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Effect of Nano -Particles on Soot Emission from A Diesel Engine

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بسم الله الرحمن الرحيم

(و أنزل الله عليك الكتاب والحكمة

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Supervisor Certification

I certify that the this a dissertation entitled **Effect of Nano -Particles on Soot Emission from A Diesel Engine** is being carried out by **Rua'a Hassan Abd-Ali** under my supervision at the Mechanical Engineering Department, College of Engineering, University of Babylon, as a partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering (Power Engineering).

I recommend that this thesis be forwarded for examination in accordance with the regulation of the University of Babylon.

Signature

Prof. Dr. Haroun A.K. Shahad

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Data: / / 2021

Dedication

To my first teacher who gave me strength

My father.

To her who planted love in my heart

My mother.

To my dear life partner

My Husband ***Ali.***

*To the family treasure, my dear sister and brothers (**zainab, ahmed, montather**)*

With Love and Respect

Ruaa Hassan 2021

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Abstract

This study aims to investigate experimentally the effect of adding Al_2O_3 nanoparticles to pure diesel fuel on soot and unburned hydrocarbon (UHC) concentrations emitted from diesel engines at different loads and compression ratios. Nano-fuel is prepared by mixing aluminum oxide (Al_2O_3) (particle diameter < 50 nm), with diesel fuel using a mixer and the ultrasonic cleaner. The investigation was carried out on a variable compression ratio, single-cylinder, four-stroke, direct-injection diesel engine with a displacement of (553 cm^3). The engine develops 3.7 kW at 1500 rpm. Three doses of Nano-AL_2O_3 particles (25, 50 and 100 ppm) are used in preparing the Nano-diesel. It is found generally that adding Nano-particles to diesel fuel reduces the emitted soot concentration. The results show that for all types of fuel (pure diesel,diesel+AL_2O_3) the soot concentration increases with load. For pure diesel at no load and compression ratio 13.5 the soot concentration is (364 mg/m^3) under while same CR but at full load the soot concentration is (900 mg/m^3). Also for pure diesel and 13.5 CR and no load the UHC concentration is (2743 mg/m^3) while at full load the concentration is (3126 mg/m^3).

The results also shows that the addition of Nano-particles to diesel fuel reduce the concentration of soot and increase that of UHC for all dose. For example, at 100 ppm dose and full load and 13.5 CR the soot concentration is (366 mg/m^3) compare with (900 mg/m^3) for pure diesel under same conditions. The UHC concentration increases from (3126 mg/m^3) for pure diesel at full load and CR13.5 to (3663.75 mg/m^3) for Nano-diesel with 100ppm dose under same conditions.

The results also reveal that adding Nano-particles to diesel fuel reduces both soot and UHC concentrations at all compression ratios. For example, with a CR 13.5, 100 ppm dose and full load, the soot

concentration is (366 mg/m^3), but at a CR 17.5, 100 ppm dose and full load, the soot concentration is (266 mg/m^3). Under the same conditions, the UHC concentration decreased from (3663 mg/m^3) for CR 13.5 to (3354 mg/m^3) for CR17.5.

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Nomenclatures

Symbol	Meaning	Unit
N	Engine speed	rpm
V	Volume	L
k	Thermal conductivity	W/m.K
m_f	Mass flow of diesel fuel	kg
m_P	Mass of Nanoparticle	kg
T	Temperature	^oC
P	Pressure	bar

Abbreviations

Symbol	Description
CI	Compression ignition
DICI	Direct injection compression ignition
PM	Particulate matter
Bu	Butanol
B	Biodiesel
UHC	Unburned hydrocarbons
PAHs	Polycyclic aromatic hydrocarbons

BP	Palm biodiesel
CNTs	Carbon nanotubes
CeO_2	Cerium oxide
DTO30	Distilled tire oil mixes
GO	Graphen oxide
AL_2O_3	aluminum oxide
TiO_2	Titanium oxide
DF	Diesel fuel
FBC	Fuel-born catalyst
DPF	Diesel particulate filter
SSCS	Separated swirl combustion system
DSCS	Double swirl combustion system
TF	Ternary fuel
HPF	High performance fuel
CVOME	Corn vegetable oil methyl ester
EAR	Excess air ratio
CR	Compression ratio
FIP	Fuel injection pressure
B/D	Butanol/Diesel

VCR	Variable compression ratio
BTE	Breake thermal efficiency
NHR	Net heat release
AME	Annona methyl ester
HSU	Hartridge smoke unit
SFC	Specific fuel consumption
SEM	Scanning electron microscope
TEM	Transmition electron microscope

CHAPTER ONE

INTRODUCTION

Chapter One :Introduction

1.1 Introduction

Compression ignition (CI) diesel engines increasingly benefit from their intrinsically high fuel efficiency and durability in surface transportation, heavy machinery and remote power production in comparison to gasoline engines. Nevertheless, diesel engines produce substantial quantities of PM pollution, sometimes referred to as soot, that jeopardize air quality and human health in especially in metropolitan contexts. Typically, the diesel soot particles consist of aggregated primary particles, with unburned hydrocarbons absorbed on their surfaces and inorganic species. Soot particles are deadly because of the high number of poisonous compounds they carry, and because of their small size, they can penetrate deep into our lungs and even enter the bloodstream. So soot emission is one of the major draw backs of diesel engines. This draw back must be dramatically reduced for save environment air quality.

These objectives need good understanding of soot formation and oxidation process that lead to soot release. Soot formation is the result of complicated physical and chemical processes, which are the foundation of soot models. Nucleation of gas phase precursors results in the formation of incipient solid soot particles [1]. As a result, surface reactions occur, resulting in growth or oxidation of the soot particles. Over the soot particles, the gas phase species condense as well. These particles coagulate with each other over time, generating bigger particles. It's crucial to have accurate kinetic models in order to forecast the gas phase species involved in all of the processes that contribute to soot formation [2]

PAHs (Polycyclic Aromatic Hydrocarbons) are widely acknowledged gas phase species for soot precursors, acetylene for surface development, and O_2 and OH for oxidation. Inception, condensation, and coagulation are all physical processes that include collisions, such as (1) gas phase precursors colliding for inception, (2) gas phase precursors colliding with a soot particle for condensation, and (3) two soot particles colliding for coagulation. Fuel vapor, acetylene, and higher PAH compounds have all been utilized as precursors in soot models over the years.

1.2 Soot Release Processes

Pyrolysis, nucleation, coalescence, surface growth, agglomeration, and oxidation are six frequently identified processes that transform liquid or vapor-phase hydrocarbons into solid soot particles and possibly back to gas-phase products. The soot production process is depicted schematically in fig(1-1) as a series of the first five processes, whereas oxidation, the sixth phase, changes hydrocarbons to CO, CO_2, and H_2O at any point in the process. These process are describing briefly in the following paragraphs.

1.2.1 Soot Formation Fundamentals

Soot formation is a complex process that involves an evolution of molecular weight or size in which a huge number of molecules undergo numerous chemical and physical interactions[3] .Despite a large number of studies on the mechanism of soot production in the literature, the process remains a mystery. A number of questions about the chemistry of soot generation remain unanswered and contested, while some are broadly accepted, such as [4]:

- Soot formation initiates with some precursors.
- Nucleation of heavy molecules forms particles.
- Surface growth of a particle facilitated by adsorption of gas phase molecules.
- Reactive particle-particle collisions lead to coagulation.

- Surface oxidation of the molecules and soot particles reduces the soot mass.

On a molecular level, the combination of light HCs (acetylene) produces big aromatic rings. Furthermore, initial soot particles are thought to develop as a result of either mass surface growth or coalescence of larger aromatic molecules. D. R. Tree et al, [1] described the soot generation process in five steps, see fig (1-1), with acetylene and PAH molecules assisting in the creation of precursor molecules (initial step). The following steps are nucleation, mass expansion, coagulation, and agglomeration. The breakdown of HC fuel results in tiny HC radical forms, [1] soot formation mechanism. These tiny HC radicals are later incorporated to the formation of unsaturated HCs after they have accumulated a sufficient number of carbon atoms in their structure. Acetylene is a key player in the development of bigger aromatic rings among these HCs. The production of primary soot particles is caused by the coagulation of the bigger aromatic rings. These basic soot particles coalesce fast, taking up gas-phase molecules for surface development at the same time [5] .

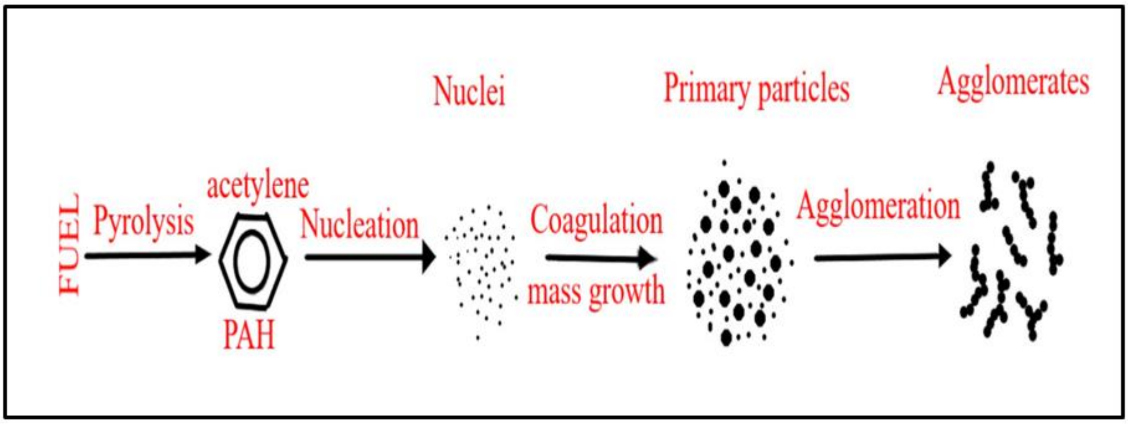

Figure (1- 1) Soot formation steps [3].

1.2.2 Pyrolysis

Pyrolysis is a process in which hydrocarbons undergo extensive breakdown and atomic realignment of fuel molecules prior to the creation of soot. There is generally insufficient oxygen delivery throughout the pyrolysis process. These reactions are endothermic in nature, which explains why they are so temperature sensitive. Fuel pyrolysis allows for the creation of soot precursors. The pace of pyrolysis and oxidation depends on the type of flame created. Because there is enough oxygen in premixed flames, less soot is created [6].

1.2.3 Formation of Precursors of Soot

Precursors are the molecules responsible for the initiation of soot production and growth. Diesel combustion produces precursors, which are then used to create soot particles via the Soot inception mechanism. Because newly generated soot particles are so minute (about 1.5 nm), it's difficult to comprehend how they develop, making experimental investigation challenging [4]. Acetylene is a significant precursor because it is involved in the creation of C3 and C4 HCs, which leads to the formation of the first aromatic ring [3]. The accumulation of C_2H_2 molecules culminates in the production of initial aromatic rings, which act as soot precursors. Because of the limited synthesis of some intermediary molecules through acetylene and the complexity of experimental research, PAHs molecules are considerably more commonly used as soot precursors than acetylene. The relative contribution of different types of PAH molecule development processes appears to be mostly a function of the type of fuel employed.

1.2.4 Particle Nucleation or Inception (Coalescence)

The creation of soot particles from heavy PAH species spans the transition from gaseous to solid-phase heavy molecules in a combustion process, resulting in the formation of juvenile soot with an atomic mass of about 2000 atomic mass unit (amu) and an effective diameter of about 1.5 nm [4] .

1.2.5 Surface Growth

The accretion of gaseous molecules such as acetylene and PAH species, particularly PAH radicles, causes the bulk development of young soot particles. There is no identifiable transition phase between the end of nucleation and the beginning of mass expansion (surface growth**)**. Rather, the two processes proceed concurrently. The surface reactions of nascent soot particles with gas-phase species are mediated by the "hydrogen – abstraction – C_2H_2 – addition" (HACA) mechanism [7]. The soot surface property is a key element in the HACA development process. C–H bonds on the soot particle's surface interact with H and OH radicals to produce reactive sites where gas-phase species (mostly acetylene) can be added to the soot particle's surface, resulting in soot surface development [8] .

1.2.6 Particles Coagulation (Agglomeration)

During the mass growth process, particles collide and stick together. During collisions, there is a significant increase in particle size and a drop in particle number, although the total mass of soot is unchanged [9] . The gaseous species continue to accrete by agglomeration following the early production of coagulated particles via sticking impacts, partially masking the identity of spherical initial particulate units, as observed in SEM micrographs of soot particles, where they form long chain-like formations.

1.2.7 Oxidation Process

Some solid soot particles and soot Precursors are oxidized into gaseous products such as CO and CO_2 mostly through surface oxidation, resulting in a reduction in soot mass. Unlike the preceding steps, which occur during a specific step, surface oxidation is a continuous process that happens during and even after soot formation. The rate of surface oxidation, like the rate of surface growth, is determined by the surface area of the soot particles. O, O_2, and OH are the oxidizing species under fuel-rich conditions, but in lean conditions, H_2O, CO_2, NO, N_2O, and NO_2 are all possible oxidizing species [3].

1.3 Soot Reduction Technique by Nano-Particles Addition

One of the most important and new subjects in internal combustion engines is nanotechnology. Nanotechnologies in ICE have numerous applications, including Nano-fluids, Nano-composites, Nano-rubbers, Nano-materials, Nano-fuel, and so on. Furthermore, the combustion properties of particular Nano-particles make them appropriate for use as Nano-fuel additives. Nano-fuel technology is used in this study.

Several studies found that adding Nano-particles to diesel fuel or diesel-water emulsions improves engine performance and reduces pollutants. These studies also demonstrated that such addition improves the cetane number and heating value of fuel, hence increasing combustion efficiency. Some fuel properties, including density, viscosity, and flash point temperature, are improved as a result of this addition. The addition of Nano-materials to fuel reduces the ignition delay, boosts combustion speed, and enhances heat release rate due to the high cylinder pressure limit. Furthermore, diesel-added Nano-particles can have high flash temperatures, resulting in a significant improvement in fuel storage and transport. They also minimize cloud point heat and improve beginning operation in cold weather circumstances, raise the surface area-to-size ratio, and improve radiation/mass transfer characteristics, resulting in better and faster ignition [10].

1.4 Layout of Dissertation

This dissertation is divided into five chapters:

1) The first chapter states the research problem and the technique used to solve it.
2) The second chapter provides a comprehensive and thorough review of the literature related to the research problem.
3) The experimental rig construction and measuring instruments are described in the third chapter.
4) In chapter four, the study's findings are presented and debated.
5) The fifth chapter summarizes the conclusions and recommendations.

1.5 Objective

The aim of the present work is to investigate the influence of the addition of Nano-particles to diesel fuel on soot release, UHC concentrations and soot morphology in the exhaust gases of a diesel engine.

Aluminum Oxide will be used for this pupose mixed with diesel fuel in a single cylinder, four stroke, water cooled variable compression ratio diesel engine.

A special soot collecting filter will used. This filter is made of glass and packed with cotton.

CHAPTER TWO

LITERATURE REVIEWS

Chapter Two: Literature Reviews

2.1 Introduction

Diesel soot is one of the main environmental pollutants. It is fine particulates generated during the pyrolysis, or the combustion of diesel fuel at high temperatures. Reducing emissions of exhaust from such engines will reduce air pollution dramatically. The addition of nanomaterials contributes to the reduction of soot in exhaust emissions.

2.2 Experimental Studies of Soot Concentration and Morphology

D. K. Srivastava et al.,(2011) [11] studied the concentration and size distributions of soot particles emitted by a naturally aspirated, water-cooled, single-cylinder, diesel-powered direct injection compression ignition (DICI) engine. The tests were carried out at a constant engine speed (1500 rpm) and with variable engine load. The bulk and size distribution of soot particles varies greatly depending on engine load. With increased engine load, the width of the generated particle size distribution widens. The process of soot generation and release in diesel engines is heavily impacted by the localized temperature distribution and fuel/air ratio, both of which vary substantially throughout the combustion chamber. The rate of soot generation and emission is affected by temperature and fuel/air ratio changes. In the fuel-rich spray zones, the rate of soot creation exceeds the rate of soot oxidation, resulting in the formation of new soot, whereas in the lean zones, the rate of oxidation exceeds the rate of formation, resulting in a reduction in soot concentration in these zones.

P. Verma et al., (2018) [12] performed the shape and nanostructure properties of soot particles utilizing three distinct fuels with varied oxygen concentration, namely D100, Bu20, and Bu30, in an experimental examination on a six-cylinder turbocharged, common rail compression ignition engine. They discovered that one of the major parameters in the morphological properties of soot particles is primary particle size. In general, main particle diameter increases as engine load increases and reduces as butanol proportion in fuel blend increases. The air-fuel ratio falls as the engine load increases, and the primary particle diameter grows. This is most likely due to higher temperatures in the combustion chamber and more fuel mass burning with less surplus oxygen. Soot is most typically found in the form of aggregates, which are made up of approximately spherical primary particles that form clusters.

P. Verma et al.,(2019) [13] investigated the morphology and nanostructure of soot particles at different engine operating modes (engine load and speed) and fuel oxygen content by the addition of n- butanol to diesel. The distribution of primary particle diameters was determined from the burning of various fuels. In general, as engine load increased, so did the size of the primary particles. As engine speed increased, the size of the primary particles dropped. A higher engine load results in a lower air fuel ratio, which causes the main particle diameter to grow. This pattern could be attributed to combustion occurring in the presence of less extra oxygen at high engine loads with increased in-cylinder temperature and pressure. Furthermore, while the engine is under heavy load, more fuel is fed into the combustion chamber and burnt during the diffusion phase of combustion. These in-cylinder conditions stimulate the nucleation and surface growth of soot particles while suppressing soot oxidation, resulting in an increase in primary particle diameter. Smaller primary particles resulting from a faster engine speed. Increasing the engine speed from 1500 to 1800 rpm at full load resulted in a 30% reduction in primary particle sizes. The decrease in particle diameter as engine speed increases could be attributed to combustion characteristic time (or combustion duration) and residence time, which is inversely proportional to engine speed. Because a faster engine has a shorter residence time for particle development, particle diameter lowers. The combustion process's diffusion phase boosts soot nucleation and surface growth, resulting in bigger sized primary particles at lower engine speeds.

J. Mei et al.,(2021)[14] carried out the detailed sooting characteristics at high equivalence ratios and low temperatures during the pyrolysis of ethylene in a flow reactor. It was found that temperature has a significant influence on the shape of soot aggregates. As the temperature drops, the particles become less fractal, and the joint becomes more visible as the primary particle size increases. Because of their poor maturity and carbonization, nascent particles easily agglomerate at lower temperatures. This can be attributed to the increased synthesis of PAHs, resulting in a faster nucleation and surface growth rate with a modest amount of oxygen. In contrast, when too much oxygen is added, the oxidation impact on soot precursors and particles takes over.

M. Salamanca et al.,(2012)[15] investigates the influence of the molecular structure of the fatty acid esters present in two neat biodiesel fuels and their blend (50% by volume) on particulate matter emission. Experiments were carried out in a four-cylinder direct injection vehicle diesel engine under carefully regulated operating conditions, so that the difference in performance and emissions was caused solely by the composition and qualities of the biodiesel fuel. Linseed biodiesel (BL100) produces more PM and unburned hydrocarbons (UHC) than Palm biodiesel (BP100) due to more unsaturated chemicals in its makeup, which favor the generation of soot precursors in the combustion zone. Linseed biodiesel contains a high concentration of linoleic and linolenic acid. As a result, it is thought that the chemical disintegration of these molecules contributes to the creation of soot precursor species to some extent.

