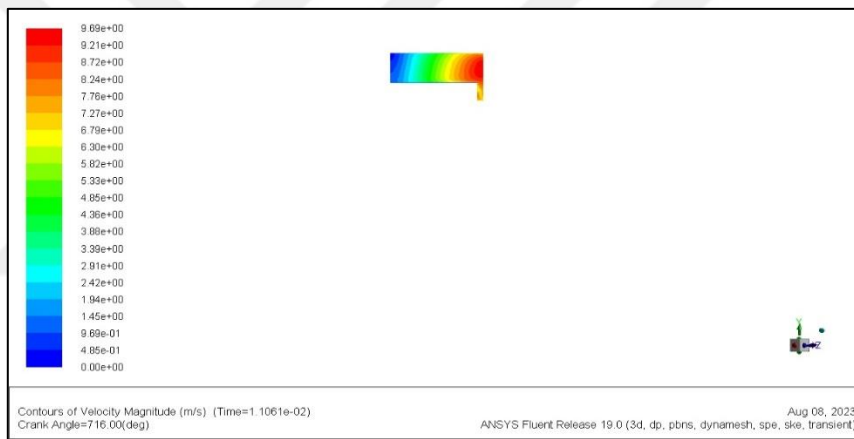


Figure 4.5: Velocity contour at TDC at 2200 RPM.



Figure 4.6: Velocity Contour at TDC at 2600 RPM.

Figures from 4.7 to 4.9 symbolize the mixture's particles within the combustion chamber; it is observed that the mixture's movement speed increases as engine rotation speed rises, and this is because the engine's rotation value facilitates the entry of more mixture into the combustion chamber.

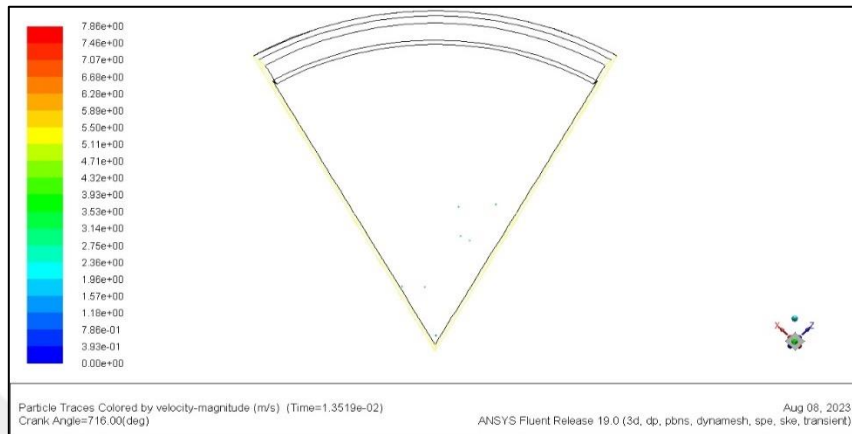


Figure 4.7: Particle Traces at TDC at 1800 RPM.

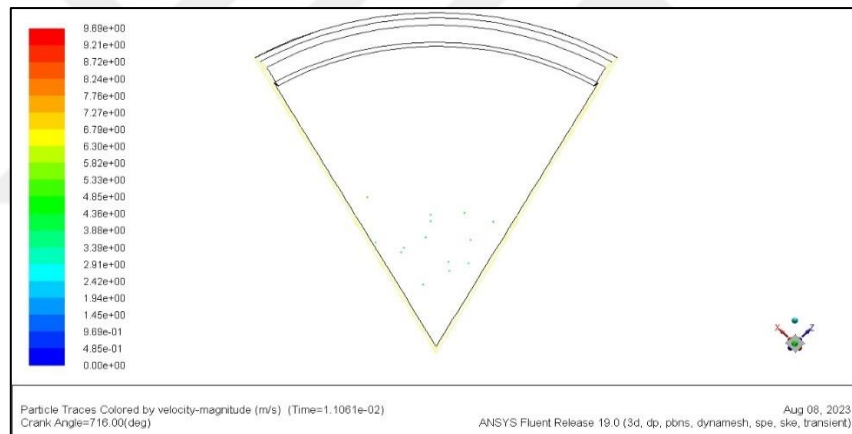


Figure 4.8: Particle Traces at TDC at 2200 RPM.



Figure 4.9: Particle Traces at TDC at 2600 RPM.

An internal combustion engine's (IC engine's) pressure characteristics are significantly influenced by the engine's rotating speed, which is expressed in revolutions per minute (RPM). Numerous aspects of engine performance can be affected by the intricate interaction between engine speed and pressure. The cylinder pressure tends to rise as engine speed rises. The increased frequency of combustion events at higher RPMs is mostly to blame for this. A four-stroke engine produces more power strokes and higher peak cylinder pressures because each complete cycle of intake, compression, power, and exhaust occurs faster at higher RPMs. The air-fuel combination ignites and quickly expands during the power stroke, which is when the combustion chamber reaches its peak pressure. Because of the faster rate of expansion, peak pressure values rise as engine speed rises. The engine's torque and power may be impacted by this. The engine's entire power production and efficiency are gauged by the term "mean effective pressure," or MEP. It represents the cylinder's average pressure during the power stroke. MEP values are more likely to increase with increasing engine speed, indicating greater power generation for a given displacement. Engine speed has an impact on scavenging pressure in two-stroke engines, which are frequently seen in things like compact motorcycles and outboard motors. Scavenging is the removal of exhaust gases and their replacement with brand-new air-fuel mixtures. Increased cylinder charging pressure and better scavenging efficiency can both be achieved with faster engine speeds.

Figure 4.10 shows the gradient of pressure with time during the different crankshaft rotation stages, as it is noted that the pressure value increased with a decrease in engine rotation, and thus a decrease in temperature.

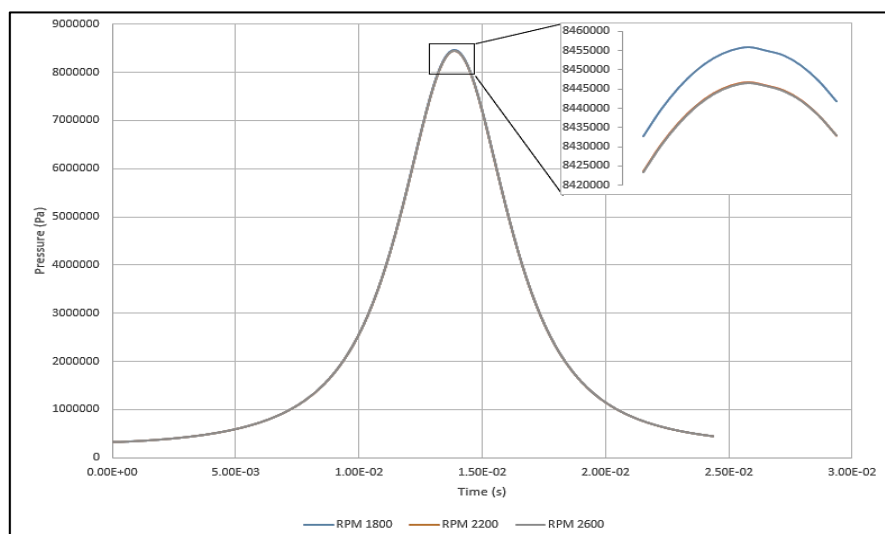


Figure 4.10: Pressure Gradient with Time at Different RPM.

4.3 THE EFFECT OF ADDING NITROGEN CONCENTRATIONS ON IC ENGINE

Depending on the circumstances and the intended use of the nitrogen, increasing nitrogen concentrations to an internal combustion engine (IC engine) can have a variety of consequences on engine temperature. It's crucial to remember that air, which constitutes the majority of the intake mixture in IC engines, already contains nitrogen (78% nitrogen and 21% oxygen, roughly). You might, however, be talking to changing the nitrogen content of the air in some way. The air-fuel mixture is burned in an IC engine. Because nitrogen behaves as an inert gas that can absorb heat during the combustion process, the presence of nitrogen in the air can help lower peak combustion temperatures. This can be especially helpful in lowering the development of dangerous nitrogen oxides (NO_x), which happen in exhaust gases at high temperatures. One method of reducing NO_x emissions is by adding nitrogen or nitrogen-based chemicals (such as nitrogen oxide inhibitors) to the engine's intake air or fuel. Nitrogen additions can aid in lowering the generation of NO_x, a significant air pollutant, by minimizing the peak temperatures reached during combustion. Nitrogen has a smaller specific heat capacity than oxygen, which provides the cooling effect. Therefore, if more nitrogen is added to the engine, the combustion process may experience a minor cooling. This can lessen the engine's high-temperature circumstances. Nitrogen can affect the stability and effectiveness of combustion. Excessive nitrogen concentrations have the ability to limit the quantity of oxygen in the air-fuel combination, which may lead to incomplete combustion and reduced power generation, even if they can assist control temperatures. When injecting nitrogen or compounds containing nitrogen, it may be necessary to make adjustments to the engine calibration and control systems in order to obtain optimum performance and emissions control. These adjustments may include adjusting the ignition, air-fuel ratio, and fuel injection timing to ensure the engine operates efficiently and within safe temperature limits. Engine knock resistance may be affected by the make-up of the intake air. By absorbing heat and lowering the effective octane rating of the fuel-air mixture, nitrogen can assist lessen the likelihood of knock (premature combustion).

