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Experimental Investigation of Effect of Nanoparticles on Fuel Spray Penetration and Cone Angle

A Dissertation

Submitted to The Mechanical Engineering Department / College of Engineering / University of Babylon as a Partial Fulfillment of The Requirements for the Degree of Higher Diploma in Mechanical Engineering (Fuel and Energy).

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بسم الله الرحمن الرحيم

هو الأول والآخر والظاهر والباطن وهو بكل شيء عليم

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Dedication

This work is dedicated to my family who provided great support to me throughout my study and research .

Yasir Fadhil Abood

Jan, 2022

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Abstract

This experimental work includes studying the effect of nanoparticles on two spray macroscopic characteristics namely spray tip penetration and spray cone angle .Three types of nano-diesel are prepared , namely diesel-Silica , diesel-Alumina and diesel-Titania .Three doses of each type is used namely 25 , 50 and 100 ppm .Therefor four types of fuel are prepared , three nano-fuels and one clear diesel . A high speed camera is used to study the effect of nano particles on injected fuel spray penetration and cone angle . Fuel is injected in a horizontal Pyrex cylinder to facilitate the photography .

The fuel spray penetration and spray cone angle are obtained from processing and analyzing the video recordings of the injection process. The processed images show that the spray tip penetration of nano fuels is increased and the spray cone angle is decreased slightly due to the addition of nanoparticles .This alteration depending on the density of the nanoparticles that added to the clear diesel fuel (DF) . As concerns to the spray tip penetration the (DF + TiO_2) has the biggest change, (16.74 % , 21.03 % and 34.66 %) for blending ratios of (25 , 50 and 100) ppm respectively , while the (DF + SiO2) has the smallest change (8.94 % , 12.11 % and 15.5 %) for blending ratios of (25 , 50 and 100) ppm respectively . Also as concerns to the spray cone angle the (DF + TiO_2) has the biggest reduction change (8.92 % , 14.26 % and 17.62 %) for blending ratios of (25 , 50 and 100) ppm , while the (DF + SiO_2) has the smallest reduction change (4.5 % ,9.31 % and 12.66 %) for blending ratios of (25 , 50 and 100) ppm respectively .

It is also noticed that as the nano-particle dose increase the effect on both characteristics increased for all types of nano-fuels .

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Nomenclature

Symbol	Description	Units
C_v , K_v	Velocity coefficient of nozzle	
D_n	Nozzle diameter	m
k_{bl} , α	Breakup parameter length	$m^{0.5}$
K_{bt}	Coefficient of breakup time	$m^{0.5}$
K_p	Coefficient of penetration	$m^{0.25}$
K_v , C_v	Velocity coefficient of nozzle	
L_b	Breakup length of liquid jet	m
ΔP	Effective injection pressure	Pa
S	Spray tip penetration	m
Š	Spray tip penetration before breakup	m
t	Elapsed time from injection start	s
t_{de}	Time from start of decay to the defined injection termination .	s
t_{decay}	The period that injection velocity decays	s
t_{inj}	The injection duration .	s
U	Spray tip velocity after breakup	m/s
Ŭ	Spray tip velocity before breakup	m/s
U_{inj}	Injection velocity	m/s

Greek Symbol

Symbol	Description	Units
α , k_{bl}	Breakup parameter length	$m^{0.5}$
Θ	Spray angle .	deg
μ_f	Dynamic Viscosity of clear diesel fuel	kg . s /m
μ_{nf}	Dynamic Viscosity of nanofuel	kg . s /m
ρ_a	Density of ambient gas	kg/m^3
ρ_f	Density of clear diesel fuel	kg/m^3
ρ_l	Density of liquid fuel	kg/m^3
ρ_{nf}	Density of nanofuel	kg/m^3
ρ_p	Density of nanoparticle	kg/m^3
φ	Solid volume fraction of nanoparticles	ppm

Subscripts

Symbol	Meaning
a	Ambient gas
b	Breakup
bl	Breakup length
bt	Breakup time
f	Clear diesel fuel
inj	Injection
l	Liquid fuel
p	Penetration
n	Nozzle
nf	Nanofuel
v	Velocity