M. Salamanca et al., (2012)[16] carried out the effect of the molecular structure of fatty acid esters found in biodiesel and their blends with diesel on the chemical properties of emitted particulate matter. The opacity index was used to calculate the amount of particulate matter emitted. When biodiesel is added to fuel, it was observed that particulate matter decreases. Transmission electron microscopy was used to approximate particle size distribution. When the concentration of unsaturated methyl esters in the fuel is low, there is a significant reduction in soot formation. This was accompanied by a decrease in the amount of aliphatic carbon in the particulate matter. This is due to an increase in the oxygen content of the fuel and the absence of aromatic and unsaturated hydrocarbon compounds in biodiesels, which promotes the reduction of soot and soot precursors. It is also discovered that the smoke opacity, which is related to particulate matter emission, was higher for diesel fuels than for biodiesel fuels. This property, however, increased with the degree of unsaturation in biodiesel fuels.

C. Sun et al,.(2019)[17] studied and investigated the injection in a light duty multi-cylinder turbo diesel engine to reduce PM. Soot emissions are reduced by 11–21% in close-coupled post injection settings, and by 28–33% in long-dwell post injection situations. Fuel from the post injection interacts with the primary injection fuel, as evidenced by the variation in soot reactivity. Furthermore, as injection dwell and post injection size grow, soot surface oxygen and amorphous carbon content rise. The size of primary soot particles and particle aggregates does not change greatly after injection. Post-injection soot reveals shrinking-core-type oxidation without graphene layer rearrangement.

2.3 Effect of Nano- Particles on Soot Concentration

Z. Zhang et al.,(2011)[18] performed experiments on a 4-cylinder direct-injection diesel engine using Euro V diesel fuel, diesel fuel plus fumigation methanol, and diesel fuel plus fumigation ethanol to compare their effects on the engine's gaseous and particle emissions under five engine loads at the maximum torque speed of 1800 rpm. Fumigation of methanol or ethanol, when compared to Euro V diesel fuel, could reduce NOx and particle mass and number emissions from diesel engines. With fumigation, methanol being more successful than fumigation of ethanol in particulate reduction. The reduction of NOx and particulates is more effective as the level of fumigation is increased. The decreased particle emission from fumigation methanol or ethanol can be attributed to a number of factors. To begin with, less diesel fuel is consumed because methanol or ethanol replaces a portion of the fuel. As a result, there is less diesel fuel combusting in the diffusion mode. Second, in the premixed mode, more diesel fuel is used due to the longer ignition delay. Third, diesel fuel is made up of a complex mixture of heavy molecules, including aromatics and unsaturated chemicals. Under fuel-rich combustion circumstances, the carbon-to-hydrogen ratio is high, and there is a tendency for soot precursors to develop. Methanol and ethanol are both free of aromatics and have a lower C/H mass ratio, resulting in reduced particle emissions. Despite the fact that more fuel is utilized in the fumigation mode, particulate emissions are reduced.

M. Mirzajanzadeh et al., (2015) [19] carried out an investigation on the influence of CeO_2 with carbon nanotube additive on biodiesel combustion . The results showed that the high surface area of the soluble Nano-sized catalyst particles, as well as their correct distribution, resulted in considerable overall improvements in the combustion process. All pollutants, including NOx, CO, UHC, and soot, were reduced by up to 18.9 %, 38.8 %, 71.4 %, and 26.3 %, respectively.

S. Karthikeyanet al,.(2018)[20] carried out an investigation on Botryococcus braunii microalgae biodiesel as an alternative fuel for diesel marine engines . Experiments with Ni-Doped ZnO nano additive mixed with algal biodiesel and neatdiesel fuel were used to validate the diesel engine. The effect of Ni-ZnO was evaluated as a potential Nano additive for compression ignition engines. It was discovered that when doped Ni-ZnO blends added to B20, emissions such as PM, UHC, NOx, soot, and smoke were reduced. The results showed that doped Nano additive blends emit less pollution than B20.

S. H. Hosseini et al., (2017) [21] investigated the performance and exhaust emissions of a single-cylinder engine using B5 and B10 fuel blends combined with carbon nanotubes (CNTs). CNTs were added to the fuel blends in doses of 30, 60, and 90 ppm. Under full load, the testing was carried out at three engine speeds: 1800, 2300, and 2800 rpm. The findings of emissions characteristics revealed that CO, UHC, and soot emissions fell by 65.70%, 44.98%, and 29.41%, respectively. NOx emissions increased by 27.49 %. One of the primary causes for the large reduction in soot concentration is the inclusion of CNTs in fuel mixes, which reduces viscosity. The presence and movement of carbon nanotubes within the gaps between fuel molecules reduced viscosity and improved fuel atomization.

H. Chen et al., (2019)[22] studied the combustion and emission characteristics of diesel, n-pentanol and methanol blends in a common rail diesel engine. Blended fuels have longer ignition delays, greater peak heat release rates, shorter combustion durations, and higher peak combustion temperatures than diesel under low and partial loads. At medium and high loads, greater oxygen concentrations cause blended fuels to have higher diffusion combustion intensities than diesel, resulting in higher peak combustion temperatures. The ignition delay lengthens, the combustion duration shortens, and the peak combustion temperature rises as the methanol blending ratio rises. Methanol also reduces soot emissions while increasing NOx emissions.

M. Chandran et al., (2020)[23] studied the effect of cerium oxide (CeO_2) as an additive to distilled tire oil mixes (DTO30) in diesel engine operation. The Nano cerium oxide (morphology: spherical with a size of 20 nm) was added to the distilled tire oil blend in amounts of 50 mg/L and 100 mg/L. The addition of this CeO_2 to tire oil blends reduces emissions, increases soot suspension time, and improves engine performance. CeO_2 is important in maintaining a lower temperature and more oxygen near the conclusion of combustion. Because of the higher surface energy of CeO_2, soot developed a layer surrounding the CeO_2. This would aid in decreasing the suspension time of soot in the atmosphere, allowing it to be deposited promptly after emission. The use of additives has been shown to reduce soot particle size by up to 20%. In TEM morphology, the size of soot particles was enlarged due of the intensity with which it binds around the cerium oxide; the size was increased up to 200 nm to 300 nm larger than normal.

Y. H. Bello et al., (2020)[24] studied the performance, combustion and emissions characteristics, and soot morphology of compression ignition (CI) engine running on diesel fuel, with different nanoparticles. Three different nanoparticles with a concentration of 50 mg/l were considered. These are graphene oxide (GO), titanium oxide (TiO_2) and GO doped with TiO_2 (GO-TiO_2).. Three distinct nanoparticles with concentrations of 50 mg/l were investigated. It has been proposed that particulate matter from oxygenated fuels has shorter fringes and more tortuosity, and that the presence of oxygen molecules is responsible for lowering particle size and number. Furthermore, the increased fringe tortuosity of 1.85 at 80 % engine load could indicate improved soot reactivity for GO-TiO_2. The presence of oxygen in the nanoparticles increased the oxidation of soot. This shows that the Nano-fuel was able to suppress PM generation due to greater reactivity and better combustion behavior, which was aided by the presence of oxygen molecules. The oxygen molecules provided by the GO-TiO_2 promoted complete carbon oxidation, limiting the creation and collision of primary particles and, as a result, restricting the formation of large particulate clusters. In the HR-TEM image, soot formation begins from the inner core to the outside shell, which clearly defines the soot particle's boundary.

X.Zhang et al., (2020) [25] investigated the effects of adding 20% vol biodiesel to petroleum diesel (to produce a mixture termed B20) on the physical properties and reactivity of the resulting exhaust soot particles. The tests were carried out at various engine loads and a constant speed. Increased engine loads result in soot aggregates with more compact morphology and primary soot particles with larger size and more structured for both petroleum diesel fuel (DF) and B20 soot. The B20 aggregates have a somewhat more compact shape and a smaller primary particle size than the DF soot. The air–fuel ratio was closely linked with the primary particle size. The air–fuel ratio for a diesel engine is approximately inversely proportional to the engine load in theory. As engine load increases, the lower air–fuel ratio is expected to encourage soot nucleation and growth, resulting in an increase in primary particle size. Utilizing biodiesel fuel reduces the size of the main particles Three causes can be attributed to the decrease in primary particle size. Firstly , the presence of oxygen in biodiesel enhances the local air–fuel ratio, encouraging soot oxidation.

Second, the reduced carbon concentration in biodiesel decreases the surface development rate of soot particles. Finally, the strong oxidative reactivity of biodiesel particles induces particle shrinking. The B20 soot has higher oxidative reactivity than the DF soot at the same engine load because it has lower values for peak temperature, burnout temperature, and apparent activation energy.

M. A. Fayad et al,.(2021)[26] studied The effect of different concentrations of aluminum oxide (Al_2O_3) nanoparticles (30, 50 and 100 mg/L) with a mixture of butanol and diesel (B20) on combustion, particle (PM) and emission characteristics . The pyrolysis of the butanol mixture was found to be catalytically improved in the presence of nanoparticles. As a result, a decrease in soot precursors delays the possible production of soot particles. The results showed that adding 100 mg/L of Al_2O_3 nanoparticles was the most effective mixture for reducing PM. The dual effect of B20 oxygen content and nanoparticles improves combustion while reducing particle production in the combustion chamber and along the exhaust pipe. Surprisingly, the particle concentration dropped as the concentration of nanoparticles added to B20 increased. This could be attributed to a decrease in precursor synthesis and a decrease in the amount of soot particles created during the combustion process. When varied amounts of Al_2O_3 nanoparticles were added to B20, the average particle diameter rose by 9.2%. This could be owing to the increased propensity for collisions between elementary particles and soot agglomerates to generate large-diameter particles. High collisions between initial soot particles enhanced the diameter of the soot agglomerates. The inclusion of nanoparticles in B20 was thought to increase the possibility for these particles to bind to other large soot particles already created, resulting in larger diameter particles.

D. Mei et al., (2019)[27] studied the impact of adding two typical Nano-materials Nano-MoO_3 (which represents metal oxides and has a favorable catalytic function) and CNT(which are non-metallic and have high thermal conductivity) to neat diesel. The suitable physical and chemical dispersion procedures were used to generate CNT-diesel and MoO_3-diesel Nano-fuels. It was discovered that CNT-diesel and MoO_3-diesel outperformed neat diesel in terms of fuel efficiency Combustion, and emissions. The use of nanoparticles (particularly CNT) enhances the heat transfer coefficient between fuel and air, promoting fuel evaporation and uniformizing the produced mixture. This can help fuel burn more efficiently, reducing soot production. The brief ignition delay of CNT-diesel and MoO_3-diesel Nano-fuel blends can lower the combustion temperature and hence reduce soot generation by repressing thermal degradation under high temperatures. Furthermore, MoO_3 functions as an oxygen-donating catalyst, providing the extra oxygen required for combustion, alleviating the rich mixture's oxygen deficit and encouraging the soot to oxidize further.

J. Liu et al., (2020)[28] selected the naphthenic acid cerium solution as the fuel-borne catalyst (FBC), which was combined with diesel fuel at four ratios. They studied the effects of a ce-based (FBC) on the catalytic oxidation of soot particles of the diesel engine. Experimental studies were conducted on a light-duty, diesel engine. They investigated the smoke emissions, particle size, soot oxidation properties, and catalytic (DPF) diesel particulate filter (DPF) regeneration. Experimental data indicated that the fuel economy of FBC fuels can be improved and emissions of exhaust gas and smoke reduced. When the engine is fueled with FBC fuels, the particle mass distribution shifts to the small particle size, the proportion of accumulation mode particles increases, and the proportion of coarse mode particles decreases. The temperature of soot oxidation decreases as the FBC ratio increases, and the temperature of DPF regeneration can be reduced as the diesel engine is fueled with FBC.

H. Zhouet al,.(2019)[29] analyzed the combustion and emission performance of the separated swirl combustion system (SSCS) under different speeds in a single-cylinder engine. According to the trial results, at 2100 rpm, the SSCS greatly reduced fuel consumption (approximately 6.54 g/(kW h)) and soot emission by 2.89 and 6.31 %, respectively. The simulation results revealed that the double swirl combustion system (DSCS) generates more incipient soot particles and soot mass than the SSCS, while the SSCS oxidizes surface soot faster. The mechanisms study revealed that the equivalency ratio in the SSCS is lower than in the DSCS, resulting in fewer incipient soot particles, and that the temperature is higher, accelerating soot oxidation. Furthermore, the SSCS has a substantially shorter combustion duration than the DSCS, which means that the interval between the end of combustion and the exhaust valve opening is longer, allowing for more soot oxidation. Soot mass is also smaller in the SSCS than in the DSCS due to less soot generation and faster soot oxidation.

H. Venu et al,.(2019)[30] focused on the combined effect of Nano additives, combustion chamber geometry and injection timing in a single cylinder diesel engine fuelled with ternary fuel (diesel-bio- diesel-ethanol) blends. Ternary fuel (TF) is doped with alumina Nano additions, resulting in high performance fuel (HPF). At higher temperatures during combustion, the in-built oxygen atoms released by Nano additions aid to oxidize the soot precursors, encouraging complete combustion and lowering UHC and soot emissions. The existence of an oxygen buffer in Nano additives, as well as lower viscosity and increased contact area of the fuel-air mixture, all contribute to the fuel's rapid heat transfer rate. Metal oxide Nano additives function as oxygen donating catalysts, supplying oxygen for oxidation. Because of enhanced in-cylinder temperatures, there is more chance of oxidation of soot precursors and reduced soot at advanced injection timing, paving the way for vaporization of ethanol in HPF, followed by improved combustion and lower smoke emissions.

S. Manigandan et al., (2020)[31] studied the corn blend biodiesel with titanium dioxide and Zinc oxide along with pentanol to examine their positive effects on a diesel engine. Diesel, corn vegetable oil methyl ester (CVOME) CVOME, CVOMEZ50, CVOMEZ100, CVOMET50, and CVOMET100 are the test fuels. The use of nanoparticles in biodiesel blends has a positive effect on attributes such as density, viscosity, cetane number, pour point, cloud point, and calorific value. CO, HC, and NOx emissions are reduced by 26%, 37%, and 19%, respectively, as a result of the addition of ZnO and TiO_2. The increased oxygen concentration of biodiesel blends, when compared to diesel, reduces emissions. Soot emissions are reduced by an additional 10% when compared to diesel. In comparison to diesel, biodiesel emits less soot. In addition, CVOMET100 produces 13.5 % less soot than the other evaluated fuels. CVOMEZ100 emits 8% less soot than diesel. Because of its low viscosity and higher calorific value, TiO_2 nanoparticles in CVOME fuel samples improve reaction stability during burning.

D. Zhang et al,(2013)[32] investigated the effects of iron based homogenous combustion catalyst on the oxidative behavior and the nanostrucular features of soot generated from a single compression cylinder inflammation engine. As the reference at ultra-low dosage rates, the catalyst was homogenously integrated into a commercial diesel. Following TEM imaging examinations, it was discovered that the irregularly shaped, aggregated soot particles were composed of a large number of spherical parent particles. The catalyst treated fuels produced smaller and more narrowly dispersed primary soot particles than the reference diesel. High-resolution TEM imaging revealed graphitic crystallite structures in soot samples from both catalyst-treated and -untreated fuels, with no noticeable differences in the nucleus core regions, indicating that the catalyst had no effect on the internal structure of the soot. The increase in soot reactivity is owing to the catalytic impact of iron contained in the soot from the catalyst treated diesel, which became increasingly apparent when the catalyst dosage ratio was increased. As identified by the TEM imaging technique, the soot particles from the catalyst-treated fuels were also smaller and constituted of narrowly distributed primary particles.

F. Tao et al,. (2009) [33] performed the prediction of soot production and oxidation processes in diesel engines. A nine-step phenomenological soot model had been created. The model includes nine generic steps: fuel pyrolysis, precursor species production and oxidation (including acetylene), soot particle inception, particle coagulation, surface growth and oxidation. Acetylene is formed during the fuel pyrolysis process. The particle is formed by a general gas-phase precursor species, which is the result of an irreversible reaction with acetylene. The acetylene addition reaction adds to the formation of soot on the surface. Particle coagulation influences particle size as well as particle density. Acetylene and precursor species each have their unique consumption pathways, which are defined by a single-step oxidation reaction. The research demonstrated that the nine-step approach is not only computationally efficient, but also fundamentally sound.

2.4 Effect of Operating Conditions on Soot Concentration

R. Minamino et al.,(2013)[34] investigates the effect of compression ratio on soot emission while the Excess Air Ratio (EAR) is kept constant and the engine is operated at a higher load. Because of the increased capacity of the combustion chamber, the results revealed that soot production decreases as the compression ratio decreases. (EAR) determines the degree of soot emissions, which can be minimized by maintaining a high EAR (lean combustion). However, lean combustion with a restricted amount of air and maximum in-cylinder pressure necessitates a reduction in fuel injection volume, which results in a reduction in engine output.

K. S. Prasad et al,. (2021)[35] investigated the effect of compression ratio CR and fuel injection pressure FIP on the combustion, performance, and emissions of a CI engine running on butanol/diesel (B/D) blends. Experiments were carried out on a Variable Compression Ratio (VCR) engine with three distinct (B/D) blends, adjusting the CR (CRs of 14:1, 15:1, 16:1, 17.5:1, and 18:1) and the FIP (FIP of 200 bar, 220 bar, 240 bar, 260 bar, and 280 bar) (butanol fraction of 0 %, 20 % and 40 % by volume). The experimental results showed that increasing the CR from 14 to 18 enhanced in-cylinder pressure, net heat release (NHR), and brake thermal efficiency (BTE) for all (B/D) blends. With an increase in the CR from 14 to 18, soot, CO, and the unburned hydrocarbon UBHC emissions dropped, however NOx emissions increased. Similarly, FIP increased in-cylinder pressure, net heat release (NHR), BTE, and NOx emissions while lowering soot CO and UHC emissions.

S. Ramalingam et al,.(2014)[36] determined the best performance and emission characteristics of a single cylinder variable compression ratio (VCR) engine using various fuel blends of Annona methyl ester (AME). It was discovered that an A20 mixed fuel (20% AME + 80%) with a compression ratio of 17:1 has greater performance and lower emissions than plain diesel. As the compression ratio is increased, the amount of smoke produced was gradually reduced. A20 produces 17.6 HSU (The smoke intensity is measured in terms of Hartridge smoke unit) at maximum load with a compression ratio of 17, resulting in a 21.4 % reduction in smoke when compared to plain diesel fuel. It's possible that this is due to biodiesel's two oxygen atoms, which cause soot to be oxidized, lowering soot emissions. It's also because the oxidation environment is better and there's a higher temperature and pressure at a higher compression ratio. The engine was run with different compression ratios (15, 16, and 17) to identify the optimum feasible combination for running with AME mixes. It's also been discovered that increasing the compression ratio raises the BTE while lowering the SFC.

V. A. M. Selvan et al,.(2014)[37] studied the performance, combustion, and emission characteristics of a variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes as fuel-borne nanoparticles additives in Diesterol (diesel–biodiesel–ethanol) mixes. To estimate the emission reduction potential of CERIA and CNT as catalysts in Diesterol blends, studies on the performance, combustion, and emission characteristics were carried out on a variable compression ratio engine using the stable Diesterol–CERIA–CNT blends under various loading conditions at an optimum compression ratio of 19:1. The addition of CERIA and CNT to E20 mix reduced smoke at higher loads (greater than 0.44 MPa) because CERIA improves combustion and CNT suppresses soot. Nonetheless, smoke emissions are observed to be high at lower loads. Carbon Nanotubes operate as a catalyst to speed the burning rate, resulting in a shorter ignition delay, a lower heat release rate, and an earlier peak heat release rate. The Cerium Oxide Nanoparticles function as an oxygen donating catalyst, supplying oxygen for the oxidation of carbon monoxide while absorbing oxygen for the reduction of nitrogen oxides.