The impact of varying the nitrogen gas concentration on the temperature values at the combustion zone, or TDC, is shown in Figures 4.11 to 4.13. It is clear from these figures that the temperature value drops as the concentration of nitrogen gas increases. because nitrogen gas is a gas that does not help combustion, but rather its main purpose is to reduce engine

temperature. The combustion chamber temperature at 0.1 moles per 1 mole of diesel was 847 K, 757 K at 0.3 moles per 1 mole of diesel, and 645 K at 0.5 moles per 1 mole of diesel.

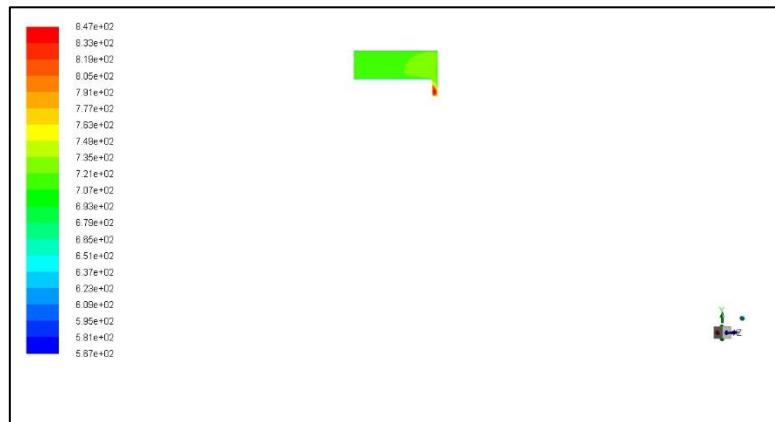


Figure 4.11: Temperature Contour at TDC: (a) 0.1 Moles per 1 Mole of Diesel.

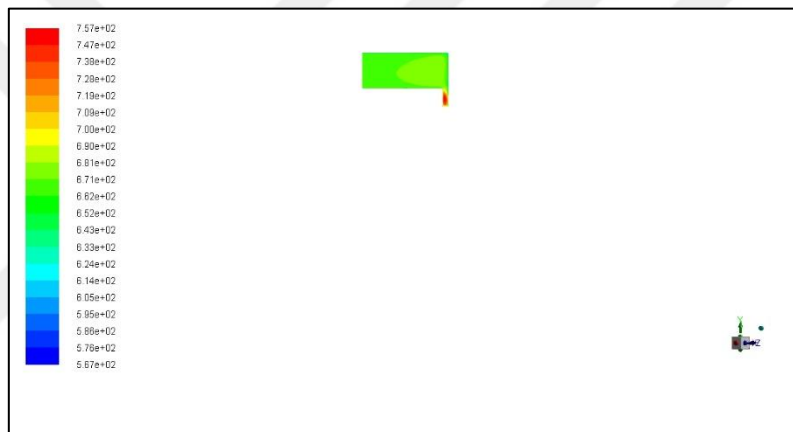


Figure 4.12: Temperature Contour at TDC at 0.3 Moles per 1 Mole of Diesel.

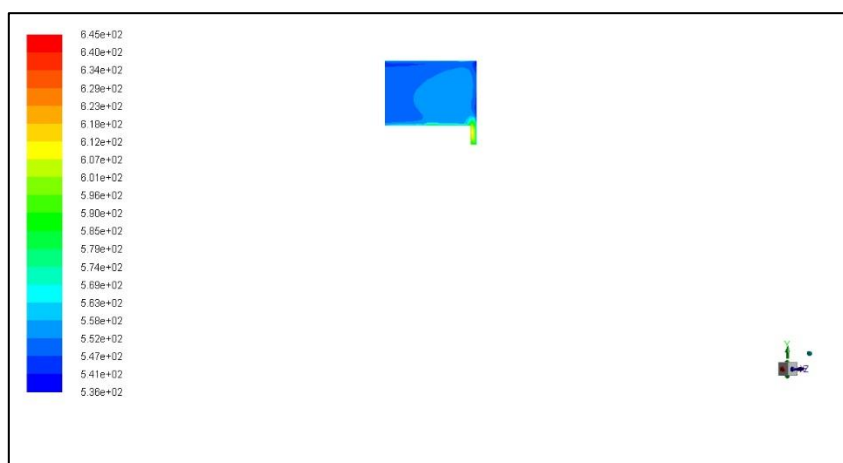


Figure 4.13: Temperature Contour at TDC at 0.5 Moles per 1 Mole of Diesel.

Figures from 4.14 to 4.16 represent the speed of the mixture flow into the combustion chamber, where it is noted that the value of the speed of movement of the mixture increases

with the concentration of nitrogen gas. The reason for this is that an increase in the nitrogen concentration increases the flow of the mixture into the combustion chamber. The mixture flow velocity was 4.02 m/s at 0.1 moles per 1 mole of diesel, 5.26 m/s at 0.3 moles per 1 mole of diesel, and 6.47 m/s at 0.5 moles per 1 mole of diesel.

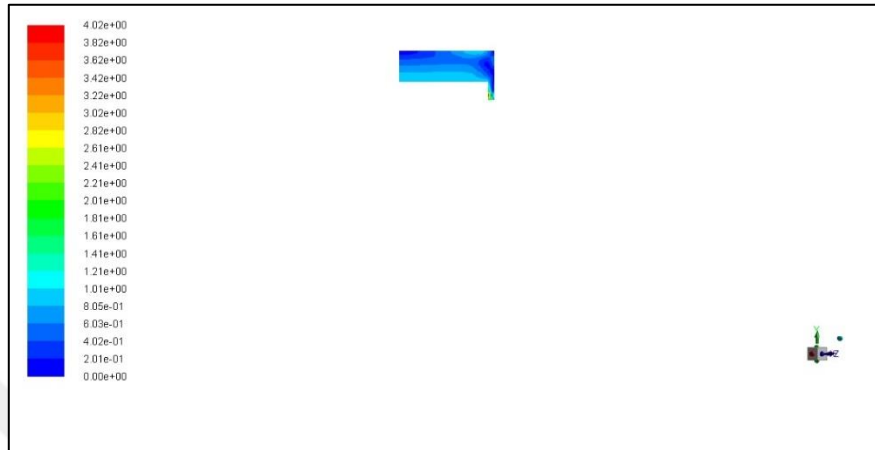


Figure 4.14: Velocity Contour at TDC at 0.1 Moles Per 1 Mole of Diesel.

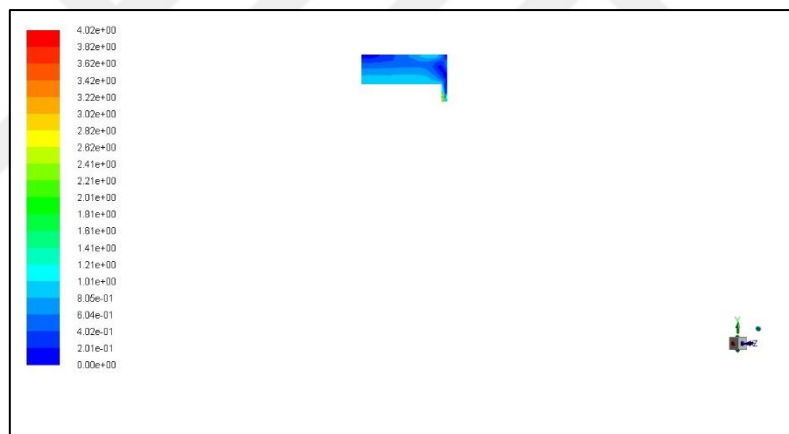


Figure 4.15: Velocity Contour at TDC at 0.3 Moles Per 1 Mole of Diesel.

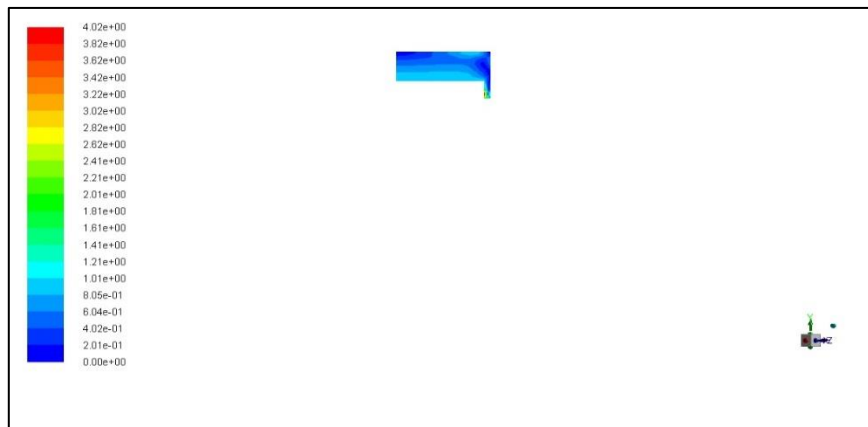


Figure 4.16: Velocity Contour at TDC at 0.5 Moles Per 1 Mole of Diesel.