Abbreviations

Symbol	Description
ATDC	After Top Dead Center
BD 65	65% Biodiesel + 35% Clear diesel
BMEP	Brake mean Effective Pressure
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
BTDC	Before Top Dead Center
BTE	Brake Thermal Efficiency
CFD	Computational Fluid Dynamic
CNT	Carbon Nano Tube
CVCC	Constant Volume Combustion Chamber
DF 100	Clear diesel
DI	Direct Injection
EOI	End Of Injection
ET	Engine Torque
FPS	Frame Per Second
GO	Graphine Oxide
HRR	Heat Release Rate
ILPG	Iraqi Liquefied Petroleum Gas
MWCNT	Multi Wall Carbon Nano Tube
NO_x	Oxides of Nitrogen
POME	Palim Oil Methyl Ester
PD	Petroleum Diesel
PM	Particulate Matter
PSJ 090	Preheated to 90 ˚C Jatropha Oil
SF_6	Sulfur Hexafluoride
SJ 030	Jatropha Oil at 30 ˚C
SMD	Sauter Mean Diameter
UBF	Ultra Biodiesel fuel
UHC	Unburnt Hydrocarbons
Cr	Compression Ratio
PPM	Part Per Million

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1.1 General

The non - renewable fossil fuel is expected to be exhausted in a few next decades . Also, burning process of this fuel causes an enormous amount of pollutants poisoning the environment of living creatures . Therefore , the searching for economic sustainable alternative fuels is very crucial and urgent matter [11] . In recent direct injection (DI) diesel engine, the fuel penetration is a serious parameter to be considered for designing of combustion chambers . Improper tip penetration of diesel spray will lead to liquid impingement on the cylinder walls particularly in small bore engines and at cold starting conditions .This may cause obvious enhancement of emissions such as oxides of nitrogen (NO_x) , unburnt hydrocarbons (UHC) , particulate matter (PM) , soot , etc . and minimize engine performance and efficiency [9] . Numerous researches were performed to decreasing the above emissions because of the very strict regulations of emissions . There are three type of improvements , the researches said , the manufacturers have to made modification in engine design in order to reduce this emissions which are changing combustion chamber design , finding a new fuels and finally treating the exhaust gases . In order to formulate a new fuel , the researches suggest to use a very small rate of nano particles with the traditional diesel fuel . This addition of nano particles blended with fuel impact strongly the properties of new nanofuel compared to the commercial traditional fuel . This enhancement of nanofuel properties are due to the particles surface area per volume rise causing large contact area during the combustion process releasing more energy of fuel [12] . The injection time starts from 15 – 30 degree BTDC and ending 5 – 10 degree ATDC . The fuel exposed to several process such as atomizing , vaporizing , mixing , self ignited and combusting .

1.2 Critical properties of diesel fuel .

- **Density**

Density or mass density of a fluid is the ratio of the mass of a fluid to its volume. The density of a liquid may be considered as constant while that of a gases change with the variation of pressure and temperature. It affects strongly the process of spraying the fuel especially the tip penetration and the cone angle. The researches showed that the addition of nanoparticles to the clear diesel improves the fuel properties including density, fire point and flash point [28].

- **Viscosity**

Viscosity is the quantity that describes a fluid's resistance to flow. It is a thermo – physical property that plays a vital action in fluid flow and heat transfer issues. It affects the fuel injection system components as the low viscosity fuel can cause a wear in it, while the high fuel viscosity can cause an excessive resistance to flow and needed more power. The researches demonstrated that the addition of nanoparticles increased viscosity [19] .

- **Volatility**

Volatility is a characteristic of a fuel which describes how fast the fuel vaporizes at a given conditions. It plays a vital role to produce a sufficient mixture of fuel and air in order to have a good ignition quality in the specified working range .The unburned hydrocarbons, and other pollutants are all affected by this property [19].

- **Cetane number**

Cetane number is a measurement of the quality or performance of diesel fuel. Higher the cetane number of a diesel fuel means better ignition properties and shorter delay time which means less knocking, while, low cetane number means longer delay time causing more knocking. It is the volume percentage of cetane (n-hexadecane , cetane number = 100 with alpha methyl naphthalene 9 cetane number = 0) , this mixture will give the standard of 13 deg (crank shaft) ignition delay at a specified compression ratio related to that sample [28] .

- **Cloud point**

Is the temperature at which crystal of wax begins to separate and observed in a petroleum products giving the liquid fuel cloudy appearance when fuel cooled to the specified temperature .The formation rate of wax crystals depend on the initial nucleation points .The nanoparticles will raise this points which eventually initiates clouds , so the starting of clouds depend on the fraction of nanoparticles [19].