Z. Xu et al., (2014)[38] investigated the influence of injection timing on exhaust particle size and nanostructure at two different engine loads on a heavy-duty diesel engine. Retarding injection timing enhances premixed combustion at low load, resulting in a drop in accumulation mode particle number, however at high load, retarding injection timing causes more intense diffusion combustion, resulting in more carbonaceous material. According to TEM pictures, the primary particle size decreases with increasing injection timing due to increase in-cylinder oxidation time and the average size of the primary soot particles is effectively lowered as engine load increases. This lowering tendency was driven by increasing particle oxidation due to greater engine load combustion temperatures. The particle oxidation rate was thought to increase faster than the particle formation rate as the temperature increased, and so the predominant particle oxidation over particle formation and growth reduced the final primary soot particle size.

D. Khatri et al., (2019)[39] studied experimentally the consequences of ZnO nanoparticles addition on performance and emissions features of a 4-stroke, single-cylinder diesel engine. Pure diesel is combined with ZnO nanoparticles in various amounts ranging from 5 to 25 mg. The oxidation of unburned hydrocarbons and soot particles is accelerated by ZnO nanoparticles, resulting in faster evaporation and a shorter ignition delay period. The premixed combustion phase shortens as a result of the shorter ignition delay interval, resulting in decreased soot emissions. At maximum load, the soot particle size decreases as the CR value rises. This could be owing to a shorter ignition delay time, which leads to fewer soot emissions. It has therefore been established that the addition of ZnO nanoparticles to diesel might be recognized as good alternative fuel because it emits lower pollutants and works as environmentally friendly fuel.

2.5 Summery

Table (2.1) summarizes researches that are similar to my work in terms of study approach and results.

Authors	Conditions	Observations
D. K. Srivastava et al,.2011)[11]	Studied the concentration and size distributions of soot particles emitted by a naturally aspirated, water-cooled, single-cylinder, diesel-powered direct injection compression ignition (DICI) engine .The tests were carried out at a constant engine speed (1500 rpm) and with variable engine load.	Soot generation and emission in diesel engines is heavily impacted by the temperature distribution and fuel/air ratio of the combustion chamber. In the fuel-rich spray zones, the rate of soot creation exceeds the rate of soot oxidation, resulting in the formation of new soot, whereas in the lean zones, the rate of oxidation exceeds the rate of formation, resulting in a reduction in soot concentration.

Authors	Conditions	Observations
(P. Verma et al.,2018) [12]	Studied the shape and nanostructure properties of soot particles utilizing three distinct fuels with varied oxygen concentration, namely D100, Bu20, and Bu30, in an experimental examination on a six-cylinder turbocharged, water after, common rail compression ignition engine.	Soot is most commonly found in the form of aggregates, which are made up of spherical primary particles that form clusters. The diameter of soot particles increases as engine load increases and reduces as butanol proportion in fuel blend increases. This is due to higher temperatures in the combustion chamber and more fuel burning with less oxygen.
(P. Verma et al.,2019) [13]	Studied the morphology and nanostructure of soot particles at different engine operating modes (engine load and speed) and fuel oxygen content by the addition of n- butanol to diesel. The distribution of primary particle diameters was determined from the burning of various fuels.	As engine speed increased, the size of the primary particles dropped. Increasing the engine speed from 1500 to 1800 rpm at full load resulted in a 30% reduction in primary particle sizes. While the engine is under heavy load, more fuel is fed into the combustion chamber and burnt during the diffusion phase of combustion. These in-cylinder conditions stimulate the nucleation and surface growth of soot particles while suppressing soot oxidation.

Authors	Conditions	Observations
(J. Mei et al.,2021)[14]	Studied the detailed sooting characteristics at high equivalence ratios and low temperatures during the pyrolysis of ethylene in a flow reactor.	It was found that temperature has a significant influence on the shape of soot aggregates. As the temperature drops, the particles become less fractal and the joint becomes more visible as the primary particle size increases. This can be attributed to the increased synthesis of PAHs, resulting in a faster nucleation and surface growth with a modest amount of oxygen.
(M. Salamanca, Mondragón, et al., 2012)[15]	Studied the influence of the molecular structure of the fatty acid esters present in two neat biodiesel fuels and their blend (50% by volume) on particulate matter emission.	Linseed biodiesel (BL100) produces more PM and unburned hydrocarbons (UHC) than Palm biodiesel. This is due to more unsaturated chemicals in its makeup, which favor the generation of soot precursors in the combustion zone. Soot particles can coexist with amorphous states including PAHs and aliphatic units.

Authors	Conditions	Observations
(M. Salamanca, Agudelo, et al., 2012)[16]	Investigated the effect of the molecular structure of fatty acid esters found in biodiesel and their blends with diesel on the chemical properties of emitted particulate matter.	When biodiesel is added to fuel, particulate matter emission decreases. This is due to an increase in the oxygen content of the fuel and the absence of aromatic and unsaturated hydrocarbon compounds in biodiesels. When the concentration of unsaturated methyl esters in the fuel was low, there was a significant reduction in soot formation.
(C. Sun, Martin and Boehman, 2019)[17]	Studied and investigated the injection in a light duty multi-cylinder turbo diesel engine to reduce PM.	Soot emissions are reduced by 11–21% in close-coupled post injection settings, and by 28–33% in long-dwell post injection situations. Fuel from the post injection interacts with the primary injection fuel, as evidenced by the variation in soot reactivity. As injection dwell and post injection size grow, soot surface oxygen and amorphous carbon content rise. The size of primary soot particles and particle aggregates does not change greatly after injection.

Authors	Conditions	Observations
(Z.Zhang et al., 2011)[18]	Studied Experiments were carried out on a 4-cylinder direct-injection diesel engine using Euro V diesel fuel, diesel fuel plus fumigation methanol, and diesel fuel plus fumigation ethanol to compare their effects on the engine's gaseous and particle emissions of the engine under five engine loads at the maximum torque speed of 1800 rev/min.	Fumigation of methanol or ethanol could reduce NOx and particle mass and number emissions from diesel engines. The reduction of NOx is more effective as the level of fumigation is increased. Methanol and ethanol are both free of aromatics and have a lower C/H mass ratio, resulting in reduced particle emissions. To begin with, less diesel fuel is consumed because methanol or ethanol replaces a portion of the fuel.
(M. Mirzajanzadeh et al., 2019) [20]	Carried out an investigation on the influence of CeO_2 with carbon nanotube additive on biodiesel combustion .	All pollutants, including NOx, CO, UHC, and soot, were reduced by up to 18.9%, 38.8%, 71.4% and 26.3% thanks to the use of Nano-sized catalyst particles, according to researchers at the University of Bristol.
(S. Karthikeyan and Dharma Prabhakaran, 2018)[20]	Carried out an investigation on Botryococcus braunii microalgae biodiesel as an alternative fuel for diesel marine engines	Results showed that doped Nano additive blends of biodiesel and neat diesel fuel emitted less pollution than B20. It was discovered that when doped Ni-ZnO blends added to B20, emissions such as PM, UHC, NOx, soot, and smoke were reduced.

Authors	Conditions	Observations
S. H. Hosseini et al., 2017) [21]	Studied the performance and exhaust emissions of a single-cylinder engine using B5 and B10 fuel blends combined with carbon nanotubes (CNTs).	Results of emissions characteristics revealed that CO, UHC, and soot emissions fell by 65.70%, 44.98%, and 29.41%. One of the primary causes of the large reduction in soot concentration is the inclusion of CNTs in fuel mixes, which reduces viscosity.
(H. Chen et al., 2019)[22]	Studied the combustion and emission characteristics of diesel, n-pentanol and methanol blends in a common rail diesel engine.	Blended fuels have longer ignition delays, greater peak heat release rates, shorter combustion durations and higher peak combustion temperatures than diesel under low and partial loads. Methanol reduces soot emissions while increasing NOx emissions by reducing NOx while increasing carbon monoxide emissions.

Authors	Conditions	Observations
(M. Chandran et al., 2020) [23]	Studied the effect of cerium oxide (CeO_2) as an additive to distilled tire oil mixes (DTO30) in diesel engine operation.	The Nano cerium oxide (morphology: spherical with a size of 20 nm) was added to the distilled tire oil blend in amounts of 50 mg/L and 100mg/L. CeO_2 is important in maintaining a lower temperature and more oxygen near the conclusion of combustion. In TEM morphology, the size of soot particles was enlarged due of the intensity with which it binds around the ceramic oxide. The use of additives has been shown to reduce soot particle size by up to 20.
(Y. H. Bello et al., 2020)[24]	Studied the performance, combustion and emissions characteristics, and soot morphology of compression ignition (CI) engine running on diesel fuel, with different nanoparticles.	Three distinct nanoparticles with concentrations of 50 mg/l were investigated. The presence of oxygen in the nanoparticles increased the oxidation of soot. Soot formation begins from the inner core to the outside shell, which clearly defines the soot particle's boundary. This shows that the Nano-fuel was able to suppress PM generation due to greater reactivity and better combustion behavior.

Authors	Conditions	Observations
(X. Zhang et al., 2020)[25]	Investigated the effects of adding 20 vol.% biodiesel to petroleum diesel (to produce a mixture termed B20) on the physical properties and reactivity of the resulting exhaust soot particles.	The air–fuel ratio for a diesel engine is approximately inversely proportional to the engine load in theory. As engine load increases, the lower air-fuel ratio is expected to encourage soot nucleation and growth, resulting in an increase in primary particle size. Utilizing biodiesel fuel reduces the size of the main particles. The B20 soot has higher oxidative reactivity than the DF soot at the same engine load.
M.A. Fayad and Dhahad, 2021)[26]	Studied The effect of different concentrations of aluminum oxide (Al_2O_3) nanoparticles (30, 50 and 100 mg/L) with a mixture of butanol and diesel (B20) on combustion, particle (PM) and emission characteristics .	The dual effect of B20's oxygen content and nanoparticles improves combustion while reducing particle production in the combustion chamber and along the exhaust pipe. Surprisingly, the particle concentration dropped as the concentration of nanoparticles added to B20 increased. This could be attributed to a decrease in soot particles created during the combustion process. The results showed that adding 100 mg/L of Al_2O_3 nanoparticles was the most effective mixture for reducing PM.

Authors	Conditions	Observations
(D. Mei et al., 2019)[27]	Studied the impact of adding two typical Nano-materials Nano-MoO_3 (which represents metal oxides and has a favorable catalytic function) and CNT(which are non-metallic and have high thermal conductivity) to neat diesel.	MoO3 functions as an oxygen-donating catalyst, providing the extra oxygen required for combustion, alleviating the rich mixture's oxygen deficit and encouraging the soot to oxidize further. The use of nanoparticles enhances the heat transfer coefficient between fuel and air, promoting fuel evaporation and uniformizing the produced mixture. This can help fuel burn more efficiently, reducing soot production.
(Liu et al., 2020)[28]	Selected the naphthenic acid cerium solution as the FBC, which was combined with diesel fuel at four ratios.	Experimental studies were conducted on a light-duty, diesel engine. They investigated the smoke emissions, particle size, soot oxidation properties, and catalytic (DPF) diesel particulate filter regeneration. When the engine is fueled with FBC fuels, the particle mass distribution shifts to the small particle size and proportion of accumulation mode particles increases. Soot oxidation decreases as the FBC ratio increases, and the temperature of DPF regeneration can be reduced when the diesel engine is powered by FBC.

Authors	Conditions	Observations
(J. Zhou, Li and Liu, 2019)[29]	Analyzed the combustion and emission performance of the separated swirl combustion system (SSCS) under different speeds in a single-cylinder engine.	The SSCS has a shorter combustion duration than the DSCS, which means that the interval between the end of combustion and the exhaust valve opening is longer, allowing for more soot oxidation. Soot mass is also smaller in the SSCS due to less soot generation and faster oxidation as a result of fewer incipient soot particles and soot mass.
(H. Zhou et al,. 2019)[30]	Focused on the combined effect of Nano additives, combustion chamber geometry and injection timing in a single cylinder diesel engine fuelled with ternary fuel (diesel-bio-diesel-ethanol) blends.	In-built oxygen atoms released by Nano additions aid to oxidize the soot precursors, encouraging complete combustion and lowering UHC and soot emissions. Metal oxide Nano additives function as oxygen donating catalysts, supplying oxygen for oxidation. The existence of an oxygen buffer in Nano additives, as well as lower viscosity and increased contact area of the fuel-air mixture, all contribute to the fuel's rapid heat transfer rate.

Authors	**Conditions**	**Observations**
(S. Manigandan et al., 2020)[31]	Studied the corn blend biodiesel with titanium dioxide and Zinc oxide along with pentanol to examine their positive effects on a diesel engine.	The increased oxygen concentration of biodiesel blends, when compared to diesel, reduces emissions of soot. CVOMEZ100 emits 8% less soot than diesel because of its low viscosity and higher calorific value.
(D. Zhang et al ,.2013)[32]	Studied the effects of iron based homogenous combustion catalyst on the oxidative behavior and the nanostrucular features of soot generated from a single compression cylinder inflammation engine.	The soot particle structure of diesel fuel is composed of a large number of spherical parent particles. High-resolution TEM imaging revealed graphitic crystallite structures in soot samples from both catalyst-treated and -untreated fuels. Iron ions from the catalyst were clearly active in the soot oxidation process rather than the early soot production stage, resulting in smaller and more narrowly dispersed primary soot particles. Soot samples from catalyst-treated fuels displayed higher oxidation reactivities than reference diesel.

Authors	Conditions	Observations
(Tao et al,.2009)[33]	Studied the prediction of soot production and oxidation processes in diesel engines.	The particle is formed by a general gas-phase precursor species, which is the result of an irreversible reaction with acetylene. Particle coagulation influences particle size as well as particle density. Acetylene and precursor species each have their unique consumption pathways, defined by a single-step oxidation reaction.
(S. Minamino et al., 2013)[34]	Investigates the effect of compression ratio on soot emission while the Excess air ratio (EAR) is kept constant and the engine is operated at a higher load.	Because of the increased capacity of the combustion chamber, the results revealed that soot production decreases as the compression ratio decreases.
(F. S. Prasad al,. 2021)[35]	Investigated the effect of compression ratio CR and fuel injection pressure FIP on the combustion, performance, and emissions of a CI engine running on butanol/diesel (B/D) blends.	Soot, CO and the unburned hydrocarbon UHC emission dropped with an increase in the CR from 14 to 18. FIP increased in-cylinder pressure, net heat release (NHR), BTE, and NOx emissions while lowering soot CO and UHC emissions.

Authors	Conditions	Observations
(S. Ramalingam,. 2014)[36]	Determined the best performance and emission characteristics of a single cylinder variable compression ratio (VCR) engine using various fuel blends of Annona methyl ester (AME).	As the compression ratio is increased, the amount of smoke produced was gradually reduced. A20 produces 17.6 HSU (The smoke intensity is measured in terms of Hartridge smoke unit) at maximum load with a compression ratio of 17. It's possible that this is due to biodiesel's two oxygen atoms, which cause soot to be oxidized, lowering soot emissions. The engine was run with different compression ratios (15, 16, and 17) to identify the optimum feasible combination.
(V. A. M. Selvan et al,. 2014)[37]	Studied the performance, combustion, and emission characteristics of a variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes as fuel-borne nanoparticles additives in Diesterol (diesel–biodiesel–ethanol) mixes.	Cerium Oxide Nanoparticles and Carbon Nanotubes are fuel-borne nanoparticles additives in Diesterol (diesel–biodiesel–ethanol) mixes. They reduce smoke at higher loads because CERIA improves combustion and CNT suppresses soot. Tests were carried out on a variable compression ratio engine with an optimum ratio of 19:1.

Authors	Conditions	Observations
(Z. Xu et al., 2014)[38]	Investigated the influence of injection timing on exhaust particle size and nanostructure at two different engine loads on a heavy-duty diesel engine.	Soot particle size decreases with increasing injection timing due to increased in-cylinder oxidation time and the average size of the primary soot particles is effectively lowered as engine load increases. This lowering tendency was driven by increasing particle oxidation due to greater engine load combustion temperatures. The particle oxidation rate was thought to increase faster than the particle formation rate as the temperature increased.
(D. Khatri et al., 2019)[39]	Studied experimentaly the consequences of ZnO nanoparticles addition on performance and emissions features of a 4-stroke, single-cylinder diesel engine.	Pure diesel is combined with ZnO nanoparticles in various amounts ranging from 5 to 25 mg. At maximum load, the soot particle size decreases as the C.R value rises. This could be owing to a shorter ignition delay time, which leads to fewer soot emissions.

Authors	Conditions	Observations
My present work	Investigate the influence of the addition of Nano-particles to diesel fuel on soot release and UHC concentrations and soot morphology in the exhaust gases of a diesel engine.	The addition of AL_2O_3 Nano particles to diesel fuel reduces the soot concentration in the exhaust gases of diesel engines. The soot concentration decrease when add Nano fuel for all compression ratio and various load . As the blending dose increases the UHC concentration increases at all compression ratios.

2.6 Scope of Present Work

The objectives of the present work to investigate the influence of Nano-particles addition to diesel fuel on soot release and UHC concentrations in diesel engines in addition to its effect on soot morphology. The work will be performed on a variable compression ratio, single cylinder, four strokes, water cooled diesel engine operated with pure and Nano-diesel fuels. Nano-particles of (Al_2O_3) will be used.

Samples of the exhaust gases will be collected by a special sampling bottle to investigate the soot and UHCs concentration. A scanning electron microscope (SEM) will be used to investigate the soot morphology.

CHAPTER THREE

EXPERIMENTAL SET UP AND PROCEDURE

Chapter Three: Experimental Set Up and Procedure

3.1 Introduction

A variable compression ratio single cylinder diesel engine is used in the study. The engine is operated with pure Iraqi diesel fuel and with diesel fuel blended with different doses of AL_2O_3 Nano particles.

3.2 The Diesel Engine

Experiments were conducted to study the impact of adding nanoparticles on the diesel of a single cylinder, four-stroke direct-injection water-cooled diesel engine (553cm^3) with variable compression and a rated power of 3.7 kW at 1500 rpm. Complete engine specification is shown in **Appendix (A) [40]**. The engine has a standard injector of fuel which has a 3-hole 0.2 mm diameter nozzle, which is separated at 120°C and is angled at the cylinder axis at a 60° angle. Injector opening pressure 160 bar is recommended by the manufacturer. A centrifugal controller is connected to the engine to control the engine speed automatically. The combustion chamber is hemispherical in the form of a push rod-operated overhead valve system.

Figure (3- 1) The Test Engine: (1) Soot filter ,(2) flow meter, (3) Dynamometer, (4) Engine, (5) PC Control, (6) Fuel tan, (7) Valves filter, (8) Control system, (9) Exhaust gas pipe.

3.3 The Diesel Fuel and the Blended Fuel Preparation

Iraqi diesel fuel which is readily available at local fuel stations is used in this research. The molecular formula is $C_{12.3}H_{22.2}$ [40] , The physical properties of the diesel fuel are shown in Appendix (B)**.** Nanoparticles of Al_2O_3 was used in the present work to prepare Nano-diesel fuel. The physical properties of this Nanoparticle are depicted in Table (3-2). The average size of the Nan-particles is 45 nm. Three blending ratios of Nano-particles are used namely 25, 50, and 100 ppm.