The velocity of the fuel inside an internal combustion engine is not immediately impacted by the addition of nitrogen concentrations to the intake air. The design of the fuel injection system and the engine's operating circumstances, such as engine speed, throttle position, and load, are the main determinants of the fuel velocity in an internal combustion engine. Delivering gasoline to the combustion chamber is the responsibility of the fuel injection system. The velocity of the fuel spray is largely determined by the fuel injector's design, which includes the injector nozzle and its operating circumstances (such as fuel pressure and injection time). The settings of these components are unaffected by the addition of nitrogen to the intake air. It is essential to guarantee fuel atomization, or the dissolving of liquid fuel into tiny droplets, in order to accomplish effective combustion. The fuel injector's design significantly influences fuel atomization, while the nitrogen concentration in the intake air has minimal immediate impact. The air-to-fuel ratio, spark timing, and combustion chamber turbulence are just a few of the variables that can have an impact on the combustion process. Nitrogen does not directly affect the fuel's velocity during combustion, despite the possibility that it might help control combustion's temperature. Nitrogen's main function in the combustion process is to reduce emissions, particularly nitrogen oxide (NO_x) emissions. By using nitrogen as an inert gas that helps to absorb heat and effectively lower the peak combustion temperatures, it is possible to reduce NO_x emissions. It's crucial to remember that this subject is not immediately tied to the fuel's velocity. Increasing the nitrogen content in the intake air of an internal combustion engine can have considerable implications on emissions control and combustion temperature, The velocity of fuel within the engine is not directly affected by this. The layout and functionality of the fuel injection system, along with the engine's operating circumstances, influence the fuel velocity. Instead of changing the intake air's makeup, any changes to fuel velocity are normally addressed through modifications to the fuel injection system itself.

Figures from 4.17 to 4.19 show the particle traces at TDC for: 4.17, 0.1 moles per 1 mole of diesel, 4.18, 0.3 moles per 1 mole of diesel, and 4.19, 0.5 moles per 1 mole of diesel.

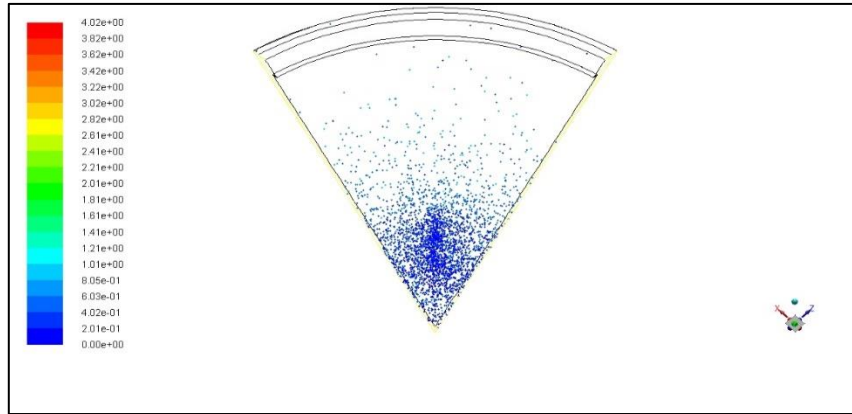


Figure 4.17: Particle Traces at TDC at 0.1 Moles Per 1 Mole of Diesel.

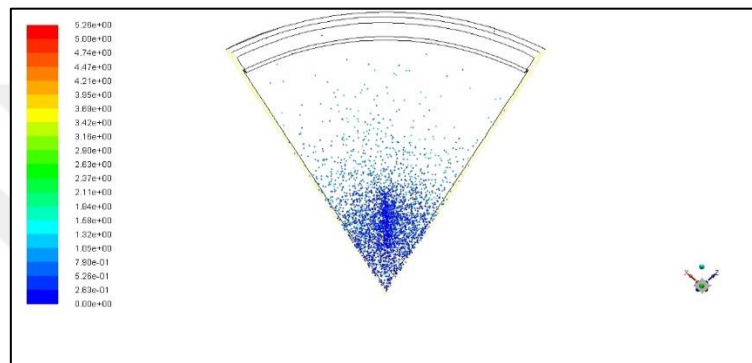


Figure 4.18: Particle Traces at TDC at 0.3 Moles Per 1 Mole of Diesel.

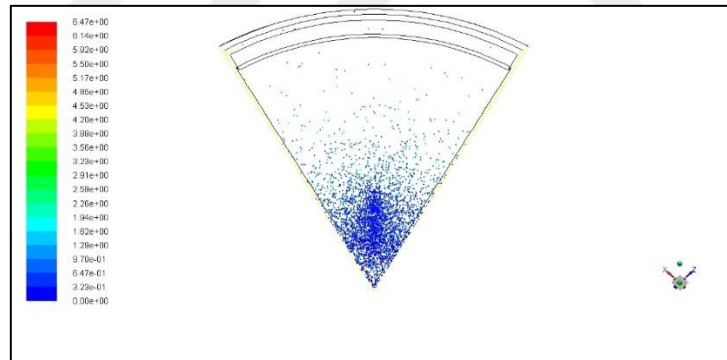


Figure 4.19: Particle Traces at TDC at 0.5 Moles Per 1 Mole of Diesel.

Adding nitrogen concentrations to an internal combustion engine's intake air can have a number of effects on engine pressure, however these effects mostly relate to the combustion process and emissions control rather than having a direct bearing on engine pressure. The addition of nitrogen to the intake air often relates to adjustments targeted at emissions control or combustion optimization because nitrogen is already a large component of the air in the atmosphere. Nitrogen, an inert gas, can operate as a heat sink to help control combustion pressure when added to intake air. Peak combustion temperatures and pressures are constrained by the nitrogen's ability to absorb part of the heat produced during combustion.

This can assist prevent pressure spikes in engines, especially in high-performance engines, and it can also lessen the production of dangerous nitrogen oxides (NO_x). Controlling emissions, especially NO_x emissions, is one of the main justifications for increasing nitrogen concentrations in intake air. Nitrogen can lessen the creation of NO_x, a significant air pollutant, by lowering the peak combustion temperatures and pressures. Compliance with environmental laws and emission reduction plans depends on this outcome. Nitrogen can also aid in reducing knock (premature combustion) and detonation in an engine. Nitrogen can improve an engine's resistance to knocking and decrease the possibility of damaging pressure spikes by lowering peak pressure and temperature. During the combustion process, the levels of nitrogen in the intake air may have an impact on the pressure profiles within the engine cylinder. The performance and longevity of the engine may benefit from a smoother, more controlled pressure rise during combustion as a result. Nitrogen addition primarily influences combustion pressure, but it also has an indirect effect on total engine efficiency. Controlling combustion pressures and temperatures can boost engine efficiency and power output, while nitrogen dilution in intake air can affect fuel-air mixture density. Peak pressures during combustion may be lower with a less dense mixture. In engines where precise power production and peak pressure management are essential, this impact is particularly significant.

Figure 4.20 shows the pressure gradient with time during the different crankshaft rotation stages with different nitrogen concentrations, as it is noted that the pressure value increases with decreasing the amount of nitrogen gas, and thus decreasing the temperature.

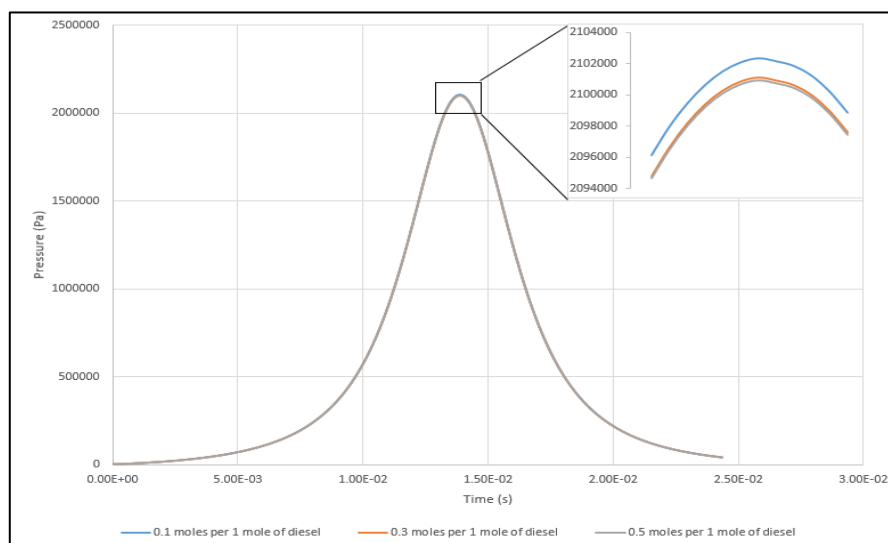


Figure 4.20: Pressure Gradient with Time at Different Nitrogen Concentrations.