- **Pour point**

Is the lower temperature at which oil is observed to flow under the conditions of the test and below this temperature the fuel ceases to flow. It is so important indication in the field of translating fluid in pipes across long distances [19].

- **Flash point**

Is the lowest temperature at which a liquid fuel will release vapor at an adequate rate to form a mixture with air that will ignites in the existence of an ignition source . Adding the nanoparticles enhance the flash point [19].

- **Fire point**

Is the temperature to which the fuel has to be heated under prescribed conditions in order to burn continuously for a five second when the mixture of fuel vapor and air ignited by a specified flame . Fire point is higher than flash point [19].

1.3 Nanoparticles

Nanoparticles are generally known as particles with size approximately between 1 and 100 nm .We can classify the nanoparticles into several groups which are metal (like Fe , Si , Zr , Ag), metal oxides (like Fe_2O_3 , Al_2O_3 , Mn_2O_3 , CeO_2 , TiO_2 , Co_3O_4 , CuO , ZnO , SiO_2 , AgO) and non-metal (like GO , CNT , MWCNT , MoO_3) nanoparticles . Nanofluid is a two phase colloidal mixture consisting of a nano-sized particles dispersing in a base of liquid. The major goal of adding nanoparticles to the diesel fuel is to provide a huge surface to volume ratio and boost the number of reactive surface. It permits the nanoparticles to behave as an operative chemical catalyst which enhance the mixing style of air and the fuel causes a fully combusted chemical reaction .The nanofuel possessed better characteristics like flash point and calorific value and consequently lower BSFC [28] .

Nano fuels play a vital role in improving the fuel features and enhancing combustion specifications and lowering the harmful pollutants and emissions. It has been proved that mixing fuels with a small amount of nanoparticles (w < 5 % wt) can elevate the fuel economy by (15 -20) % , while reducing the pollutant emissions by (40 – 60) % due to that nano fuels have better surface area and better suspension stability [21] . Nanoparticles mixed with diesel fuel shortening the ignition delay time through acceleration of chemical reactions by reducing the evaporation time , consequently improving the ignition properties [22] .

- **Aluminum oxide nanoparticles (Alumina , Al_2O_3) :**

Nano-sized alumina occurs in the form of spherical or nearly spherical nanoparticles, and in the form of oriented or undirected fibers. It has a high specific surface area (>100 m^2/g). Aluminum based nanoparticles are the most used as an additives in diesel fuel. It has a positive influence on the performance, combustion and emissions of diesel fuel DI engine. Different size of alumina nanoparticles are studied when added to a clear diesel, it increases cetane number, density and viscosity of the fuel. It decreases the delay time due to this elevation of viscosity. It decreases the emissions of NO_x , CO and UHC . A considerable increasing in BTE and BP and decreasing in BSFC , due to the improvement in the combustion features of the mixture of the nanofuel and the enhancement air mixing ratio [28] .

- **Titanium Oxide (Titania , TiO_2) nanoparticles :**

It's also knowing as flamenco , rutile , titanium dioxide and dioxotitanium . It is an inorganic compound and has a wide range of applications especially there ability to prevent bacterial vegetation The addition of TiO_2 nanoparticles enhanced the fuel features including fire point , viscosity , density , calorific value and decreasing CO , NO_x , UHC and smoke emission . The adding of this nanoparticles to the clear diesel fuel contributed to the most significant reduction in the delay time . Its amendment to nanofuel is due to the function of TiO_2 nanoparticles as oxygen buffers and fuels booster which resulted in complete combustion and higher thermal efficiency [28] .

- **Silicon Dioxide (SiO_2) nanoparticles :**

It's also knowing as silica nanoparticles or nano-silica . It appears in white powder. The SiO_2 nanofuel (nano SiO_2 + clear fuel) mixture showed a lower fuel density, with no considerable change in the calorific value compared to a clear diesel fuel with a lower viscosity feature [28] . Table (1.1) shows some physical properties of nano-particles used in present work .

Table 1.1 : Specifications of nanoparticles [19] .