Table (3- 1) Properties of Nano-particles [42]

Particle	***Al_2O_3***
Density (kg/m^3)	3970
Specific heat (kJ/kg.K)	765
Thermal conductivity (W/m.C)	40
Average size (nm)	45
Shape	Spherical
Appearance	White

The mass of Nanoparticles required for each dose is calculated using the following equation [41]:

$$\emptyset = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p}+\frac{m_f}{\rho_f}} \qquad (3.1)$$

Where:

(ϕ) Solid volume fraction of nanoparticles .

m_p: mass of nanoparticle

ρ_p: density of nanoparticle

m_f: mass of fuel

ρ_f: density of fuel

In addition to five litters (5 liters) of pure diesel fuel, the determined volume of nanoparticles is constantly mixed by homogenizer blender over an hour period (RZR 2021 overhead stirrer, digital display, mechanical speed control, with 10.5 mm chuck, maximum torque 400 N.cm, maximum stirring capacity 25 L H20, maximum viscosity 60 Pa.s). The mixer is illustrated in figure (3-2). To guarantee that nanoparticles are distributed over the diesel fuel and to avoid the agglomeration of particulates. Figure (3-3) shows the ultrasonic kind of cleaner (JTS-1018) manufactured from the melting process (Guangdong, China). It will take another six hours to mix. The characteristics of the ultrasound cleaner are presented in Table (3-3).

Figure (3- 2) The Mixer

Figure (3- 3) The Ultrasonic Cleaner

Table (3- 2) The Ultrasonic Cleaner Bath Specifications.

Model	***JTS-1018***
Water tank dimensions (mm)	L1= 406 , W1=305, H1=460
Overall dimension (mm)	L1= 586 , W1=485, H1=680
Ultrasonic frequency	40 kHz
Ultrasonic power	720 Watt (variable)
Digital timer control	1-30 min
Capacity	54 liter
Temperature control range (ºC)	< 90 ºC
Ultrasonic power output	800 W

Figure (3- 4) Nano fuel photograph.

The physical properties of Nano-diesel is shown in table (3- 4) .

Table (3.6) Calculated Results of Nano fuel

Dose of Nano (ppm)	density of Nano fuel (kg/m^3)	viscosity of Nano fuel (kg/m.s)	Thermal conductivity (W/m.k)
25	278.11	2.79	34
50	859.93	2.81	38
100	875.56	2.85	43

3.4 The Soot Collection Filter

A special soot collection glass filter is fabricated. It consists of two easy fitted glass pieces with two valves one at inlet and the other at exit. Any filler media can be used with the filter. In this research the medical cotton is used. The filter is shown in figure (3-5).

Filter before sampling

Filter after sampling

Figure (3- 5) Soot Collection Filter

3.5 The Scanning Electron Microscope (SEM)

A Scanning electron microscope (SEM) type Inspect S50 /FEI, made in Netherland is used in this study to investigate the effect of Nano-particles blending with diesel fuel on soot morphology. A sample slide is prepared from the soot collected in each experiment to be investigated under the SEM. Figure (3-6) show the Scanning electron microscope. This microscope is at the laboratories of college of since /University of Kufa.

Figure (3- 6) Scanning Electron Microscope (SEM).

3.6 Other Experimental Accessories

3.6.1 The Digital Balance

A digital balance type Sartorius ENTRIS124-1S , readability 0.1 mg, is used to measure the soot collected in the filter. The balance is shown in figure (3-7).

Figure (3- 7) Digital Balance

3.6.2 The Vacuum Drying Oven

A vacuum oven, Model DZ-2BC made in Hebei, China, is used to dry the filter from all humidity and partially burned and unburned fuel formed during combustion process and enters through the collecting line . The oven temperature is kept in the range from 200°C to 250°C. This equipment has a strong and high-quality pressure chamber, seals, and pump. The Vacuum Degree <133Pa. The oven is shown in figure (3-8).

Figure (3- 8) Vacuum Drying Oven

3.6.3 The Desiccator

A desiccator is a sealable enclosures containing desiccants used for preserving moisture-sensitive items. The lower compartment of the desiccator contains lumps of silica granules, to absorb water vapor. The substance needing desiccation is put in the upper compartment, usually perforated ceramic plate. The desiccator is used to keep the filters before and after soot collection to prevent contamination with moisture. The Desiccator used in this work is shown in figure (3-9).

Figure (3- 9) Desiccator

3.6.4 The Flow Meter

A gas flow meter (or flow sensor) is used to measure the volumetric flow rate of the sampled exhaust gases. The gas flow meter is connected after the filter as shown in figure (3.10) and (3.11).

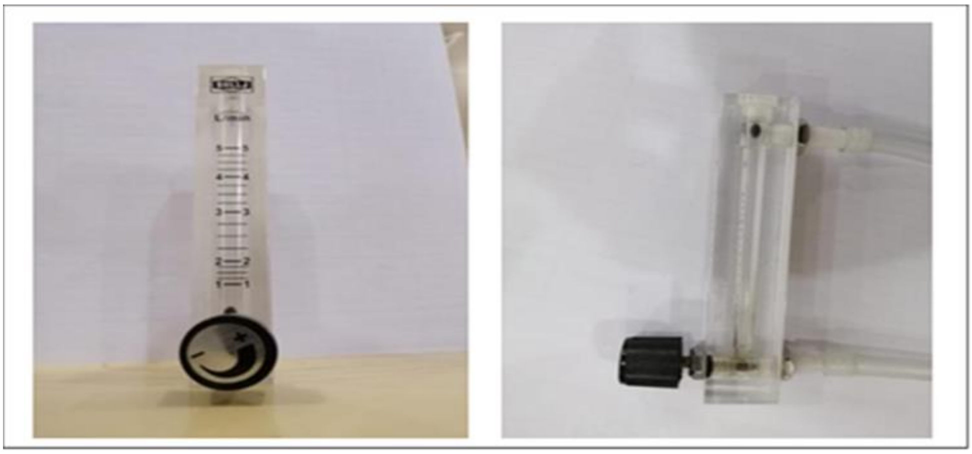

Figure (3- 10) Exhaust Gas Flow Meter

The flow meter is calibrated with a hot wire anemometer. The calibration result is shown in figure (3-12). Note that the Central Organization for Standardization and Quality Control could not perform the calibration due to lack of calibration device as shown in their letter no. 9322 dated 31/10/2021 (Appendix B).

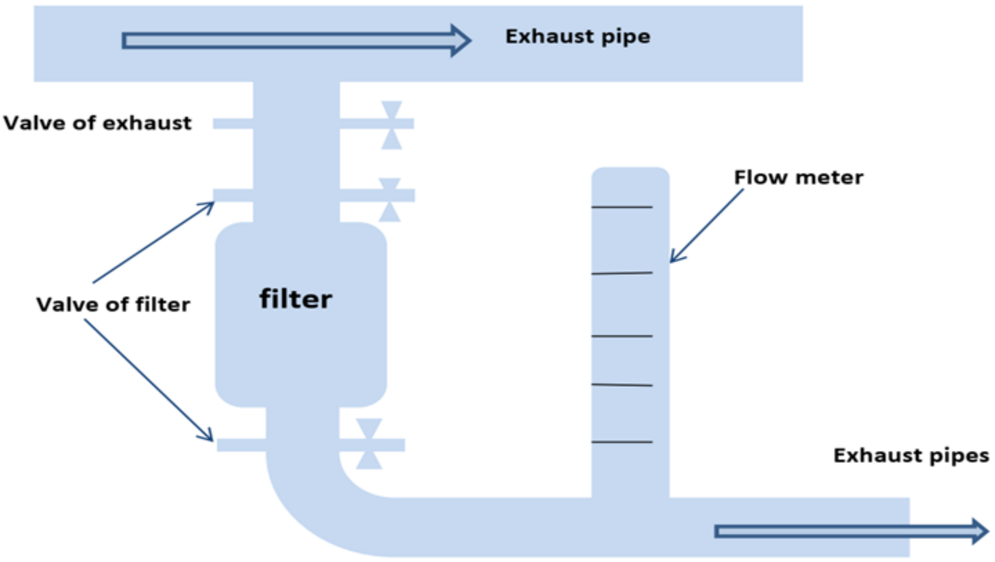

Figure (3- 11) Schematic Diagram of Sampling Process

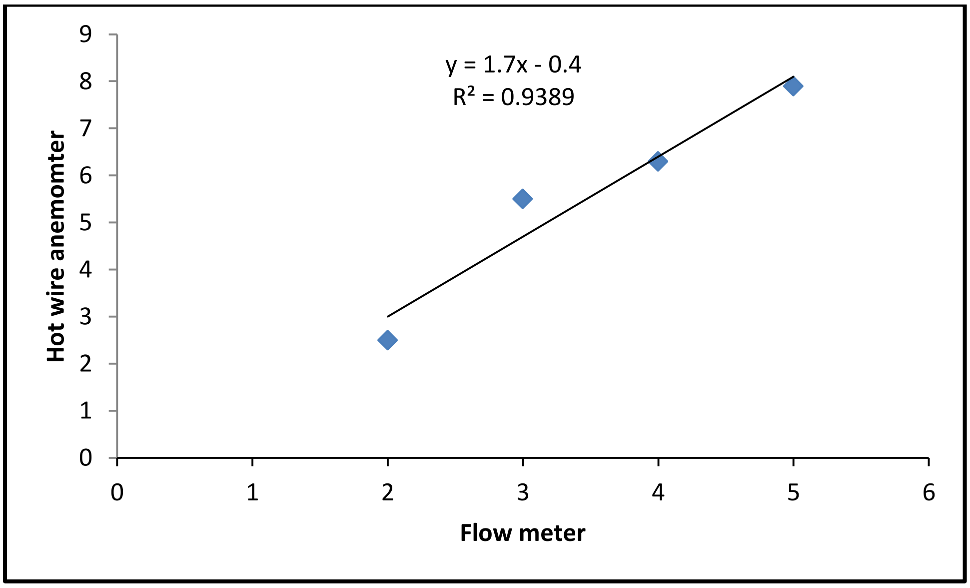

Figure (3-12) Calibrate of Flow Meter and Hot Wire Anemometer

3.7 Soot Collection Filter Preparation

1- Pack the glass filter with the filling media (cotton).
2- Weighs the filter.
3- The packed filter is put in the vacuum oven at a temperature of 110°C (different drying periods,10, 20, 30 and 40 min.). It was found that the weight of the filter remains constant at 30 min and longer. So this time was used as the drying period for all tests.
4- Weigh the filter after drying.
5- Keep the filter in the desiccator.
6- The filter is ready now for soot collection.

3.8 Test procedure

As mentioned earlier all tests were performed at a constant speed of 1500rpm. In all tests the sampling procedure is not started until the engine reaches thermal equilibrium (about 30 minute period).

The engine is set at the operating conditions which are: load, compression ratio and type of fuel. Measurements of soot emissions are taken from a special tab in the exhaust pipe via the sampling line.

Before each test, the engine was run for 10 minute to reach thermal equilibrium (until the exhaust gas temperature remains constant).

When changing the fuel type the engine was run for 10 mins to consume all the quantity of previous fuel in the fuelling system before taking the new samples.

The following sampling procedure is followed:

1-When the engine reaches thermal equilibrium and steady state connect the prepared filter to the sampling line as shown in fig (3-10).

2- Open both inlet and exist valves of the filter and leave the exhaust gases flows through the filter for 10 mints.

3-Close both valves remove the filter from the sampling line.

4-Weigh the filter after sampling.

5-Keep the used filter in the desiccator again.

6-Put the filter in a vacuum oven at a temperature 110℃ for 30 mins to drive all the humidity and the volatile unburned hydrocarbons (UHC) .

7-Weigh the filter again.

8-The difference between the weights of filter before sampling and its weight after sampling and drying equals the weight of collected soot.

9-The difference between the weight of filter after sampling and the weight of filter after drying equals the weight of UHC and water vapor in the collected gases.

10-Record the gas flow rate through the filter during the collection period.

3.9 Relevant Calculations

3.9.1 Soot Concentration Calculation

As mentioned earlier the volume flow rate of the collected gases is measured during a specified period (sampling duration) and the weight of collected soot is also measured (as in step 8 in section 3.8) Therefore the soot concentration is calculated using the following equation; equation (3.2).

$$soot\ cocentration\ = \frac{mass\ of\ collected\ \ soot\ (mg)}{volume\ \ flow\ rate\ (m^3/s) x\ sampling\ duration\ (s)} \qquad (3.2)$$

3.9.2 UHC Concentration Calculation

From the knowledge of volume flow rate of sampled gases, and sampling duration and the weight of (UHC) (as in step 9 in section 3.8), the UHC concentration is calculated from equation (3.3).

$$UHC\ cocentration\ = \frac{mass\ of\ collected\ \ UHC\ (mg)}{volume\ flow\ rate\ (m^3/s) x\ sampling\ duration\ (s)} \tag{3.3}$$

Table (3- 3) Experimental Program

	Cr=13.5			Cr=15.5			Cr=17.5		
		soot concentration (mg/m^3)	UHC concentration (mg/m^3)		soot concentration (mg/m^3)	UHC concentration (mg/m^3)		soot concentration (mg/m^3)	UHC concentration (mg/m^3)
Pure Diesel	No Load			No Load			No Load		
	50%			50%			50%		
	100%			100%			100%		
25ppm	No Load			No Load			No Load		
	50%			50%			50%		
	100%			100%			100%		
50ppm	No Load			No Load			No Load		
	50%			50%			50%		
	100%			100%			100%		
100ppm	No Load			No Load			No Load		
	50%			50%			50%		
	100%			100%			100%		

CHAPTER FOUR

Results And Discussion

Chapter Four: Results and Discussion

4.1 Introduction

In this chapter the results of this investigation are presented and discussed. For ease of discussion the results are divided into five parts which are:

1. Effect of engine load on soot.
2. Effect of compression ratio on soot.
3. Effect of Nano-particles dose on soot.
4. Morphology characteristics of soot particle.
5. Effect of Nano-particles dose and the operating conditions on unburned hydrocarbon (UHC).

Three different Nano-particle doses are used namely (25,50,100) ppm. Also the engine is operated with three compression ratio namely (13.5,15.5,17.5) and different loads (no load, half load and full load).

4.2 Repeatability of Results

The engine is operated with pure diesel at 1500 rpm and a compression ratio 15.5. This test is repeated five times at different date under same operating conditions to confirm the repeatability of result. The result of these tests is shown in figure (4-1). The figure shows the variation of soot concentration (mg/m^3) with load. The figure indicated an acceptable reproducibility of results with error percentage between the different tests of 4% , the error is calculated from equation (4.1): maximum minimum

$$Error\ Percentage = \frac{maximum\ value - minimum\ value}{maximum\ value} \quad \text{-------} \quad (4.1)$$

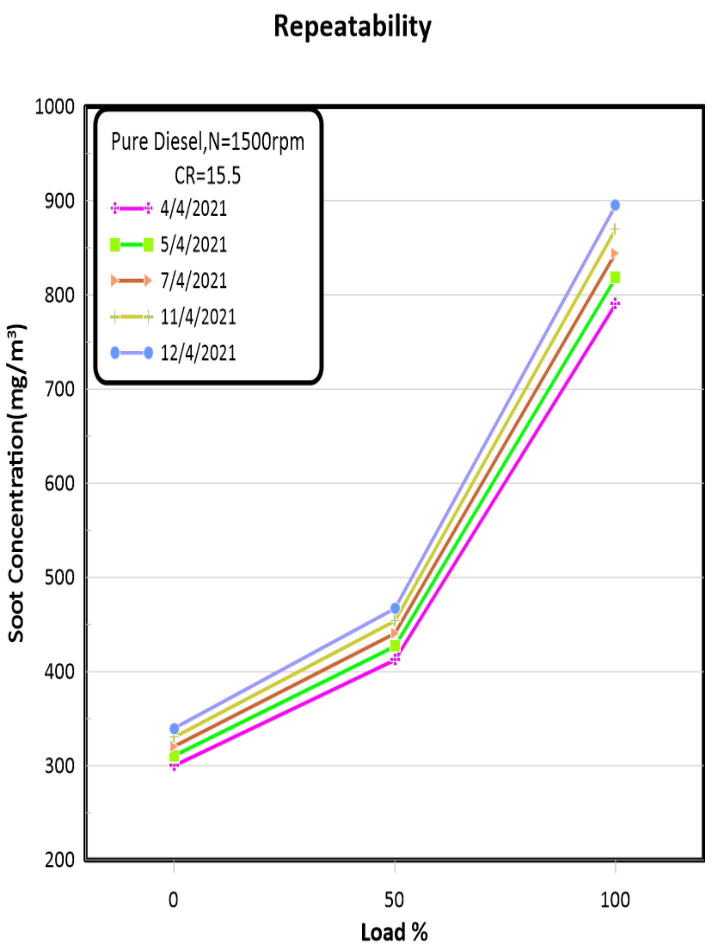

Figure (4- 1) Variation of the soot concentration with load (repeatability test).

4.3 Effect of Load on Soot Concentration

The soot concentration variation with load for different Nano particle doses and different compression ratio is shown in fig (4.2-4.4). It is noticed that soot concentration increases as the load increases. This is due to more fuel is injected as the load increases and hence part of the fuel is partially burnt and converted to soot .The figures also show that the addition of Nano-particles to diesel fuel reduces the emitted soot concentration at all loads .This may be attributed to the high thermal conductivity of Nano-particle which raises the temperature of the soot particle and hence improves its oxidation rate . It may be also attributed that the Nano particle acts as the oxygen donner which also improves the soot particle oxidation rate.