4.4 THE EFFECT OF DIESEL FLOW RATE ON IC ENGINE

The rate at which diesel fuel is injected into an internal combustion engine (IC engine) can affect the engine temperature in a number of ways, most of which are connected to the combustion process and heat management. Diesel flow rate affects engine temperature, fuel intake, and combustion chamber rate, depending on engine design, load, and operating conditions. Peak combustion temperatures may increase as a result of increased fuel combustion due to higher flow rates. The combustion chamber and nearby components' temperatures may rise as a result of elevated combustion temperatures. The temperature of the combustion gases inside the cylinder might rise as more diesel fuel is poured into it. This may have an impact on the cylinder's temperature, which may then have an effect on the temperatures of nearby engine parts including the piston, cylinder head, and cylinder walls. The temperature of the exhaust gases leaving the engine can be impacted by the flow rate of diesel fuel. In general, a higher diesel flow rate causes more heat to be produced during combustion, raising the temperature of the exhaust gases. The performance of turbochargers and exhaust systems may be affected by this. In order to avoid overheating, the heat produced by the combustion process must be controlled. Higher diesel flow rates can make the engine produce more heat, which puts more strain on the cooling system. To keep the engine's temperature within a safe limit, the cooling system must effectively dissipate this extra heat.

Figure 4.9 illustrates how altering the mass flow rate affects the temperature readings at the combustion zone, or TDC. The figure indicates that as the mass flow rate increases, the temperature value lowers. The combustion chamber's temperature was 945 K at a mass flow rate of 0.00015 kg/s and 868 K at a mass flow rate of 0.00025 kg/s.

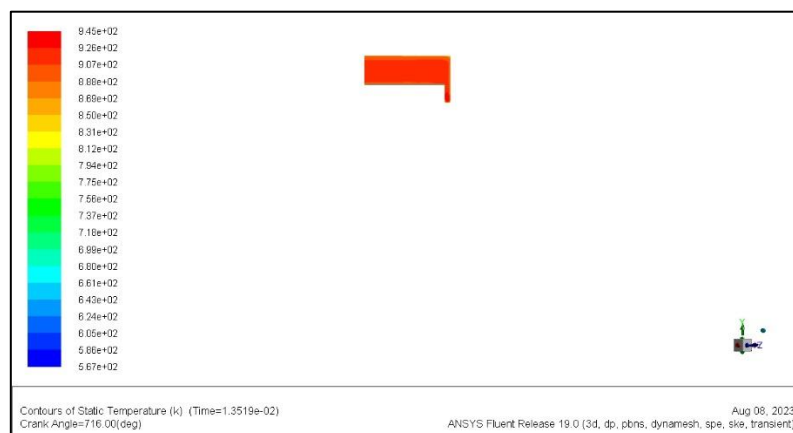


Figure 4.21: Temperature Contour at TDC: (a) Mass Flow Rate 0.00015 kg/s.

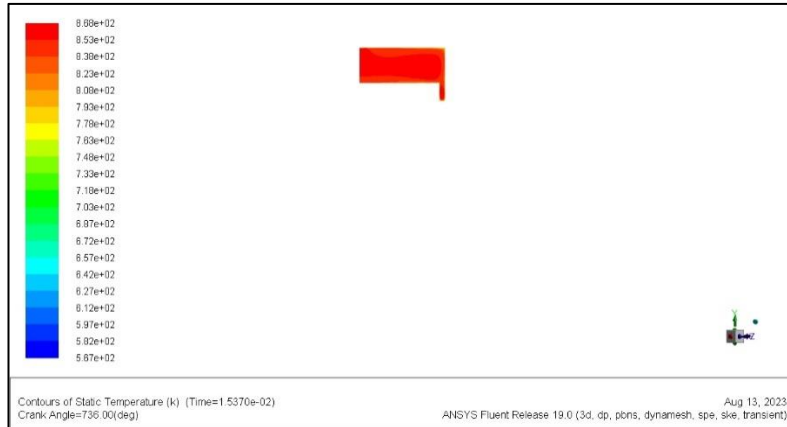


Figure 4.22: Temperature Contour at TDC at Mass Flow Rate 0.00025 kg/s.

The mixture's flow velocity entering the combustion chamber is shown in Figures 4.23 and 4.24, where it can be seen that the mass flow rate of the mixture causes the mixture's velocity to rise. When the mass flow rate was 0.00015 kg/s, the mixture flow velocity was 7.96 m/s; when it was 0.00025 kg/s, it was 7.85 m/s.

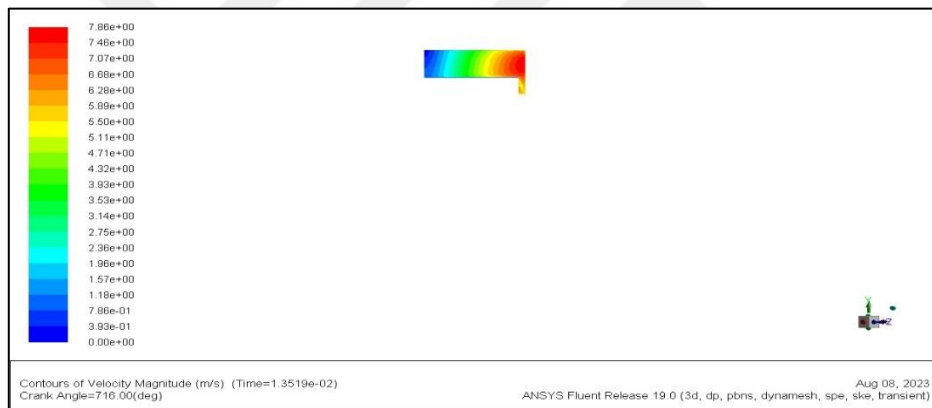


Figure 4.23: Velocity Contour at TDC at Mass Flow Rate 0.00015 kg/s.

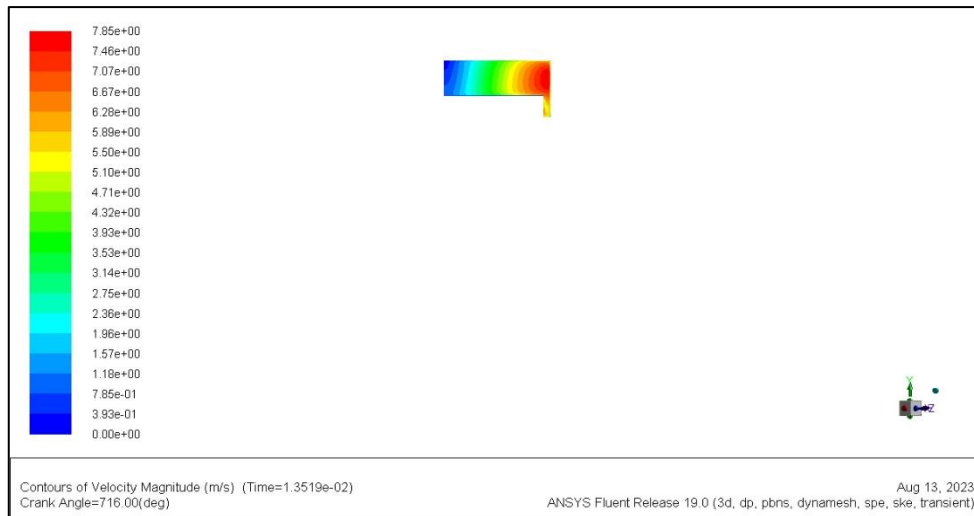


Figure 4.24: Velocity Contour at TDC at Mass Flow Rate 0.00025 kg/s.

The flow rate of diesel fuel into an internal combustion engine (IC engine) does not directly affect the speed of the fuel once it reaches the combustion chamber, but it may affect the fuel's velocity inside the engine's fuel injection system. The fuel velocity within the combustion chamber is mostly determined by the design of the fuel injection system and the specific injection settings. The fuel injection system of an internal combustion engine is composed of many components, such as the fuel pump, fuel injectors, and fuel lines. The control of fuel velocity is greatly influenced by the design of these parts. Larger fuel injectors and fuel lines are often needed for higher diesel flow rates to accommodate the extra fuel. The fuel velocity is significantly influenced by the size and design of the fuel injector nozzle. Higher flow rates can be handled by larger injectors and nozzles, but they may have an impact on the speed at which the fuel is poured into the combustion chamber. Higher fuel velocities produced by smaller nozzles can result in better fuel atomization and higher combustion efficiencies. The timing of the fuel injection has a big impact on the fuel velocity within the combustion chamber. The engine's control system decides how much fuel is injected and how long the injection event lasts. To achieve the desired properties of the air-fuel mixture and combustion efficiency, proper injection time is crucial. Fuel delivery and air combination may be influenced by the geometry of the combustion chamber, which includes the piston bowl shape and injector location. For a specific diesel flow rate, engineers build combustion chambers to maximize fuel-air mixing and combustion efficiency.

The article traces at TDC for the following mass flow rates: 0.00015 kg/s and 0.00025 kg/s, as shown in figures 4.25 to 4.26.