	Particles	Nano SiO_2	Nano Al_2O_3	Nano TiO_2
1	Density (kg/m^3)	2400	3970	4230
2	Specific heat(J/kg .K)	705	765	710
3	Thermal conductivity (W/m .K)	1.4	40	9
4	Average size (nm)	50	50	50
5	Shape	Spherical	Spherical	Spherical
6	Appearance	white	white	white

1.4 Advantages of using nanoparticles .

Nanoparticles are used to improve several physical properties of diesel fuel .The advantages of using nanoparticles with clear diesel fuel are :

1- The nanoparticles blended with diesel fuel enhanced the surface area of contact with air and therefore enhanced the combustion effectiveness [29].
2- The metal oxide nanoparticles have the activity as an oxygen buffer that release oxygen , so enhances the complete combustion [29] .
3- It improves the engine performance . It increases the brake power (BP) , break thermal efficiency (BTE) , engine torque (ET) and peak pressure and decreases the specific fuel consumption (BSFC) [12].
4- It reduces the toxic emissions from engine . It decreases the fractions of pollutants in exhaust gases such as CO , CO_2 , NO_x , smoke and particulate matter (PM) [31].
5- It accelerates the reaction and minimizes the delay period [27].
6- It improves cetane number [28].

1.5 Disadvantages of using nanoparticles .

There are some disadvantages in using nanoparticles like :

1- The viscosity increases if the particles concentration increased in the solution [19].
2- The nanoparticles has the ability to accumulate into larger agglomerates that may causing clogging in the pipes of fuel feeding system or in the orifice of injector [19].
3- Exhaust gases of the engine operates with metal nanoparticles contains solid metal oxide as a residual particulate matter which possesses a great health risk .
4- Extra costs associated with using nanoparticles due to using surfactants prevent them from agglomeration , surface modifications and electrostatic repulsion [31] .

1.6 Objective of Present work .

The aim of this research is to study the effect of adding small average size (50 nm) silica, alumina and titania nanoparticles with lower concentrations of 25, 50 and 100 ppm for each separately to a clear traditional Iraqi diesel on two of macroscopic characteristics of spray namely spray length penetration and spray cone angle .

1.7 Layout of the dissertation .

The dissertation comprises of five chapters. In chapter 1, an introduction, critical properties of fuel, nanoparticles and a general overview is submitted. In chapter 2 , a systematic literature review of several chosen researches that related to the research topic are presented , and this survey includes experimental and theoretical according to their published date from older to the newest . Chapter 3, introducing the experimental constructions and measuring apparatus. In chapter 4, the results of the work and discussion of them are presented. Conclusions and suggestions for some future works are summarized in chapter 5.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Experimental Researches:

Arai and Amagai [1994] [1] , studied the configuration of multi – stage diffusion diesel spray such as the tip penetration , spray angle , breakup height , and the diameter with distribution of fuel droplets experimentally .This multi- stage spray was configured by the three split fuel impulses at one diffusion stage .The time and displacement of spray features were captured and measured by utilizing drum camera YAG Laser visualization system .They proposed a novel idea about a diesel diffusion or spray in order to explain the spray construction .The results showed that the injection period of the split sprays impacted on the spray angle and accumulated diffusion volume .The equivalence ratio of multi – stage diffusion was less in comparison to that of a single diffusion .

Crua et al. [2010] [5] , analyzed experimentally the establishment and breakup of fuel spray in a common rail injector utilize along range microscope . A rapid compression machine with ambient maximum pressure up to 8 Mpa was used to perform the test at atmospheric conditions and injection pressure about 160 Mpa .The resolution of the images was 0.6 µm / pixel and a viewing range of 768 x 614 µm to be viewed .The authors conducted the experiment through a reciprocating rapid compression machine of single cylinder and two stroke engine. They controlled the extent and timing of the spray and the amount of pressure separately by a tradition – built controller .The diameter of nozzle orifice was 135 µm with cylindrical shape and a length of 1 mm . The authors showed that an oblate spheroid cap for a wide range of situations were formed of residual fluid from the last injection which have been stayed in the nozzle orifice .They described the effect of engine operating conditions on the spatiotemporal establishing and progressing of the spheroid cap under non-evaporating and evaporating situations .