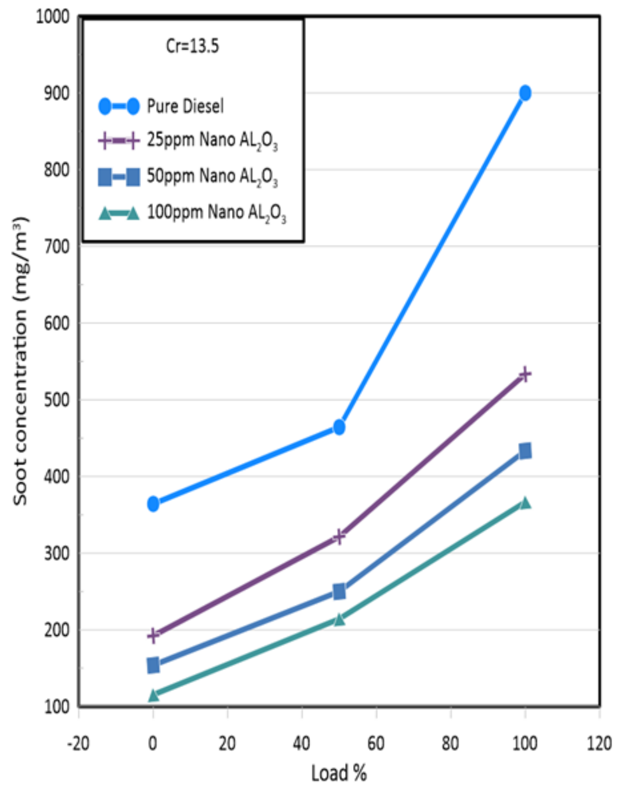

Figure (4- 2) Variation of soot concentration with load at CR 13.5

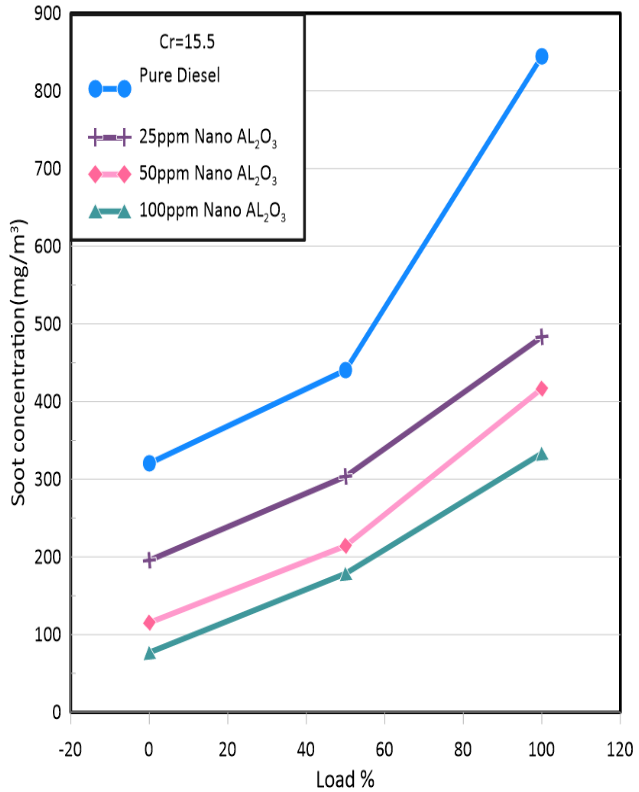

Figure (4- 3) Variation of soot concentration with loads CR=15.5

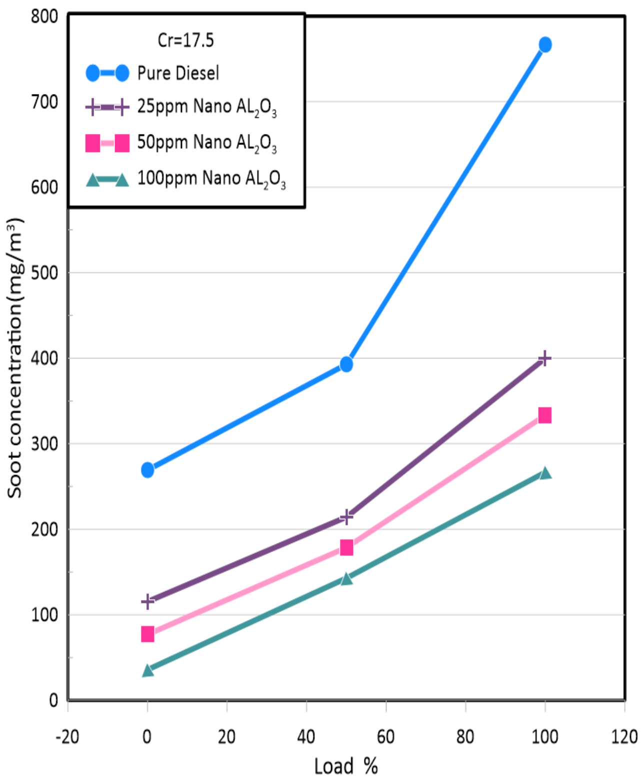

Figure (4- 4) Variation of soot concentration with loads CR=17.5

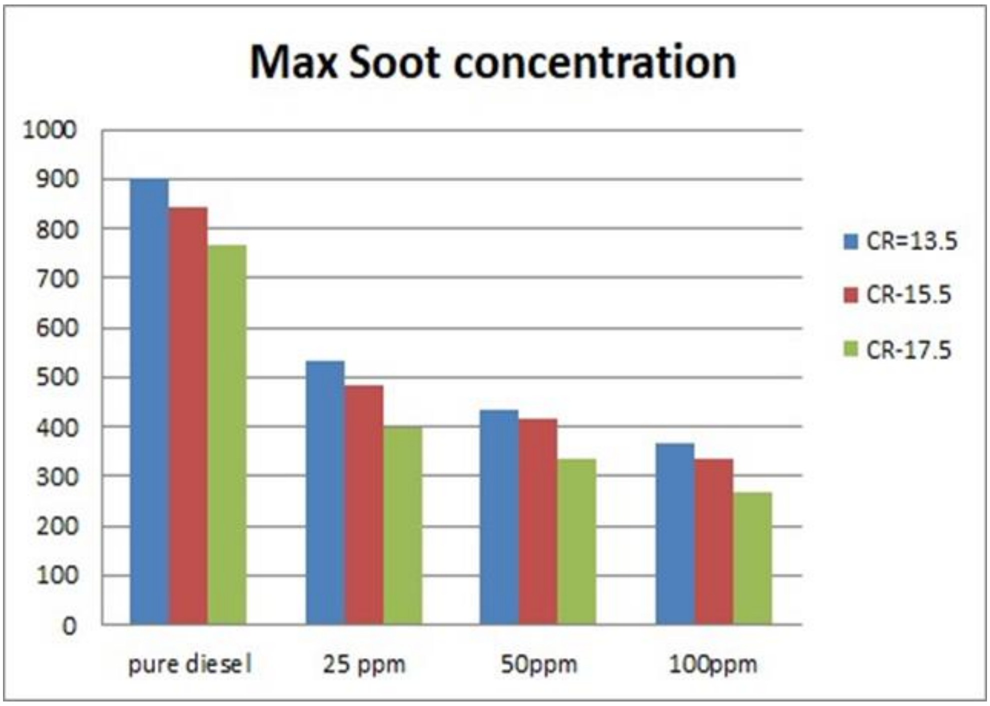

Figure (4- 5) Max soot concentration(mg/m^3).

Fig (4-5) shows the variation of maximum soot concentration of pure and blended diesel at full load for different compression ratios and different

Nano-particles doses . The presence of Nano-particle in the fuel droplets improve the evaporate rate which leads to better mixing process between air and fuel vapor. This improves combustion efficiency which yields less soot for all loads, Nano-particle doses and compression ratio .

In addition to that the presence of Nano-particles in the combustion chamber during combustion process acts as soot formation precursors that should grow to soot particles. However, due to the large surface area of the Nano particle and the high thermal conductivity, these precursors are fastly oxidized which leads to less emitted soot concentration and smaller soot particles in the exhaust.

4.4 Effect of Compression Ratio on Soot Concentration

Figures (4.6-4.9) show the variation of soot concentration with compression ratio for pure diesel and other blended fuels at different loads.

It is noticed that for constant load and constant dose the soot concentration decreases with increases compression ratio. This may be attributed to the increase of combustion chamber temperature as the compression ratio increases. This increase in temperature raises the oxidation rate of both soot precursors and soot particles since the oxidation reaction is a strong function of temperature.

Figure (4-6) shows that the soot concentration decrease from (900 mg/m^3) at compression ratio 13.5 to (766 mg/m^3) at compression ratio 17.5 for pure diesel while figure (4-9) shows that the soot concentration decrease from (366 mg/m^3) at compression ratio 13.5 to (266 mg/m^3) at compression ratio 17.5 for 100ppm dose.

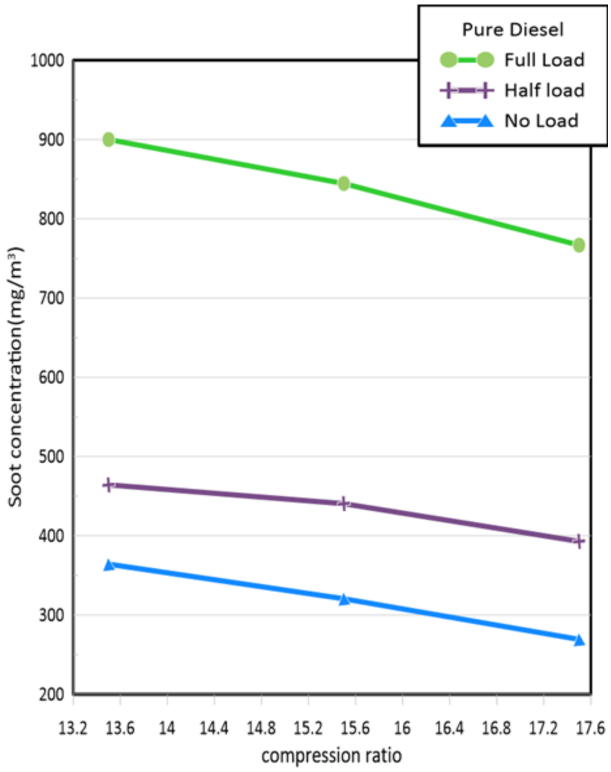

Figure (4- 6) Variation of soot concentration with varies CR without nano

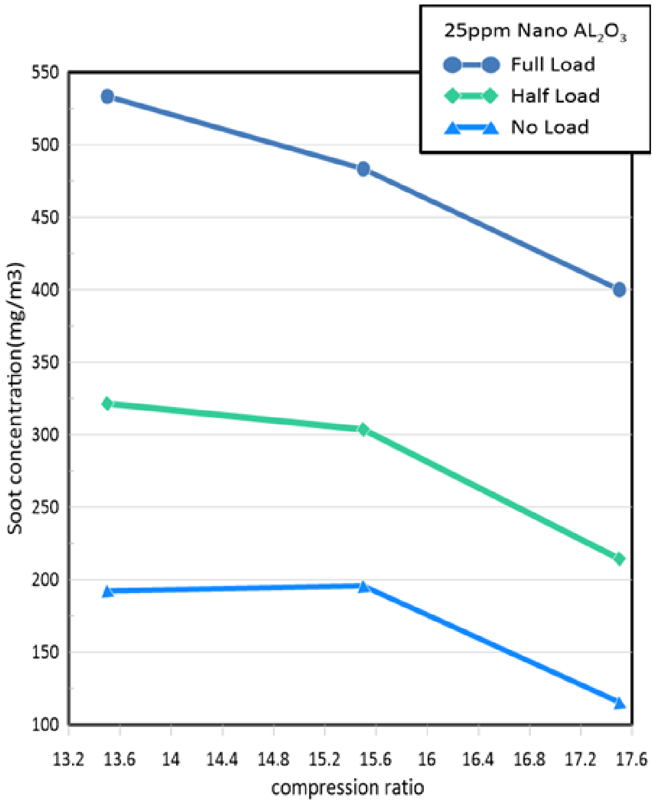

Figure (4- 7) Variation of soot concentration With varies CR at 25ppm

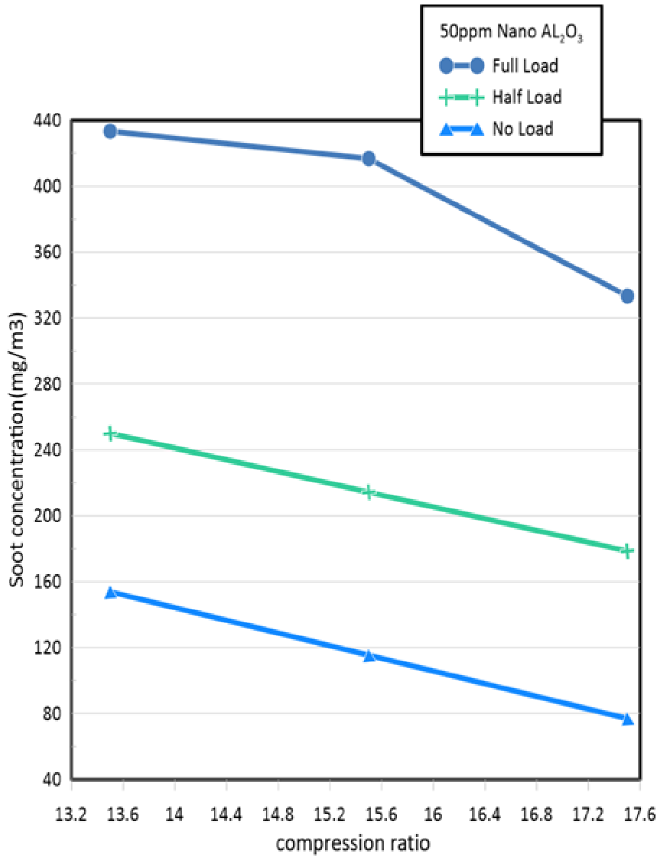

Figure (4- 8) Variation of soot concentration with varies CR at 50 ppm.

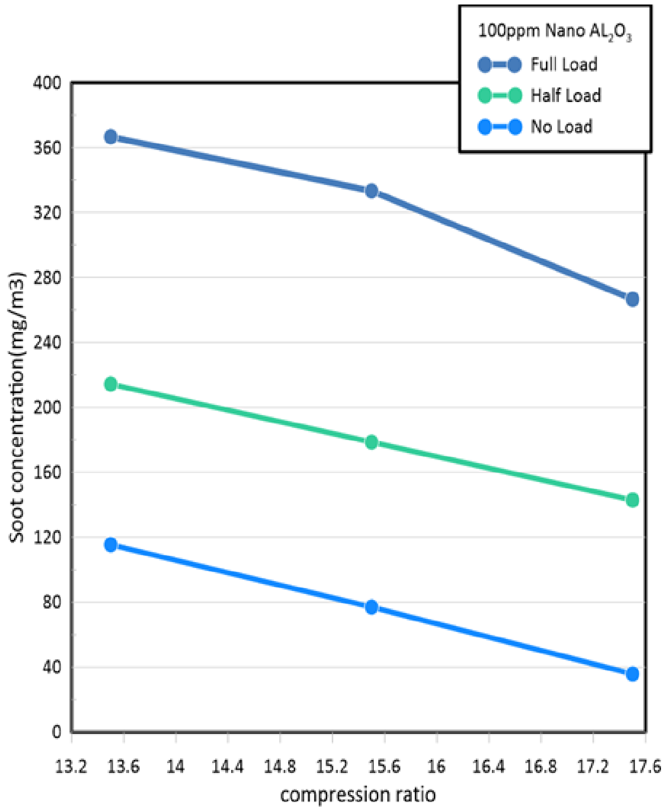

Figure (4- 9) Variation of soot concentration with varies CR at 100ppm

4.5 Effect of Nano-Particles Dose on Soot Concentration

The effect of Nano particles dose on soot concentration is shown in fig (4.10 - 4.12) for different compression ratios at different loads. It is noticed that the addition of Nano-particles reduces the soot concentration. As the nanoparticles dose increases the soot concentration decreases compared to pure diesel. The result shows that the soot concentration of pure diesel at full load and 13.5 CR is (900 mg/m^3) while the soot concentration at (25,50,100) ppm doses are (533 mg/m^3 respectively. The reduction in soot concentration with the addition of AL_2O_3 Nano-particles may be due to many factor such as:

1- High reactivity rate of Nano-particles which increases soot oxidation.
2- High evaporation rate of fuel droplets due to high thermal conductivity of Nano particles which improves mixing process and hence combustion process.
3- Better atomization process of fuel due to large surface area of Nano particles.
4- Efficient combustion process which leads to higher in cylinder pressure and temperature. The higher in cylinder temperature the higher is the rate of soot oxidation as precursors and as soot particles.
5- As the dose increases more oxygen is donated from the Nano particles which also improves soot oxidant rate.

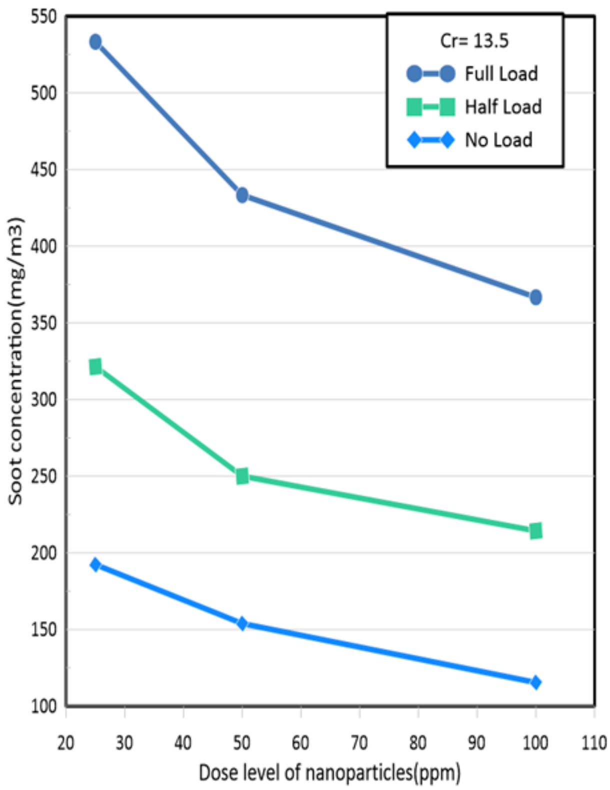

Figure (4- 10) Variation of soot concentration at different dose and CR 13.5

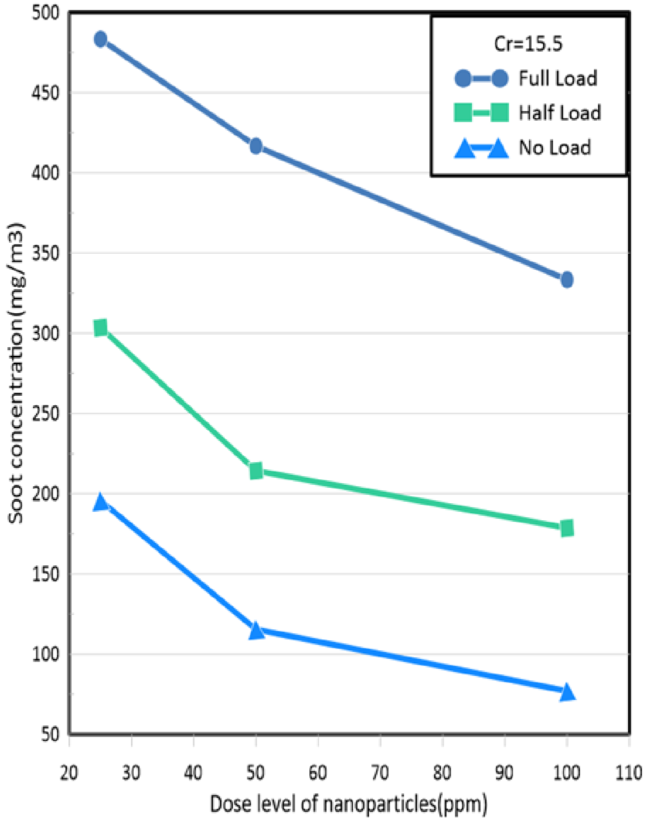

Figure (4- 11) Variation of soot concentration at different dose and CR 15.5.

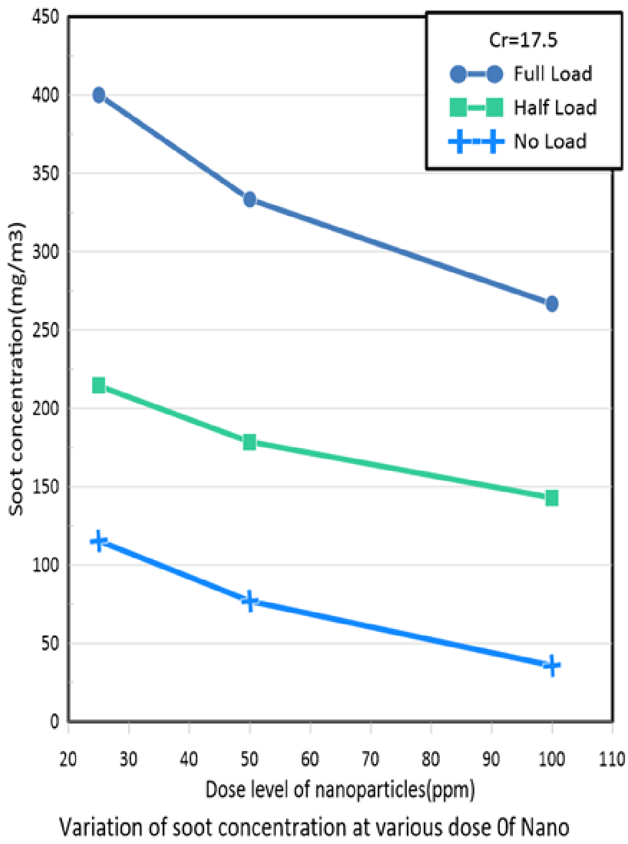

Figure (4- 12) Variation of soot concentration at different dose and CR17.5

4.6 Effect of Nano-Particles on Soot Morphology

As mentioned in chapter three a scanning electron microscope is used to investigate the effect of Nano-particles blending with diesel fuel on the morphology of soot particles and aggregates. Different samples of soot at different loads, different compression ratios, and different doses are prepared and analyzed. Photographs of these analysis are shown in plate (4.1-4.2).