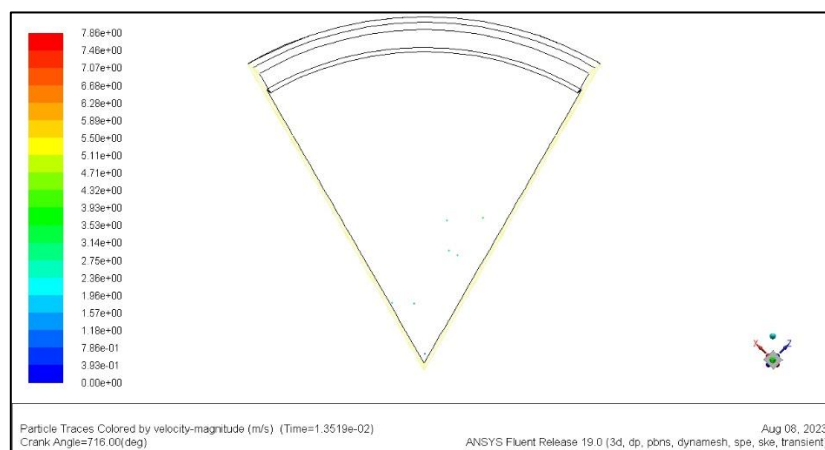


Figure 4.25: Particle Traces at TDC at Mass Flow Rate 0.00015 kg/s

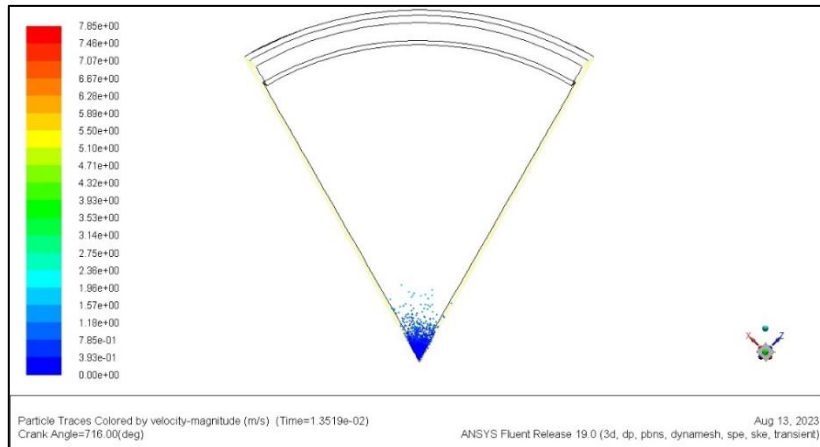


Figure 4.26: Particle Traces at TDC at Mass Flow Rate 0.00025 kg/s.

The rate at which diesel fuel is fed into an internal combustion engine may have a significant influence on engine pressure, especially within the combustion chamber (IC engine). The combustion process is directly impacted by the diesel flow rate, which in turn affects cylinder pressure. One of the key variables influencing the rate and intensity of combustion in the engine is diesel flow rate. The rate at which diesel fuel is fed into an internal combustion engine may have a significant influence on engine pressure, especially within the combustion chamber (IC engine). The rate and efficiency of combustion have a direct impact on the peak cylinder pressure. Greater peak cylinder pressures may come from more fuel being available for burning as a result of a greater diesel flow rate. This may have a direct effect on the output of power and torque from an engine. The exothermic nature of diesel fuel burning results in pressure and temperature rise. More fuel is burnt per cycle with a higher diesel flow rate, which can cause the temperature and pressure to rise more noticeably. Combustion pressures that are elevated might put more mechanical strain on engine parts. The diesel flow rate has an impact on the production of particulate matter (PM) and nitrogen oxides (NO_x) during combustion. Higher combustion pressures and temperatures from higher diesel flow rates may result in higher NO_x emissions. In order to control these pressures and temperatures and adhere to regulatory standards, effective emissions control systems are required. Engine efficiency is influenced by the diesel flow rate. While larger fuel flow rates might result in more power being produced, they can also result in less thermal efficiency if air intake and combustion parameters are not correctly matched. To maximize performance and fuel efficiency, it is important to properly manage the link between diesel flow rate, pressure, and engine efficiency. The uncontrolled, early igniting of the air-fuel mixture, also known as detonation or knock, can be made more likely by excessive diesel flow rates. If

knock is not regulated, it can result in high cylinder pressures and temperatures, which may harm an engine. During the combustion cycle of an engine, the rate at which diesel fuel is injected and consumed can affect the pressure profiles within the cylinder. Smoother pressure curves and improved peak pressure management may arise from accurate calibration and control of diesel flow rates.

Figure 4.27 shows the pressure gradient with time during the different phases of crankshaft rotation with the difference in mass flow rate, as it is seen that the pressure value rises as the mixture's mass flow rate increases.

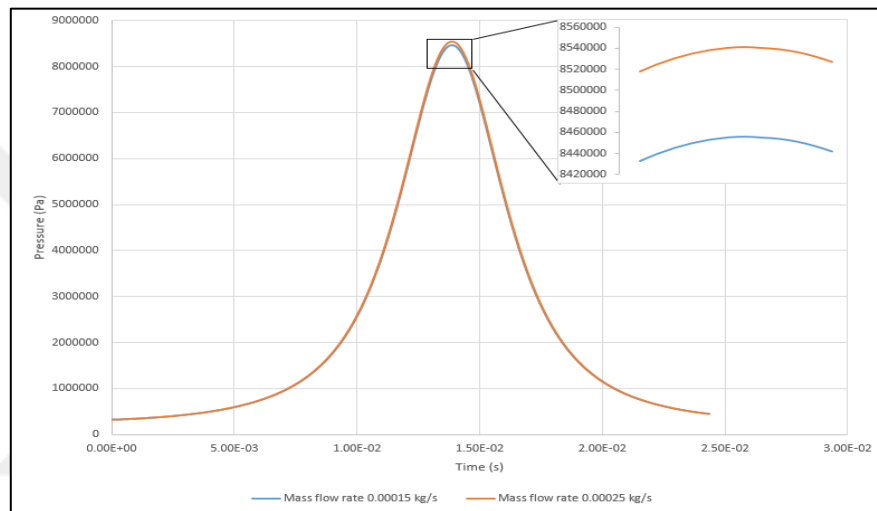


Figure 4.27: Pressure Gradient with Time at Different Mass Flow Rate.

4.5 THE EFFECT OF ENGINE ROTATIONAL SPEED ON CRANKSHAFT

The crankshaft deformation is shown in Figures 4.28 to 4.30 in relation to the engine's varying rotational speed. It seems as if the distortion increases as internal combustion chamber pressure lowers. As it was at a speed of 1800 RPM, the deformation value was 6.306 mm, at 2200 RPM it was 6.299 mm, and at 2600 RPM it was 6.294 mm.

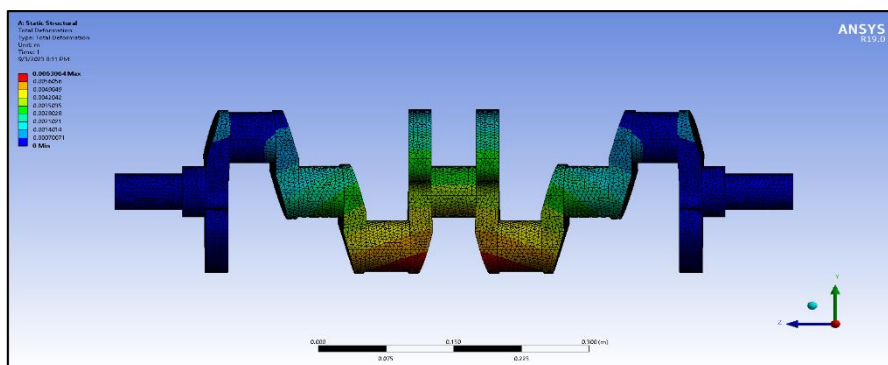


Figure 4.28: Deformation Contour at TDC at 1800 RPM

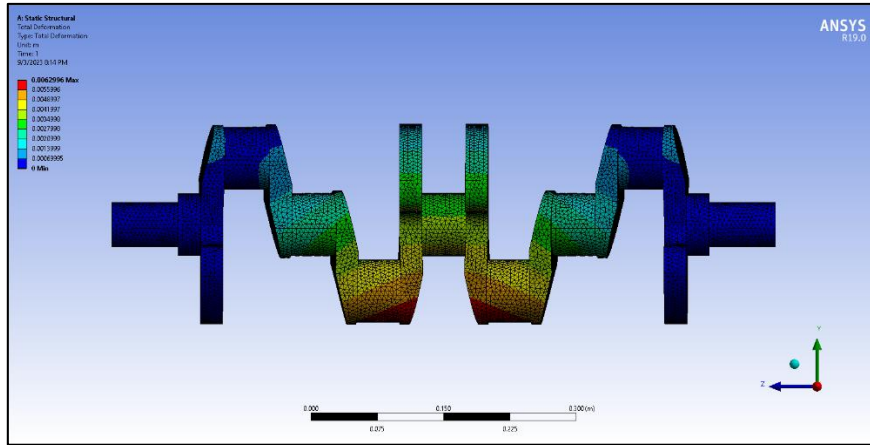


Figure 4.29: Deformation Contour at TDC at 2200 RPM.

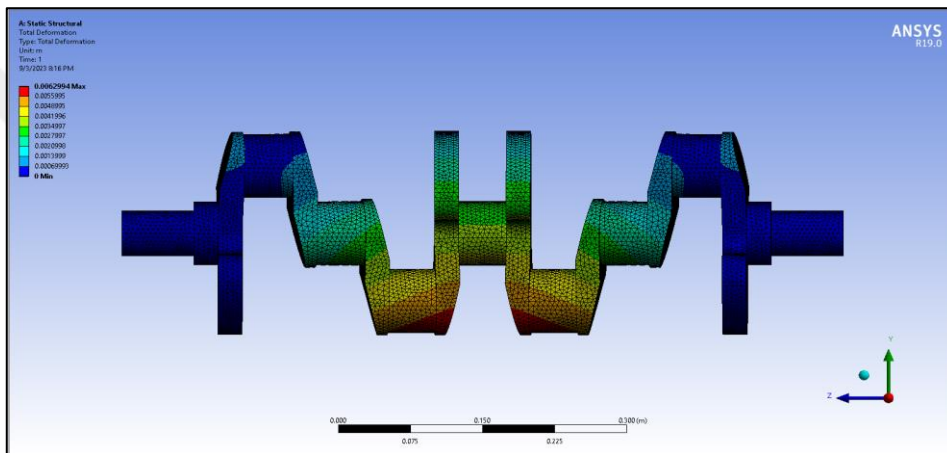


Figure 4.30: Deformation Contour at TDC at 2600 RPM.

Figure 4.31 to 4.33 shows the stress on the crankshaft with the difference in engine rotational speed, as if the amount of pressure decreases in the internal combustion chamber and thus the stress becomes greater, as at 1800 RPM the deformation value was 1.451 GPa and at 2200 RPM it was 1.449 GPa and at 2600 RPM it was 1.449 GPa.

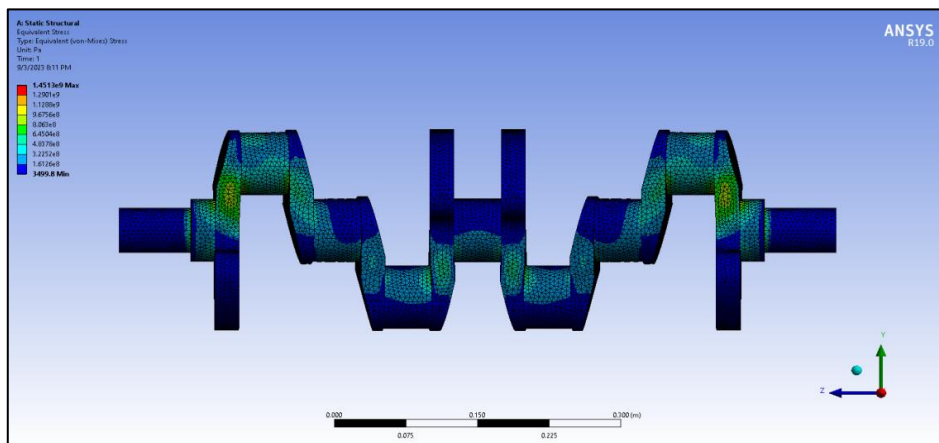


Figure 4.31: Stress Contour at TDC at 1800 RPM.

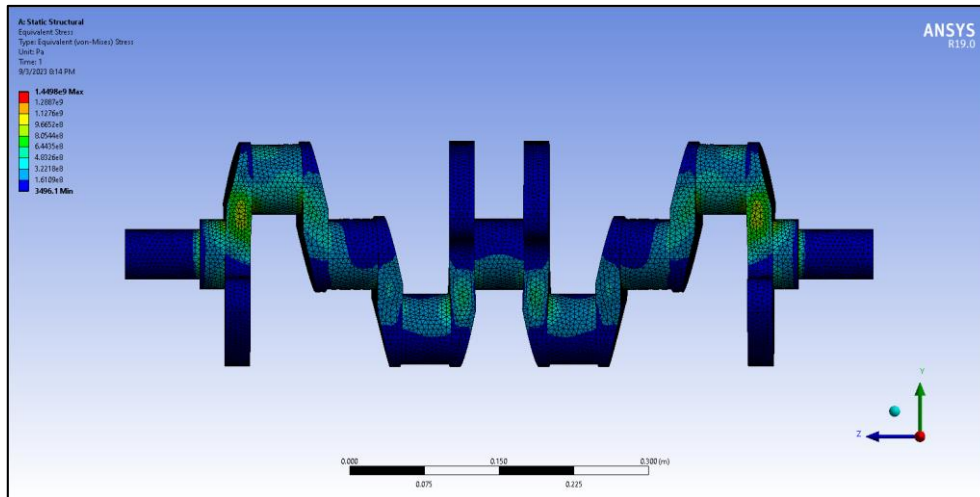


Figure 4.32: Stress Contour at TDC at 2200 RPM.

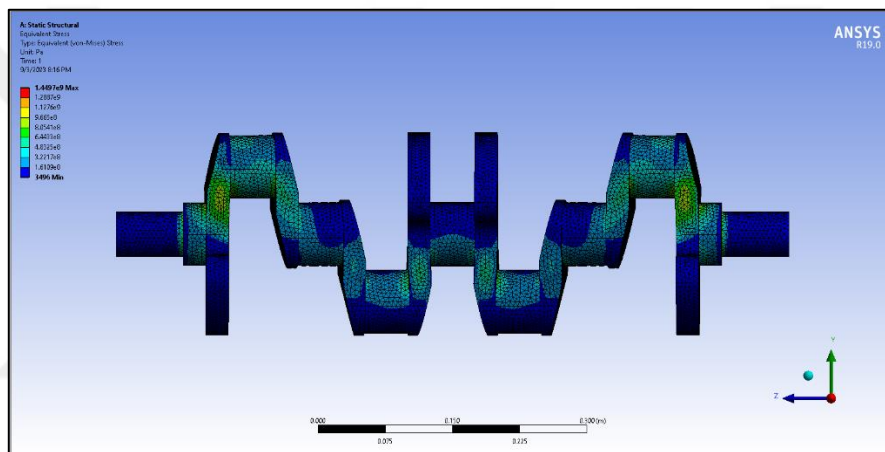


Figure 4.33: Stress Contour at TDC at 2600 RPM.

4.6 THE EFFECT OF ADDING NITROGEN CONCENTRATIONS ON CRANKSHAFT

Figure 4.34 to 4.36 show the deformation of the crankshaft with the difference in nitrogen gas concentrations, as if the amount of pressure decreases in the internal combustion chamber and thus the deformation becomes larger. As it was at 0.1 moles per 1 mole of diesel, the deformation value was 1.568 mm, and at 0.3 moles per 1 mole of diesel was 1.567 mm, and at 0.5 moles per 1 mole of diesel it was 1.5669 mm.

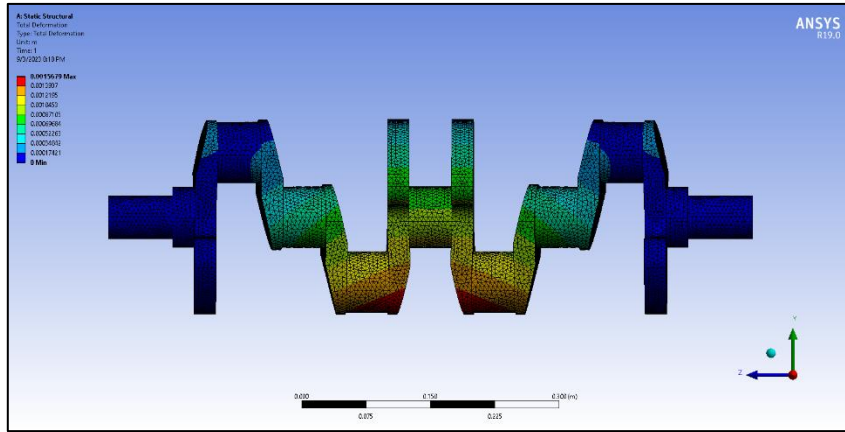


Figure 4.34: Deformation Contour at TDC at 0.1 Moles Per 1 Mole of Diesel.

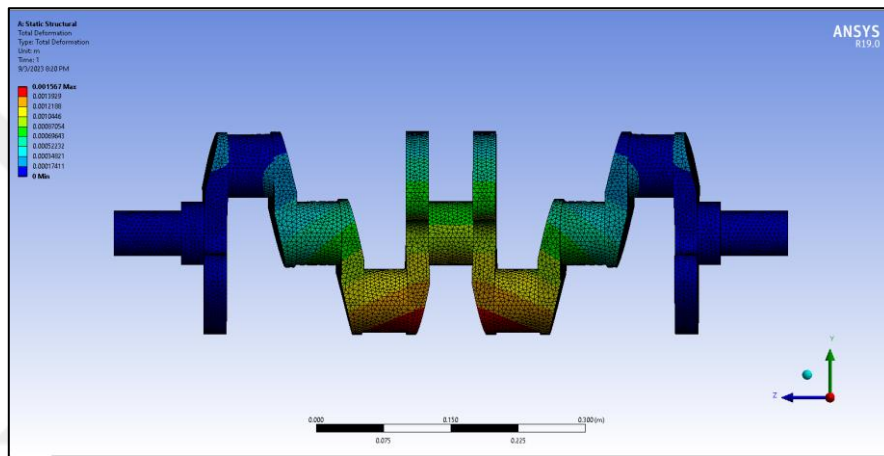


Figure 4.35: Deformation Contour at TDC at 0.3 Moles Per 1 Mole of Diesel.