It is noticed from the plates that for pure diesel the soot aggregates have a chain-like and grape-like structure. However for blended diesel fuel the aggregates appear more like chain-like or beads like structure .This may be due to fact that Nano fuel produces fewer PAHS during the different stage of combustion .This is in good agreement with the findings of (Fayad and Dhahad, 2021)[27]. The plates also show, however not so clear , that the size of soot particles is smaller for blended diesel compared with pure diesel .

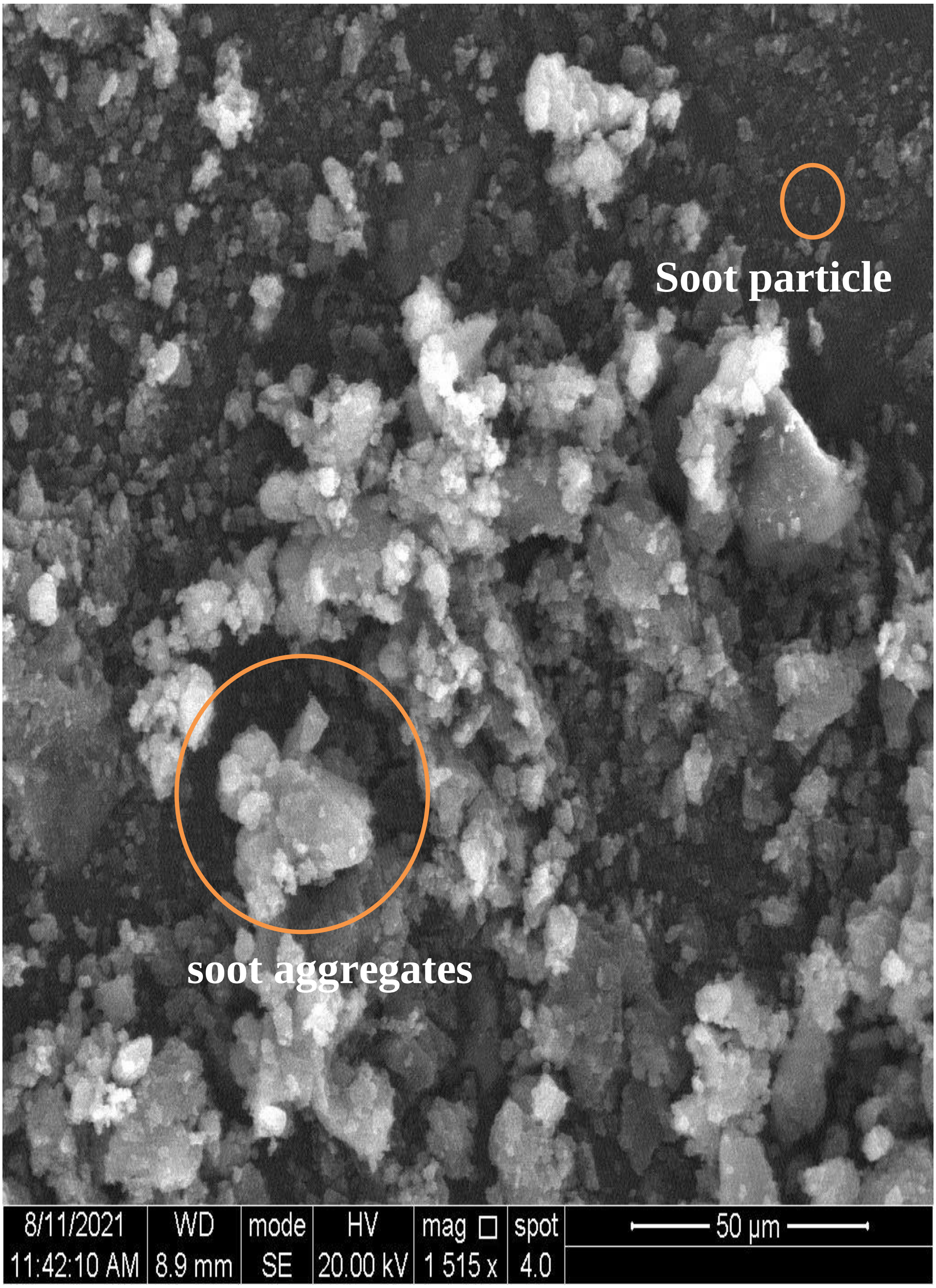

Plate (4- 1) SEM photos at speed 1500 rpm and CR= 15.5(NanoAL_2O_3).

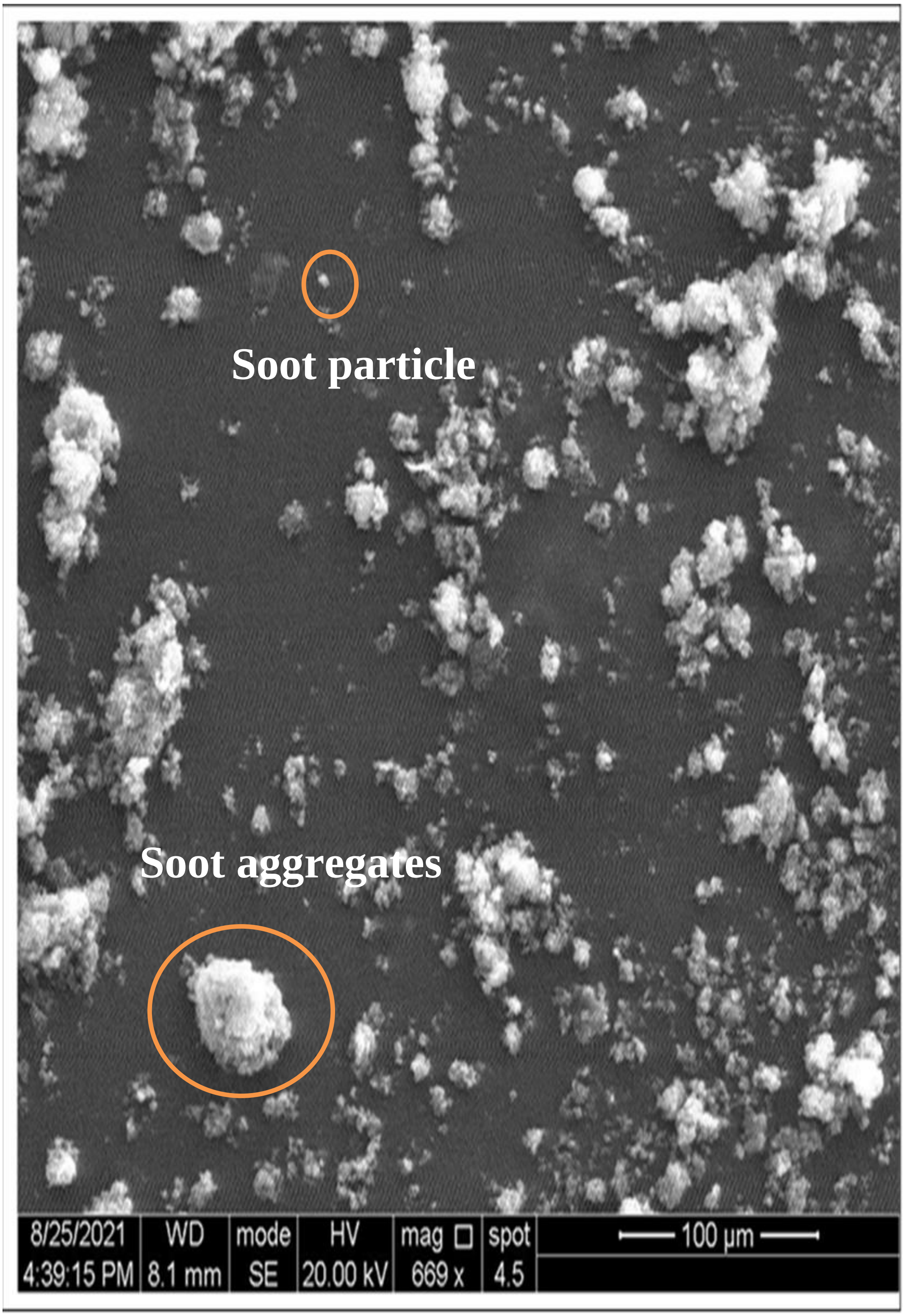

Plate (4- 2) SEM photos at speed 1500 rpm and CR= 15.5 Without Nano.

4.7 Effect of Nano-Particles on Unburned Hydrocarbons(UHC)

The concentration of the UHC is obtained from the difference in sample weight before and after drying. There may be some error in the results due to the presence of water vapor. Figs (4.13-4.15) shows the effect of Nano-particles dose on UHC concentration in the exhaust at different loads and different compression ratios.

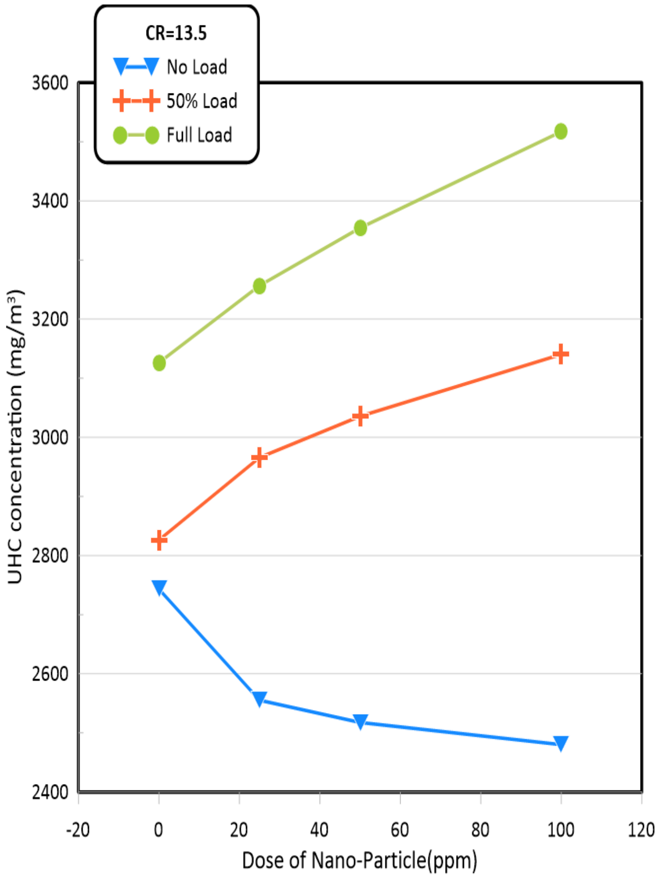

Figure (4- 13) Variation of UHC and Does at CR13.5

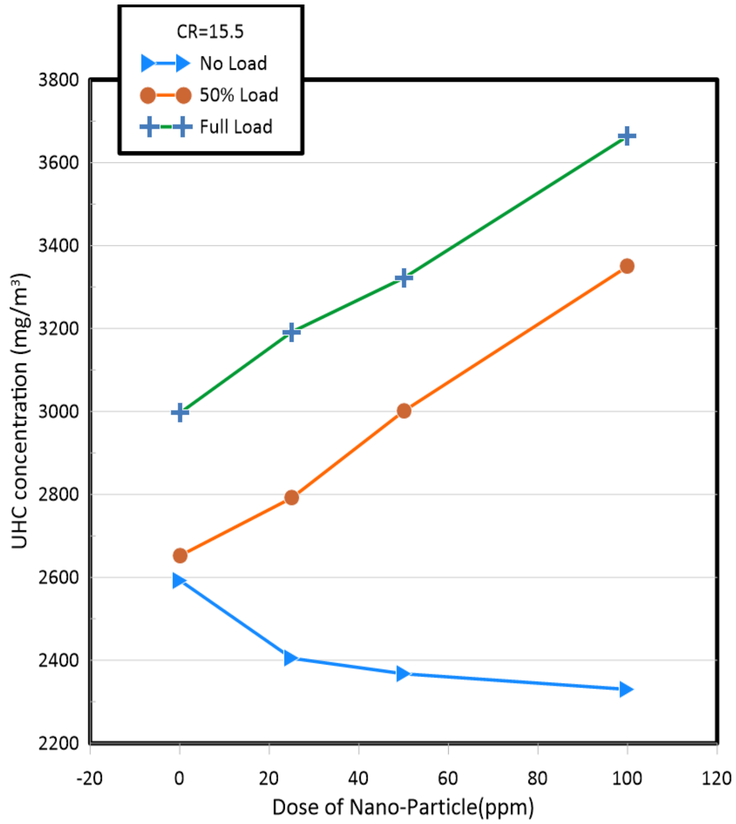

Figure (4- 14) Variation of UHC and Does at CR15.5.

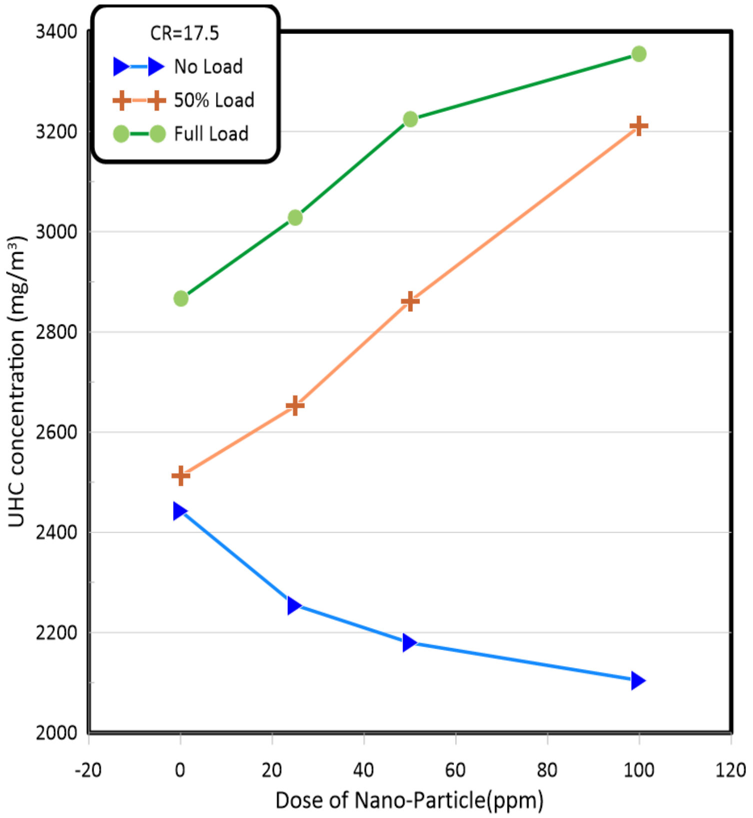

Figure (4- 15) Variation of UHC and Does at CR17.5

The figs indicated that with no load the UHC concentration decreases with increasing the dose for all compression ratios. This is due to small amount fuel injection with no load. However, at higher loads the concentration of UHC increases with dose due to high fuel evaporation rate caused by the presence of Nano-particles. Fig (4.16) present a comparison of UHC concentration for pure diesel and Nano-diesel with different blends at different compression ratios and different loads. The comparison shows that as the compression ratio and load increase the UHC concentration decrease since more fuel is injected and evaporated.

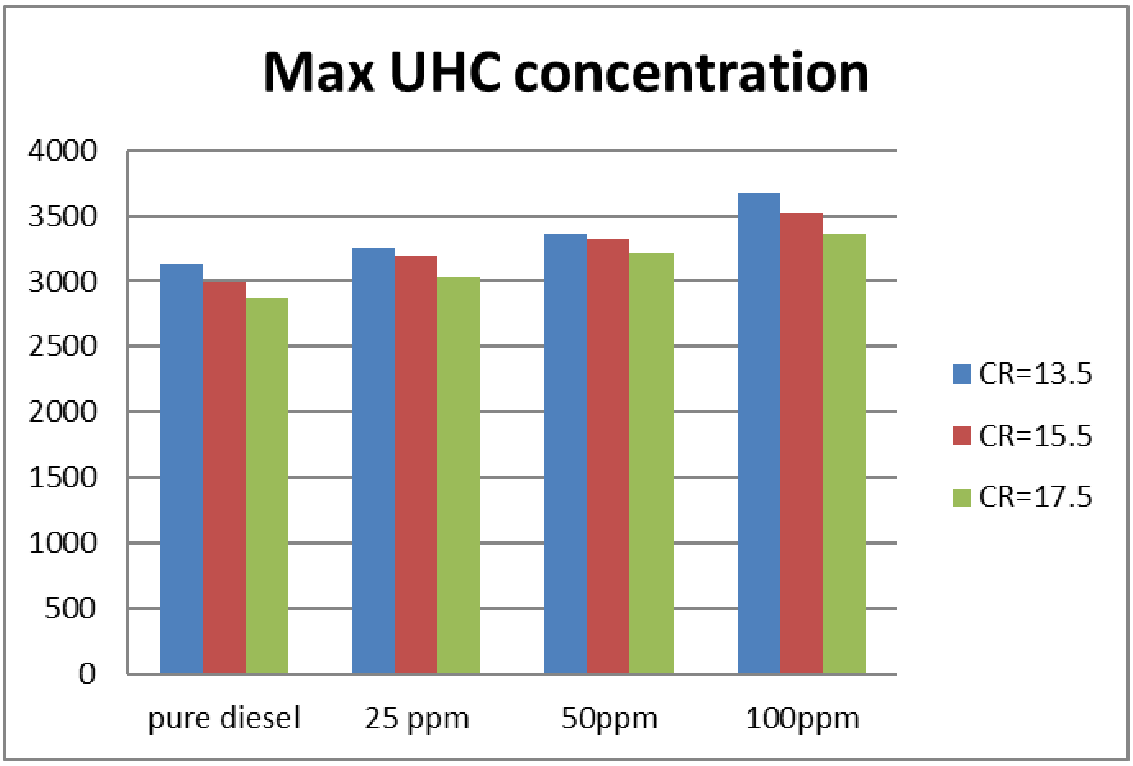

Figure (4- 16) Max UHC(mg/m^3)

Chapter Five

Conclusions and Future Work

Chapter Five: Conclusions and Future Work

5.1 Conclusions

The effects of adding three concentrations of AL_2O_3 Nano Particles (25,50 and 100) ppm on soot release and morphology and UHC concentration emitted from a diesel engine under different engine loads and varying compression ratio were experimentally investigated. According to the results of this study, the following conclusions can be revealed:

1) The addition of AL_2O_3 Nano particles to diesel fuel reduces the soot concentration in the exhaust gases of diesel engines.
2) The addition of AL_2O_3 Nano-particles to diesel fuel yields smaller soot particles.
3) Increasing the compression ratio of the engine reduces the soot concentration in the exhaust gases for pure diesel fuel and blended fuels. The soot concentration at full load decreases by 15% when the CR increases from 13.5 to 17.5.
4) Increasing the dose of the AL_2O_3 Nano-particles reduces the soot concentration in the exhaust gases. The soot concentration is reduced by about 31% when the dose increases from 25 to 100 ppm at CR13.5 and full load.
5) As the blending dose increases the UHC concentration decreases at all compression ratios. The UHC concentration at compression ratio 13.5, full load, decreases by 7% when the dose increases from 25 to 100 ppm.
6) As the compression ratio increases the UHC concentration decreases for all doses. UHC concentration at full load, 100ppm decreases by 4.6% when the compression ratio increases from 13.5 to 17.5.

5.2 Suggestions for Future Work

The following is a list suggestion for further work:

1) Studying the effect of adding a mixture of two types or more of nanoparticles to diesel fuel.
2) Studying the effect of adding different sizes of nanoparticles, such as range 30 or 40 nm.
3) Studying the effect of adding high dose of Nano-particles to diesel fuel, such as (150,175,200) ppm.
4) Studying the effect of Nano-particles on soot particles and agglomerates morphology using transmission electron microscope (TEM).
5) Studying the effect of Nano-particles on the chemical composition of UHC in the exhaust.

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APPENDIXES

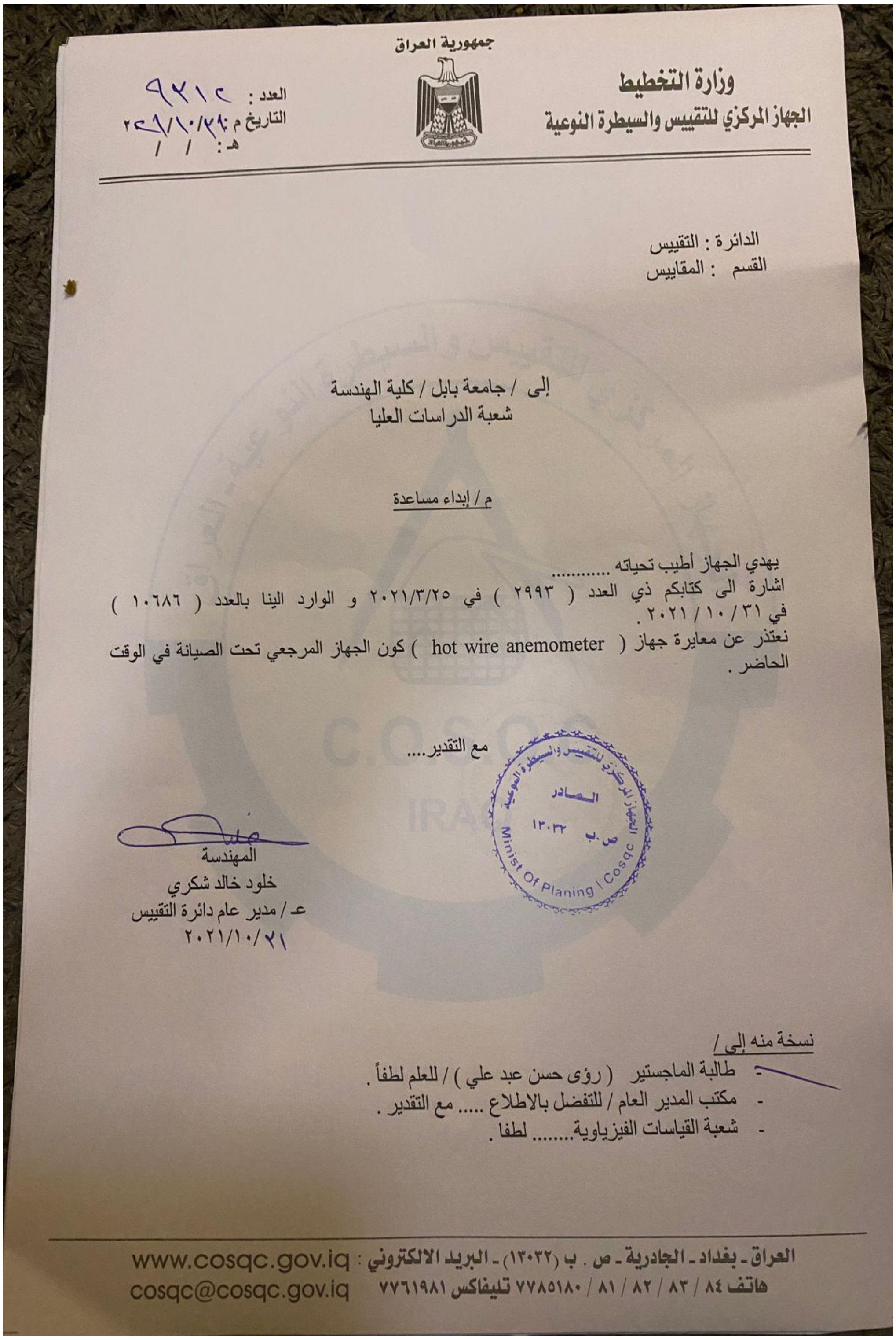
Appendix (A): Engine Specifications[40]

Make and Model	**Kirloskar**
General details	Single cylinder, four stroke, compression ignition, vertical, direct injection, water cooled
Bore	80 mm
Stroke	110 mm
Rating speed	1500 rpm
Swept volume	553 cm^3
Clearance volume	0.03687 m^3
Compression ratio	12.5-17.5
rated power	3.7 kW
Static injection timing	-30 BTDC
Injection pressure	160 bar
Density of fuel	828 kg/m^3
Start of Injection	150 ^{0}CA
End of Injection	190 ^{0}CA
Injection Duration	40 ^{0}CA
Discharge Coefficient of Orifice	0.65
Nozzle Diameter	0.02 mm
Water Flow Transmitter	0 to 10 l pm
Air Flow Transmitter	0-250 wc
Weighing Balance for fuel	0 – 2 kg

Piezo Sensor	0 to 5000 psi with low noise cable
Software	Labview
Combustion chamber	Hemispherical open
Starting	Hand start with cranking handle

Appendix (B): Diesel Fuel Properties

Calibrate of Flow Meter and Hot Wire Anemometer


جمهورية العراق

وزارة التخطيط
الجهاز المركزي للتقييس والسيطرة النوعية

العدد : ٩٧١٢
التاريخ م : ٢٠٢١/١٠/٢٧
هـ : / /

الدائرة : التقييس
القسم : المقاييس

إلى / جامعة بابل / كلية الهندسة
شعبة الدراسات العليا

م / إبداء مساعدة

يهدي الجهاز أطيب تحياته ....
اشارة الى كتابكم ذي العدد (٢٩٩٣) في ٢٠٢١/٣/٢٥ و الوارد الينا بالعدد (١٠٦٨٦) في ٣١ / ١٠ / ٢٠٢١ .
نعتذر عن معايرة جهاز (hot wire anemometer) كون الجهاز المرجعي تحت الصيانة في الوقت الحاضر .

مع التقدير....

المهندسة
خلود خالد شكري
عـ / مدير عام دائرة التقييس
٢٠٢١/١٠/٢١

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ص . ب ١٣٠٣٢
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نسخة منه إلى /
- طالبة الماجستير (رؤى حسن عبد علي) / للعلم لطفاً .
- مكتب المدير العام / للتفضل بالاطلاع ..... مع التقدير .
- شعبة القياسات الفيزياوية........ لطفا .

العراق - بغداد - الجادرية - ص . ب (١٣٠٣٢) - البريد الالكتروني : www.cosqc.gov.iq
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Appendix (B): Diesel Fuel Properties

Physical Properties of Diesel Fuel laboratory test

الشركة العامة لإنتاج الطاقة الكهربائية
المنطقة الجنوبية
قسم الوقود والمعالجة

العدد : ٢٨
التاريخ : ٧ / ٧ / ٢٠٢١

م/نتائج فحص زيت الغاز

اشارة الى كتاب جامعة بابل كلية الهندسة شعبة الدراسات العليا المرقم ٥٢٠٠ في ٢٠٢١/٦/٢٢ ادناه نتائج فحص نموذج من زيت الغاز والذي تم فحصه في مختبر فحص الوقود يوم ٢٠٢١/٧/٧

Analysis	Unit	Standard Method	Sample 1
Flash Point	oC	ASTM D-93	68
Viscosity @ 40C°	cst	ASTM D-445	2.520
Density @ 15	g/cm³	ASTM D-1298	0.8239
Water content	ppm	ASTM D-6304	77.8
Pour Point	oC	ASTM D-97	- 16
Sulfur	wt%	ASTM D-4294	0.2759
Centen Number		CORR. ASTM D-613	53.7

رئيس كيمياويين اقدم
فارس عبد المهدي هادي
٢٨/٧/٢٠٢١

وزارة الكهرباء
الشركة العامة لانتاج الطاقة
المنطقة الجنوبية
قسم الوقود والمعالجة

Appendix (C): The published papers

Scopus

Date: August **29**, 2021
Paper ID: IICPS_**60**

LETTER OF ACCEPTANCE

Dear Authors,

On behalf of the IICPS -21 Committee, and based on the reviewers' evaluation after double blind peer review and Guest editors' approval we are pleased to inform you that your paper entitled:

" Effect of Nano-Particles on Soot Release in Diesel Engine -Review "

Written By

Haroun A. K. Shahad and Ruaa Hassan Abd-Ali

Has been accepted and will be processed to publication in the IOP Journal of Physics (Online ISSN: 1742-6596, Print ISSN: 1742-6588, IICPS-2021). It is our pleasure to invite you to attend the Iraqi Academics Syndicate 2nd International Conference for Pure and Applied Sciences (IICPS), Babylon Branch, Babylon, Iraq at 14-15 November 2021 to present your paper. We congratulate you for your achievement, the technical details about the publication will be informed later. The publication of the accepted paper will be provided by the end of **January 2022**.

We Will encourage more quality submissions from you and your colleagues in future

Regards,

Prof. Dr. Shubham Sh. Sharma
Special Issue Guest Editor of IICPS

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Caution: This Acceptance Letter Made by IICPS Conference Guest Editors and All Approval Inquiries Should Addressed to Editorial Board Committee of IICPS. .

Design Engineering

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Experimental Investigation of AL_2O_3 Nano Particles Effect on Soot Release and Morphology Emitted from A Diesel Engine

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University of Babylon/ Babylon-Iraq

ABSTRACT

The goal of this study is to evaluate the influence on the concentration of soot generated by gasoline engines at varying load and compression levels by adding Al2O3 nanoparticles to pure diesel oil. Nano-fueled gasoline produced from aluminum oxide (Al2O3) mixed with diesel fuel (particle diameter <50 nm). The study was conducted on a single cylinder, four-stroke, direct-injecting diesel engine with a variable compression ratio of displacement (553 cm3). The engine develops of 3.7 kW at 1500 rpm. Three doses of nano-AL_2O_3 particles (25, 50 and 100 ppm) are prepared. It is found generally that adding Nano-particles to diesel fuel reduces the emitted soot concentration. However the effect of adding nanoparticles is most significant at a dose of 100 ppm at full load. The results also show that the soot concentration is further reduced by increasing the engine compression ratio for all loads and doses.

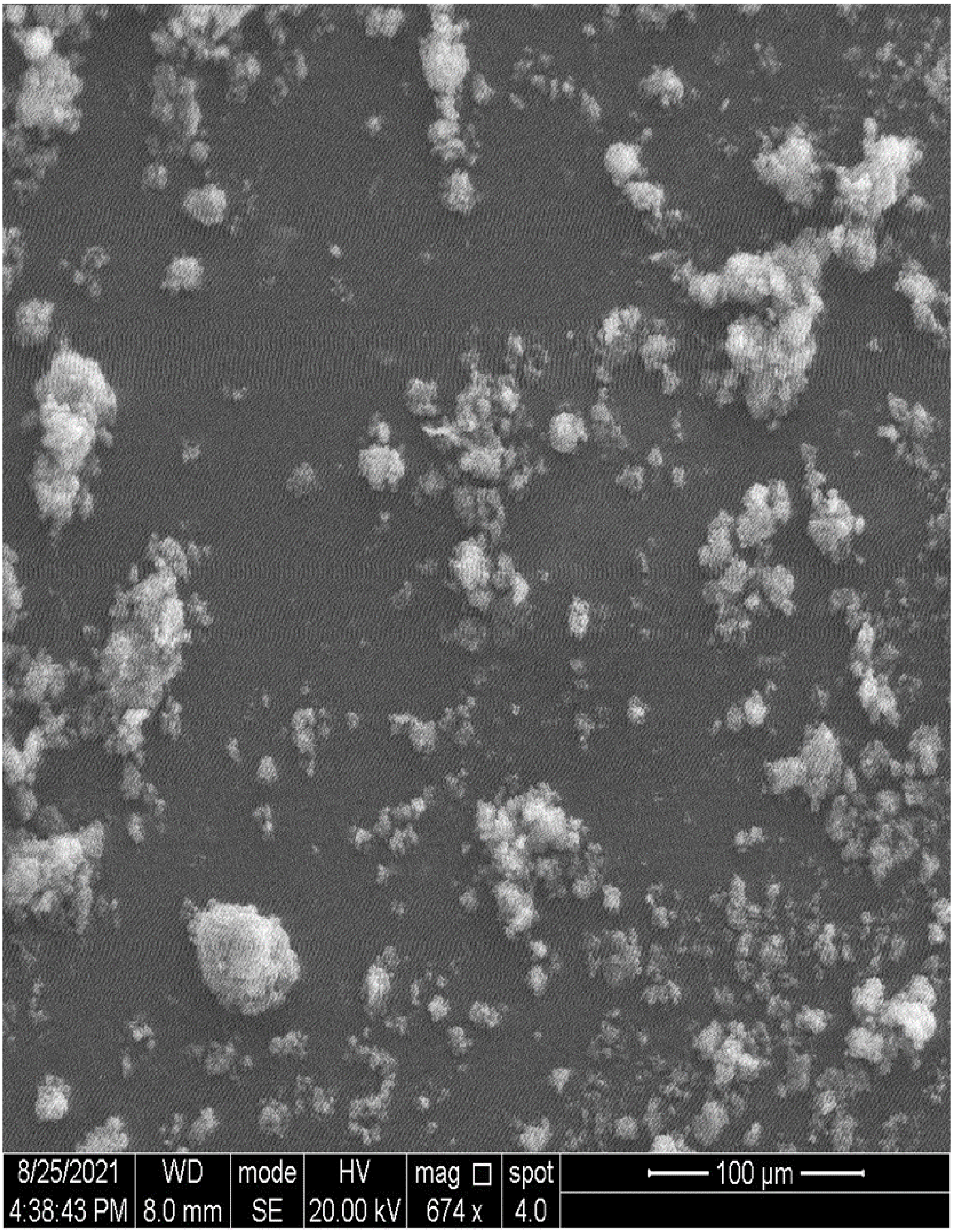
Keywords: Nano-Particle, Soot concentration, Diesel Engine, emissions, compression ratio , Iraqi diesel, SEM.

1. Introduction

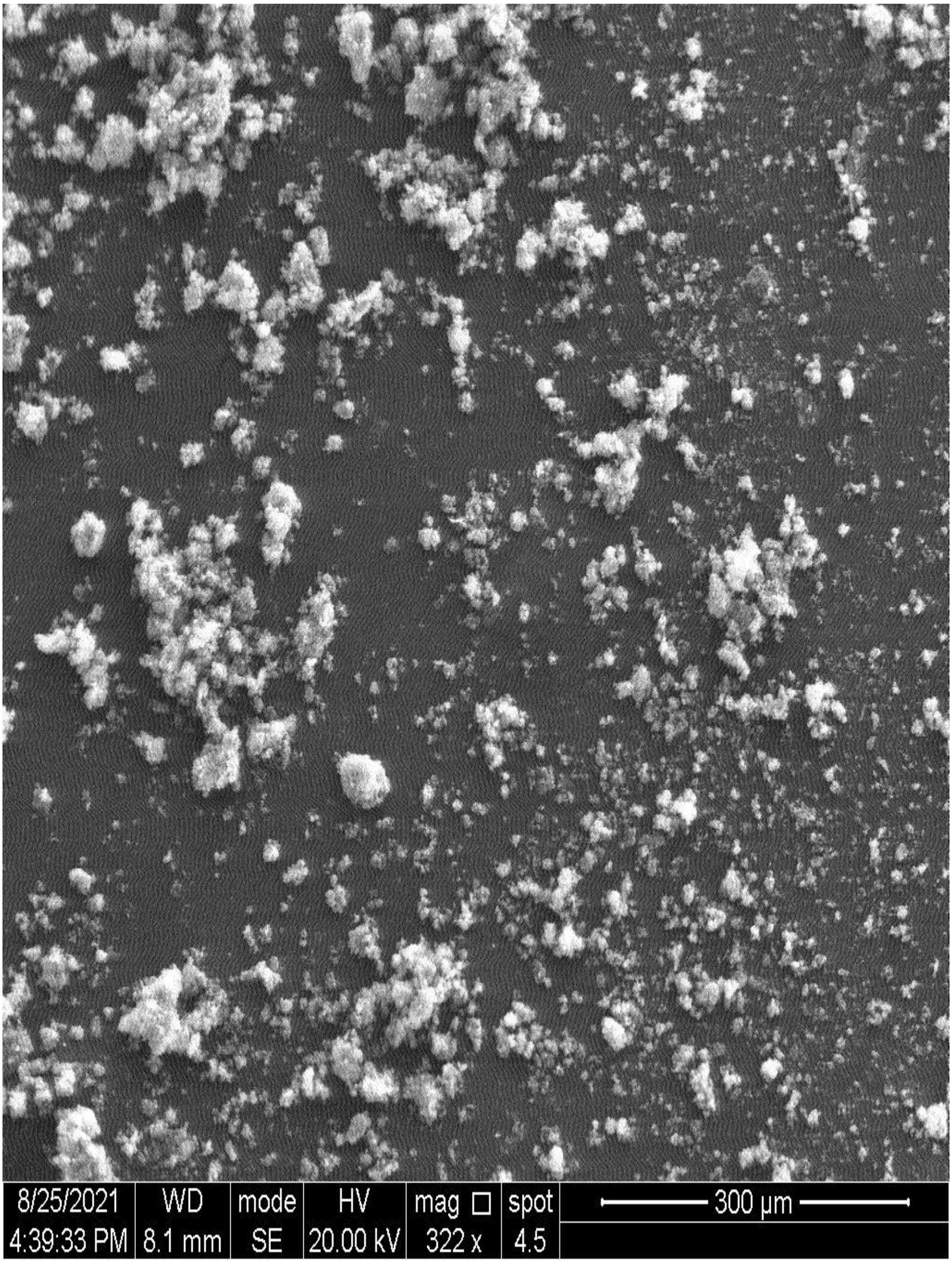
Compression Ignition (CI) diesel engines are more favorable for surface transportation, large machines, and distant power production, which naturally are more effective and durable than spark Ignition Gasoline. However, diesel engines create substantial volumes of emissions of soot (PM), which are threatening air quality and public health, especially in metropolitan areas[1]. This type of soot particulate matter consists in agglomerated primary particulate matter and on Unburnt hydrocarbons and inorganics are absorbed from their surfaces[2]. Many investigations have revealed that particulate matter (PM) accumulates and even penetrates cell membranes in the breathing system producing inheritable mutations[3]. In consequence a number of nations set stringent limits on diesel PM emissions, which in the future will be much stricter[4]. Many efforts were undertaken to minimize emissions of diesel PM by altering the design and fuel injections of engines and to reform the combustion process' fuel properties[5]. Included here is