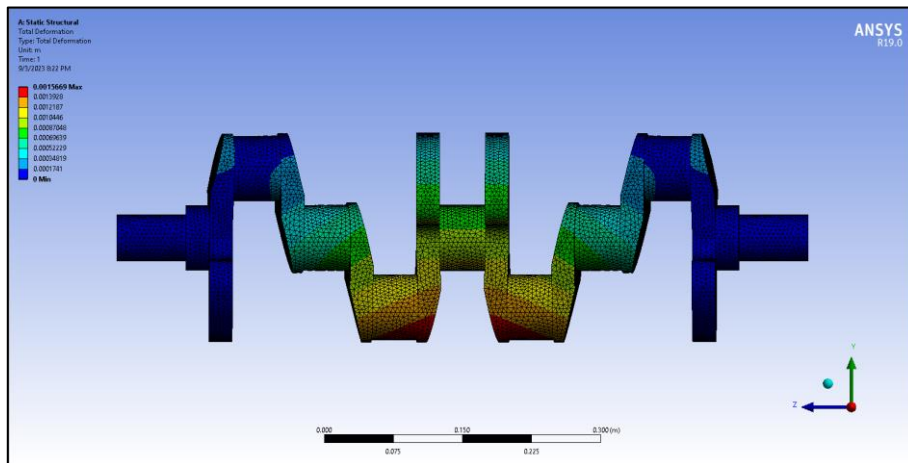


Figure 4.36: Deformation Contour at TDC at 0.5 Moles Per 1 Mole of Diesel.

Figures 4.37 to 4.39 show the pressure on the crankshaft with the difference in nitrogen gas concentrations, as if the amount of pressure decreases in the internal combustion chamber and thus the pressure becomes greater, as at 0.1 moles per 1 mole of diesel the deformation

value was 0.3608 GPa and at 0.3 moles per 1 mole of diesel was 0.36062 GPa and at 0.5 moles per 1 mole of diesel it was 0.36060 GPa.

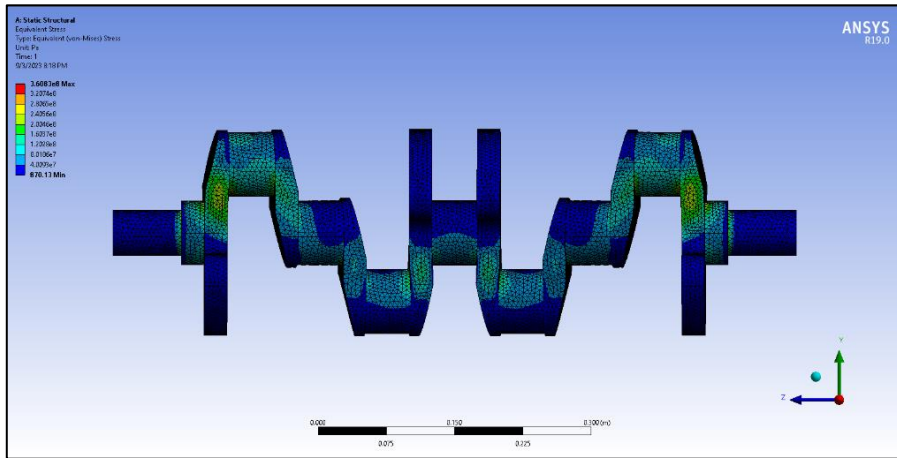


Figure 4.37: Stress Contour at TDC at 0.1 Moles Per 1 Mole of Diesel.

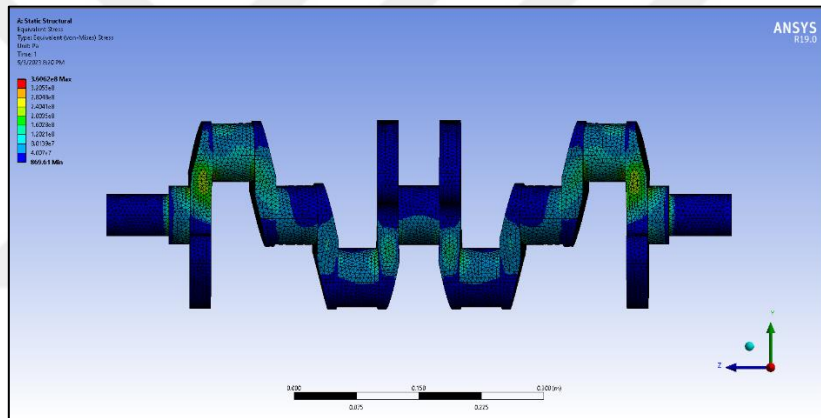


Figure 4.38: Stress Contour at TDC at 0.3 Moles Per 1 Mole of Diesel.

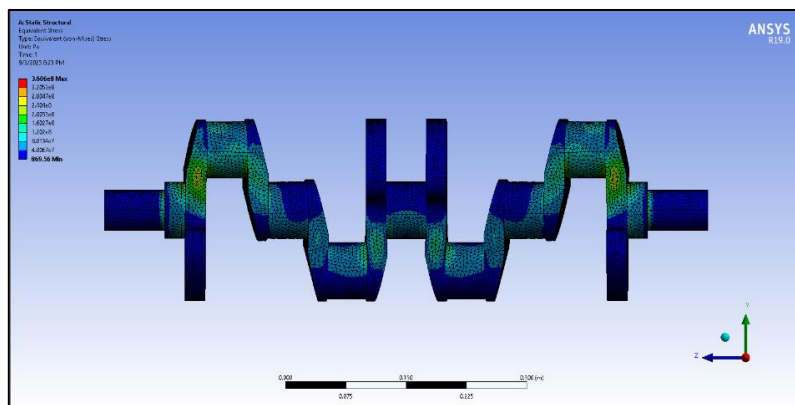


Figure 4.39: Stress Contour at TDC at 0.5 Moles Per 1 Mole of Diesel.

4.7 THE EFFECT OF DIESEL FLOW RATE ON CRANKSHAFT

The crankshaft deformation is shown in Figures 4.40 and 4.41 in relation to the mass flow rate differential. As the pressure inside the internal combustion chamber lowers, the deformation increases. The value of the deformation was 6.3064 mm at the mass flow rate of 0.00015 kg/s and 6.3701 mm at the mass flow rate of 0.00025 kg/s.

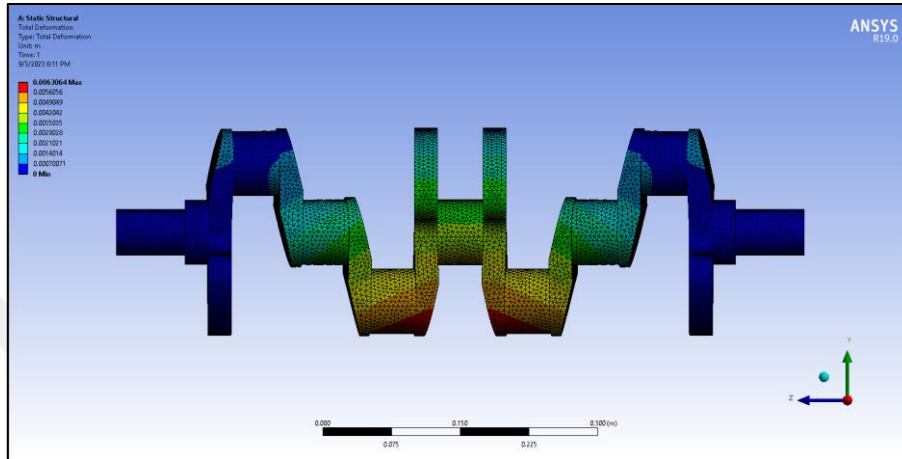


Figure 4.40: Deformation Contour at TDC at Mass Flow Rate 0.00015 kg/s.

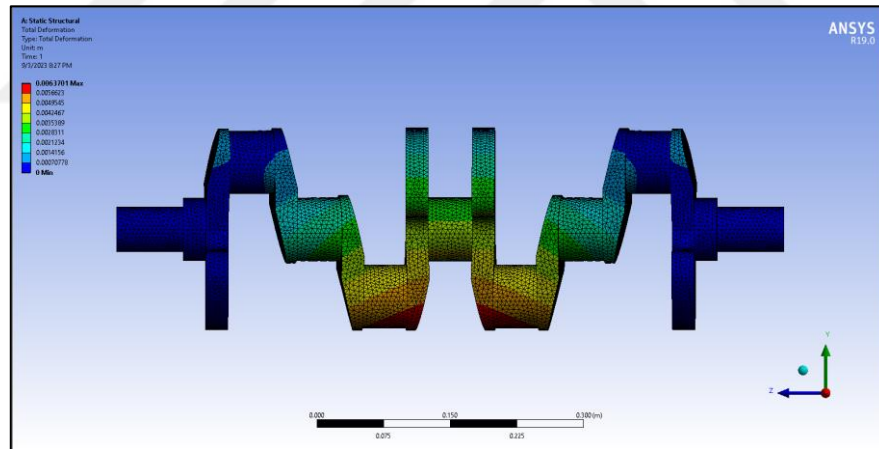


Figure 4.41: Deformation Sontour at TDC at Mass Flow Rate 0.00025 kg/s.

Figures 4.42 and 4.43 depict the pressure on the crankshaft as a function of mass flow rate. At mass flow rates of 0.00015 kg/s and 0.00025 kg/s, respectively, the deformation value is 1.4513 GPa and 1.4666 GPa. As the pressure inside the internal combustion chamber decreases, the pressure increases.

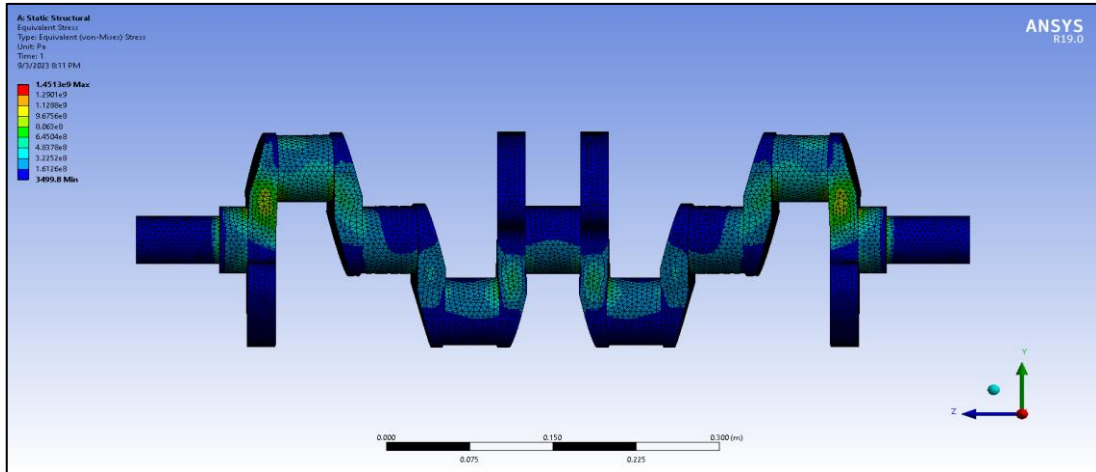


Figure 4.42: Stress Contour at TDC at Mass Flow Rate 0.00015 kg/s.

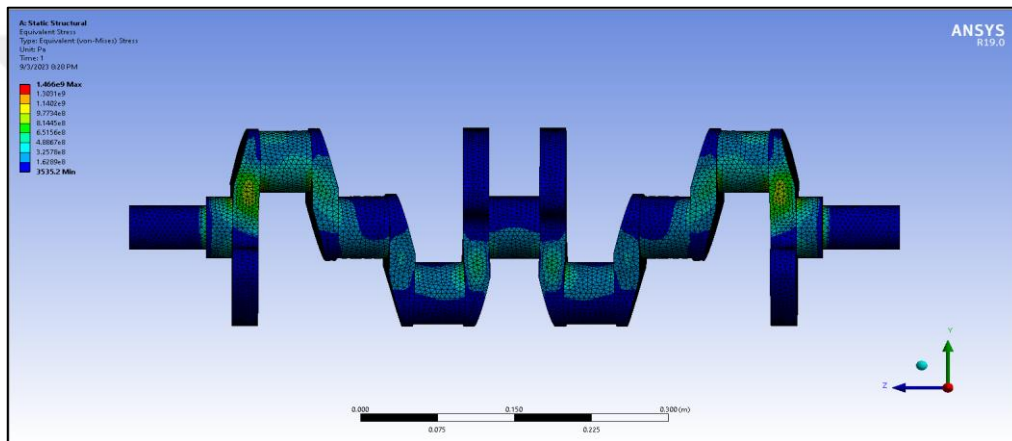


Figure 4.43: Stress Contour at TDC at Mass Flow Rate 0.00025 kg/s.

4.8 THE TORQUE OF CRANKSHAFT

Table 4.1 shows the torque of crankshaft. An internal combustion engine's (IC) crankshaft torque is not directly affected by nitrogen concentrations, as nitrogen makes up 78% of the air we breathe. Nitrogen, which makes up 78% of the atmosphere, is present in the intake air and is not significantly affected by changes in nitrogen content that fall within the typical range of ambient air composition. The primary mechanism by which engines generate torque is through the combustion process, namely the combustion of a mixture of fuel and air. The presence of nitrogen has the potential to influence emissions control, hence indirectly affecting engine performance through its impact on the production of nitrogen oxides (NO_x). Engine designers and manufacturers employ a range of technologies and strategies to effectively control nitrogen oxide (NO_x) emissions while simultaneously optimizing engine torque. Nitrogen can also serve as a preventive measure against engine knock, hence indirectly influencing engine torque through its heat absorption capabilities during

combustion and inert gas properties. In brief, the introduction of nitrogen concentrations into the intake air does not have an immediate impact on engine torque within the typical range of atmospheric composition. The combustion of the air-fuel combination determines engine torque, and any changes to torque are typically made by adjusting fuel delivery, ignition timing, and other engine characteristics, rather than adjusting the nitrogen content of the intake air. The torque produced by an engine's crankshaft is significantly impacted by diesel flow rate in an internal combustion engine (IC engine). Torque is produced by the combustion process being influenced by the quantity of diesel fuel injected into the engine. The combustion process is stronger and more vigorous, with higher fuel mass causing higher peak cylinder pressures and additional torque on the crankshaft. Diesel flow rate can influence the shape of an IC engine's torque curve, which depicts the engine's torque output over its RPM range. The load an engine is driving also impacts the torque it produces. Increased diesel flow rates can produce more torque, especially when dealing with heavy loads. However, raising the diesel flow rate can also decrease fuel efficiency if not matched with the air intake and other engine parameters. Efficient emissions control technologies are required to manage torque improvements without violating pollution rules. In conclusion, diesel flow rate directly impacts the crankshaft torque of an IC engine, with a richer air-fuel ratio resulting in increased torque output. Accurate engine calibration is essential to ensure torque improvements do not jeopardize fuel efficiency, emissions compliance, or engine durability. Engineers carefully balance these elements to improve engine performance for specific applications and operational needs.

Table 4.1: Torque of Crankshaft.

Variable	Torque of crank shaft (N.m)
RPM 1800	27893
RPM 2200	27563
RPM 2600	27163
0.1 moles per 1 mole of diesel	6934.9
0.3 moles per 1 mole of diesel	6910.8
0.5 moles per 1 mole of diesel	6830.4
Mass flow rate 0.00015 kg/s	27893
Mass flow rate 0.00025 kg/s	31856

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The results can be summarized as in the following:

- a. The velocity at which the mixture enters the combustion chamber is inversely correlated with the mass flow rate. The highest velocity is 7.96 m/s when measured at a mass flow rate of 0.00015 kg/s, however it is much lower at 7.85 m/s when the mass flow rate is 0.00025 kg/s. When the engine rotates faster, the crankshaft deforms more quickly. Observed deformation values occur at 1800, 2200, and 2600 RPM. The measured deformation values at 1800 RPM, 2200 RPM, and 2600 RPM demonstrate a positive correlation between the crankshaft's stress and engine speed. Crankshaft deformation and pressure are affected by nitrogen gas concentrations, with deformation values found at a ratio of 0.1 mole per 1 mole of diesel.
- b. This research looks at how the concentration of nitrogen gas affects the temperature values in the combustion zone, particularly at top dead center (TDC), and the velocity at which the mixture flows into the chamber. Temperature and nitrogen gas concentrations are inversely related, with higher nitrogen gas concentrations leading to lower temperatures. This action is consistent with nitrogen gas' primary ability to reduce engine temperature. With values ranging from 4.02 m/s to 6.47 m/s, the mixture flow velocity increases as nitrogen gas concentration rises. It is shown that the nitrogen gas concentration is connected to the decrease in pressure gradient seen between crankshaft rotation stages, indicating a connection between nitrogen gas concentration and temperature.
- c. The velocity at which the mixture enters the combustion chamber is inversely correlated with the mass flow rate. Specifically, for a mass flow rate of 0.00015 kg/s and 0.00025 kg/s, the flow velocities are 7.96 m/s and 7.85 m/s, respectively. Observations of 6.306 mm at 1800 rev/min show a positive correlation between the degree of crankshaft deformation and engine rotational speed (RPM).
- d. Both the engine's rotational speed and the nitrogen gas concentration have an impact on the stress on the crankshaft. The deformation value is measured as 1.449 GPa at 2200 RPM compared to 1.451 GPa at 1800 RPM. Deformation values are influenced by the amount of nitrogen gas present; for instance, 0.1 moles of nitrogen per 1 mole of diesel

results in a 1.568 mm deformation, 0.3 moles of nitrogen per 1 mole of diesel causes a 1.567 mm deformation, and 0.5 moles of nitrogen per 1 mole of diesel produces a 1.5669 mm deformation.

- e. The deformation of the crankshaft increases with mass flow rate, as internal combustion chamber pressure decreases. At mass flow rates of 0.00015 kg/s and 0.00025 kg/s, the deformation value is 6.3064 mm and 1.4513 GPa, respectively, indicating varying pressures in the internal combustion chamber.

5.2 RECOMMENDATIONS

- a. The combustion process can be improved by adding hydrogen concentrations due to its flammability.
- b. Different engine shapes and designs can be used and compared.
- c. Different types of fuel can be used to see the resulting effects through simulation results.
- d. The simulation condition can be described using different numbers, types and shapes of cylinders.

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
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