Appendix (D1): SEM photos

at speed 1500 rpm and CR= 15.5 pure diesel



Appendix (D2)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WD
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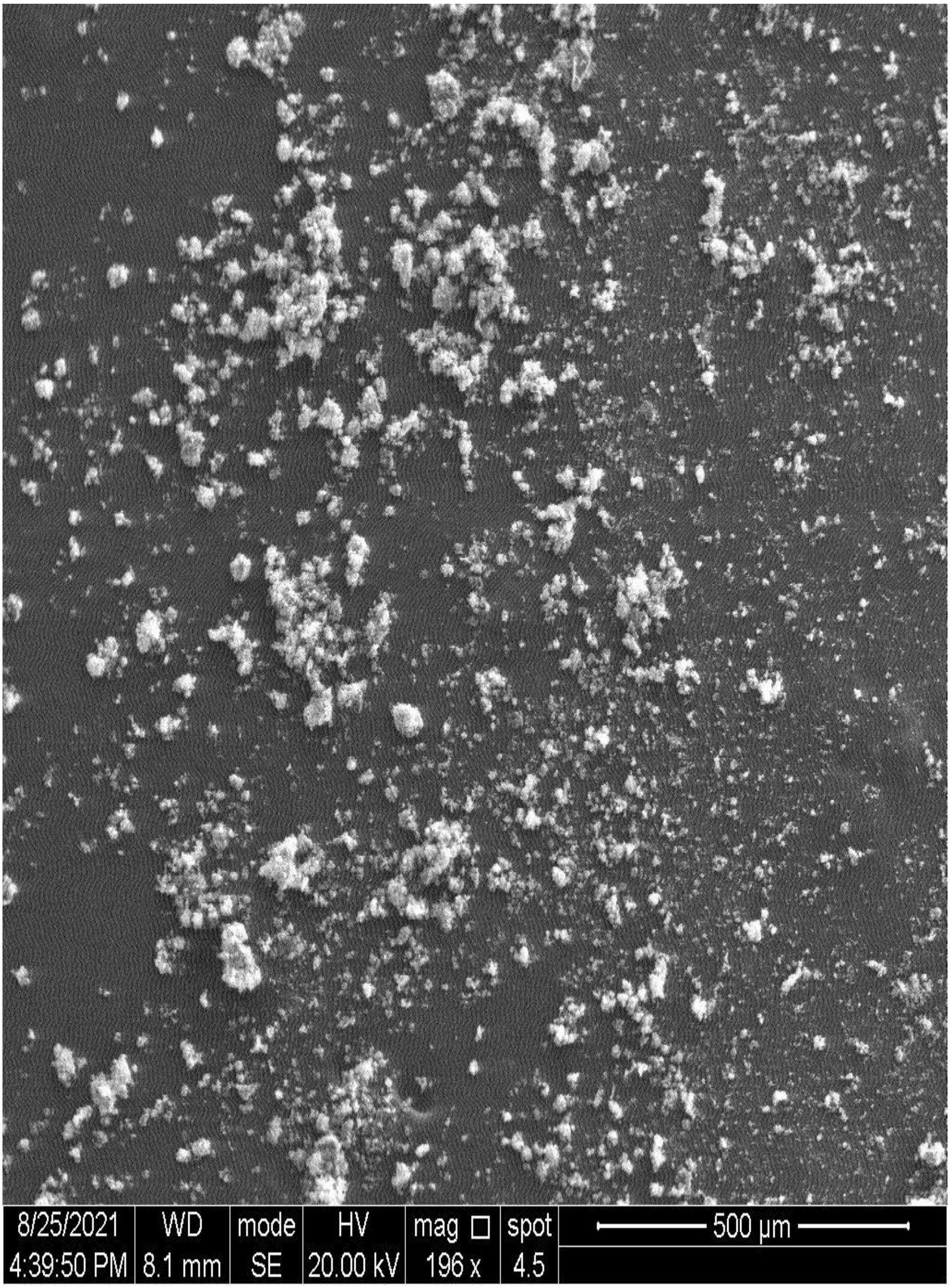
mode
SE
HV
20.00 kV
mag □
322 x
spot
4.5
300 µm

Appendix (D3)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WD
8.1 mm
mode
SE
HV
20.00 kV
mag □
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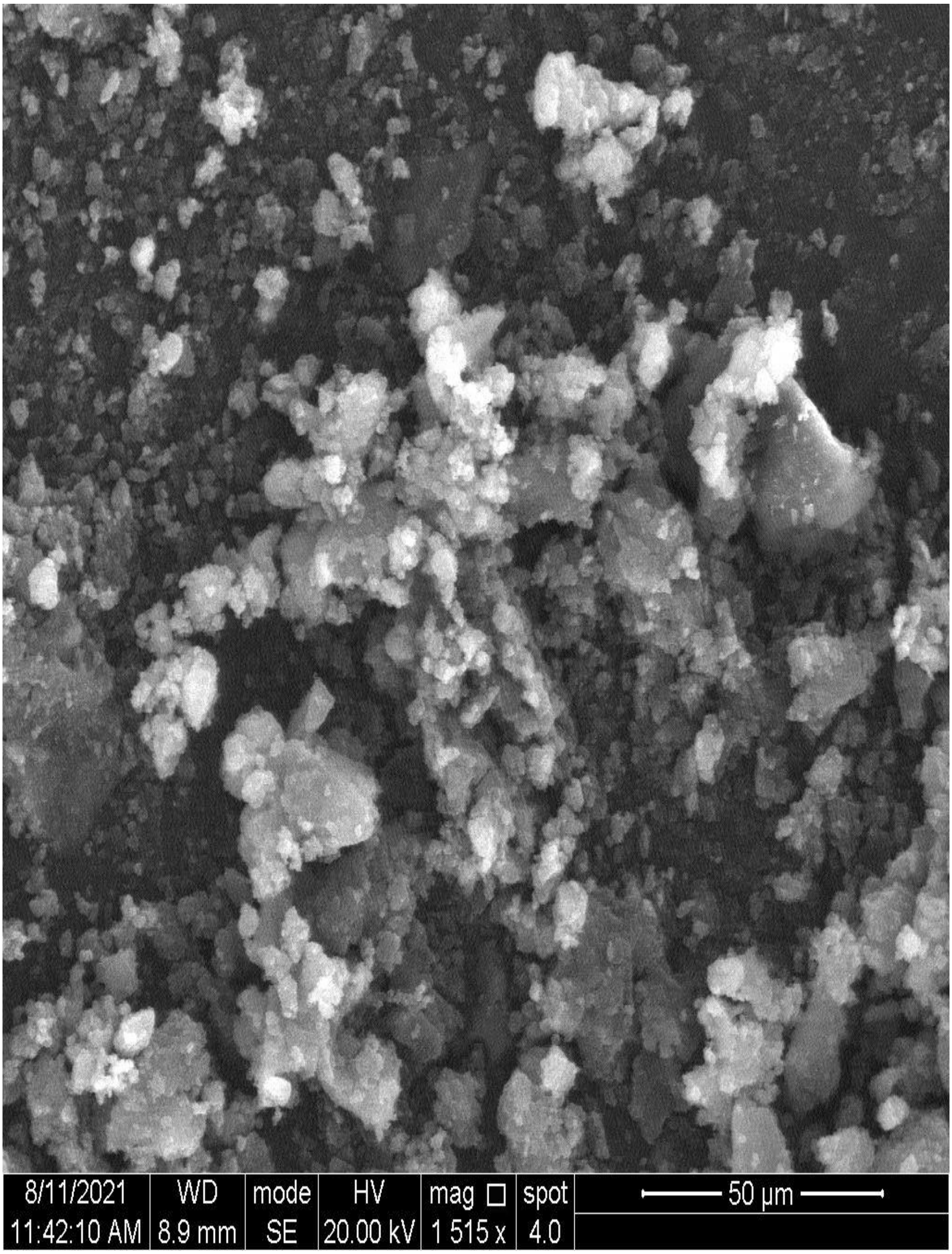
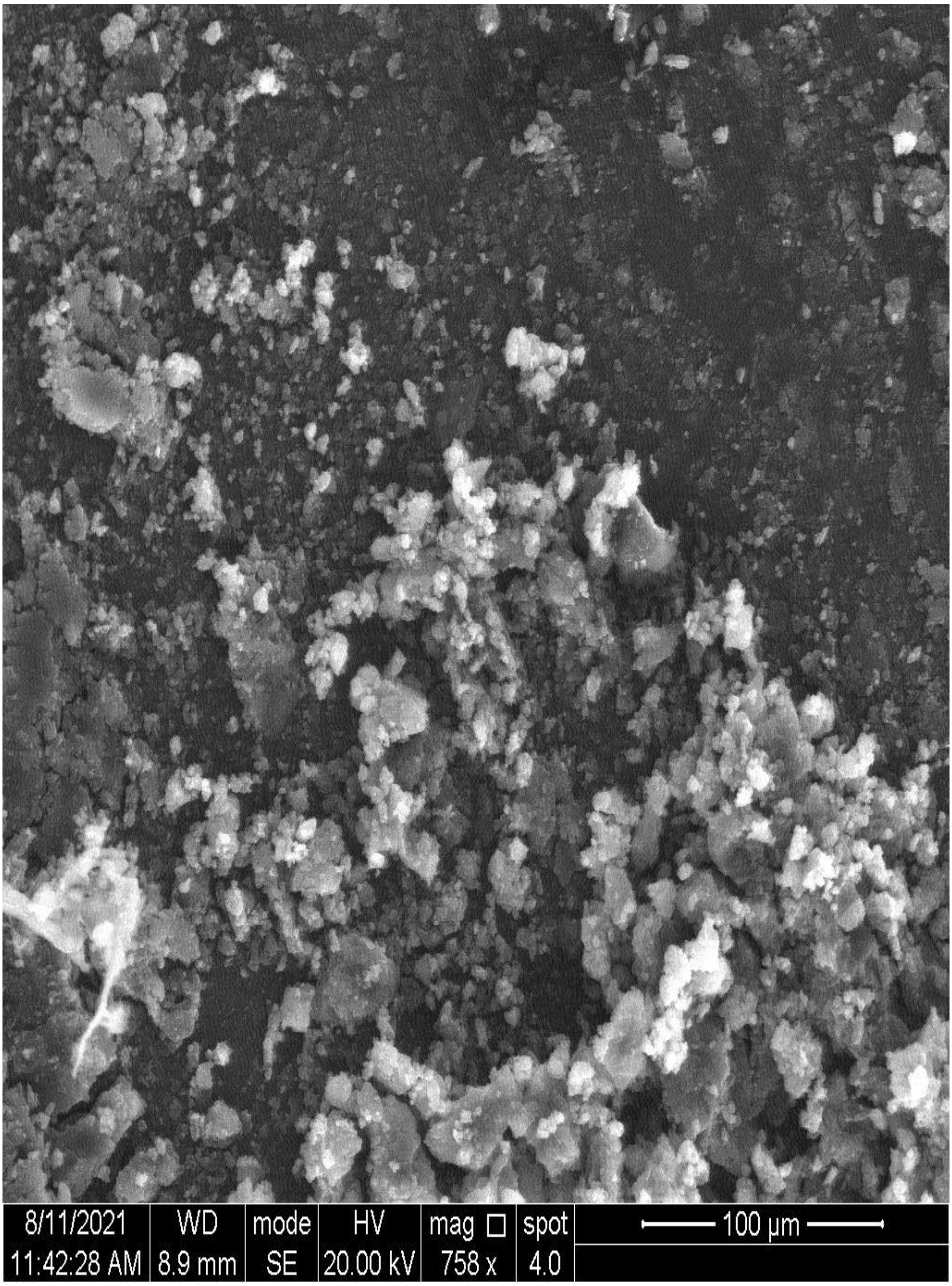
spot
4.5
500 µm

Appendix (D4)

SEM photos at speed 1500 rpm and CR= 15.5 Nano-diesel



Appendix (D5)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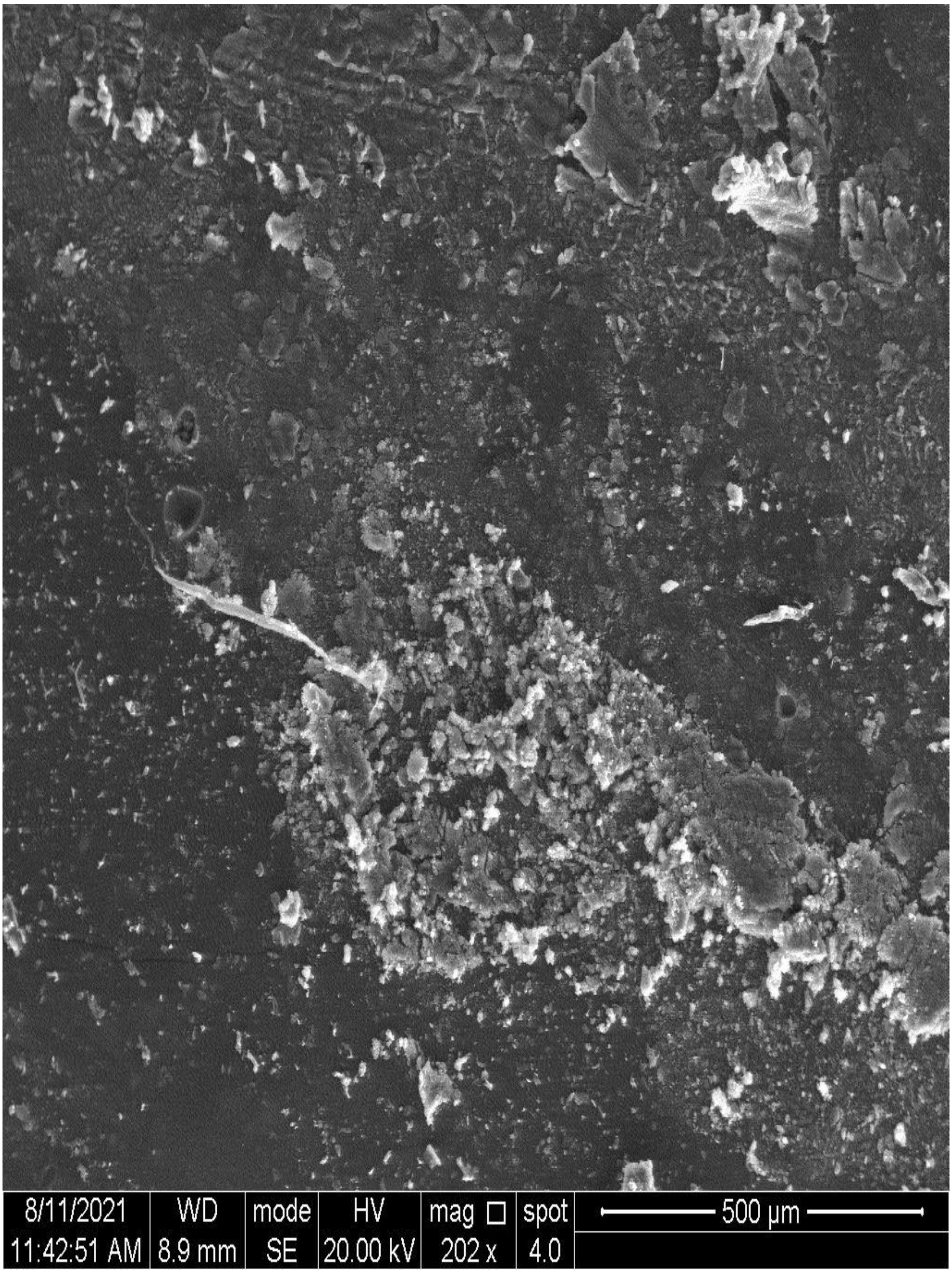
8.9 mm
mode
SE
HV
20.00 kV
mag
758 x
spot
4.0
100 µm

Appendix (D6)


8/11/2021
11:42:51 AM
WD
8.9 mm
mode
SE
HV
20.00 kV
mag
202 x
spot
4.0
500 µm

المستخلص :

تهدف هذه الدراسة إلى التحقيق التجريبي في تأثير إضافة جزيئات Al_2O_3 النانوية إلى وقود الديزل النقي على تركيزات السخام والهيدروكربون غير المحترق المنبعثة من محركات الديزل عند الأحمال ونسب الضغط المختلفة. يتم تحضير وقود النانو عن طريق خلط أكسيد الألومنيوم (Al_2O_3))قطر الجسيمات <50 نانومتر) ، مع وقود الديزل باستخدام الخلاط والمنظف بالموجات فوق الصوتية. أجري التحقيق على محرك ديزل ذو نسبة انضغاط متغيرة ، أحادي الأسطوانة ، رباعي الأشواط ، ذو حقن مباشر ، إزاحة (553 سم 3). يولد المحرك 3.7 كيلو واط عند 1500 دورة في الدقيقة. تستخدم ثلاث جرعات من جسيمات Nano-AL_2O_3 (25 و 50 و 100 جزء في المليون) في تحضير الديزل النانوي. وجد بشكل عام أن إضافة جزيئات النانو إلى وقود الديزل يقلل من تركيز السخام المنبعث. أظهرت النتائج أنه بالنسبة لجميع أنواع الوقود (الديزل النقي ، الديزل (AL_2O_3 + يزداد تركيز السخام مع الحمل. بالنسبة للديزل النقي بدون حمل ونسبة ضغط 13.5 ، يكون تركيز السخام (364 مجم / م 3) تحت نفس CR ولكن عند التحميل الكامل يكون تركيز السخام (900 مجم / م 3). أيضًا بالنسبة للديزل النقي و 13.5 كرون ، ولا يوجد حمل ، يكون تركيز التغطية الصحية الشاملة (2743 مجم / م 3) بينما عند التحميل الكامل يكون التركيز (3126 مجم / م 3.(

تظهر النتائج أيضًا أن إضافة جزيئات النانو إلى وقود الديزل تقلل من تركيز السخام وتزيد من تركيز UHCلجميع الجرعات. على سبيل المثال ، عند جرعة 100 جزء في المليون وحمل كامل و 13.5 درجة مئوية ، يكون تركيز السخام (366 مجم / م 3) مقارنة بـ (900 مجم / م 3) للديزل النقي تحت نفس الظروف. يزداد تركيز UHC من (3126 مجم / م 3) للديزل النقي عند التحميل الكامل ومن CR13.5إلى (3663.75 مجم / م 3) للنانو ديزل بجرعة 100 جزء في المليون تحت نفس الظروف.

تكشف النتائج أيضًا أن إضافة جزيئات النانو إلى وقود الديزل يقلل كلاً من السخام وتركيزات UHC في جميع نسب الضغط. على سبيل المثال ، مع جرعة100جزء في المليون والحمل الكامل ، CR 13.5 ، يكون تركيز السخام (366 مجم / م 3) ، ولكن عند جرعة100جزء في المليون والحمل الكامل ، CR 17.5 ، يكون تركيز السخام (266 مجم / م 3). في ظل نفس الظروف ، انخفض تركيز الهيدروكربونات الغير محترقة من (3663 مجم / م 3) لـ CR 13.5 إلى (3354 مجم / م 3) لـCR17.5

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل / كلية الهندسة
قسم الهندسة الميكانيكية

دراسة عملية التأثير خلط الحبيبات النانونيه لأوكسيد الالمنيوم مع وقود الديزل على تركيز السناج المنبعث من عادم محرك الديزل

رسالة
مقدمة إلى كلية الهندسة – جامعة بابل وهي جزء من متطلبات نيل درجة ماجستير في الهندسة/ الهندسة الميكانيكية/ قدرة

أعدت من قبل
رؤى حسن عبد علي عبد
(بكالوريوس علوم في الهندسة الميكانيكية, ٢٠٠٧)

بأشراف

الاستاذ الدكتور هارون عبد الكاظم شهد

٢٠٢١ م ١٤٤٢ هـ