Ghurri et al. [2011] [6] , investigated experimentally the features of clear diesel spray (DF 100) and biodiesel mixture (BD 65) injected into an atmospheric chamber through making use of image processing software .The density was 850 kg/m^3 for DF 100 and 884 kg/m^3 for BD 65 , viscosity was 3.25 mm^2/s for DF 100 and 4 mm^2/s for BD 65 .The injection system was a common rail with 5 side holes injector with needle diameter of 0.2 mm , injection duration was 1000 µs with injection pressure of 30 , 60 , 90 Mpa . The atmospheric pressure and temperature were 1 atm and 283 K . The authors showed that at lower injection pressure , the spray penetration of BD 65 was lightly shorter than that of DF 100 , while at high injection pressure spray penetration of BD 65 was longer than that of DF 100 and at higher injection pressure the spray cone angle of BD 65 was narrower than that of DF 100 .

Lequien et al. [2013] [9] , studied the influence of hot gases reservoirs on the liquid phase length of diesel spray in an optical very tough DI diesel fuel engine . They focused on how jet – jet influenced the liquid phase interference penetration . The test engine was Scania D12 changed to get optical entrance to the chamber of combustion . The engine was single cylinder with four valves, compression ratio of 15.6/1 and swirl number of 2.18 . The results showed that the hot gas reservoirs do not significantly affect the liquid length . It was also found that a closer jet causes a more pronounced evaporative cooling which seems to explain the longer liquid length noticed on the confined jets .

Dizayi et al. [2014] [10] , examined the fuel jet features of the UBF (Ultra Biodiesel Fuel) and it's mixture with PD (Petroleum Diesel) . The study showed the effects of density , viscosity and lower heating value of the UBF and it's mixtures with PD on the jet specifications like penetration tip length, SMD , jet angle and jet velocity at various engine speeds and timings of injection , considering the piston head dimensions as a limit for the longest jet penetration . The tested engine is a Mercedes Benz engine model OM 457 LA EURO 5 with 6 in line cylinder , 18.5/1 compression ratio , rated power of 315 kW at 1900 rpm , a maximum torque of 2100 Nm at 1100 rpm , maximum injection pressure of 1800 bar , number of injection holes was 7 with a diameter of 200 µm and exhaust gas temperature of 530 ˚C . The authors classified the fuel jet features with UBF content into two groups . The first was the percentage difference in spray features for UBF content variation in the mixtures from (0 – 80) % . It followed an approximated fixed degree of change in jet features . The difference in jet features at 40 ˚C was nearly twice of those at 90 ˚C . The second group was the difference of UBF content in the mixture from (80 - 100) % which showed a great alteration in jet features . Comparing the fuel jet features for this groups at 90 ˚C with (0 – 80) % showed that : The degree of rise of SMD was 5.5 times higher , the degree of cone angle reduction was about 4 times lower and the degree of jet length was 4.7 times higher . Performing the same comparison at 40 ˚C gave the SMD rise , cone angle reduction and spray penetration rise in the following order : 14.25 % , 6.45 % and 8.84 % respectively .

Xie et al. [2015][11] , studied the macroscopic spray specifications of different mixtures of fuel extracted from drainage oil and diesel on different ratios , like spray tip penetration , average spray angle , spray area and volume under various pressure of injection from 60 to 100 MPa and for various ambient pressure from 0.1 to 0.9 MPa using common rail system attached with fixed volume chamber .The test rig composed of high speed capturing system , and enhanced pressure system for injection The results was as following :

1- While injection pressure is increased, penetration, peak mean penetration velocity were increased too .
2- Angle and mean angle of spray were slightly increased with increase of ambient pressure .
3- Spray penetration and peak mean penetration speed decreased with increasing of ambient chamber pressure .
4- The penetration showed little variation when blend ratio is increased . Spray angle and mean angle of spray diminishes slightly and the spray profile became narrower .
5- Clear traditional diesel gave wider spray angle when compared to other fuel.
6- Spray area and volume increased dramatically with enhancement of spray penetration .
7- viscosity and surface tension were main properties that affect the spray specifications and they both are increased when the blend ratios of biodiesel are increased .

Venkatesan and kardiresh [2015] [12] , studied experimentally the influence of adding nano – aluminum oxide (nano- alumina) to diesel fuel on combustion engine performance . The test engine was a single cylinder , four strokes , water – cooled with rated power of 3.5 kW . The nanoparticles size was 40 nm . The particles was mixed with diesel fuel at the rate of (1 – 1.5) g / l .The results showed improvement in brake thermal efficiency (BTE) by 6.17 % and 2.27 % for D + 1.5 Al and D + 1 Al respectively . Emissions of HC , NO_x , Smoke and CO was reduced for (D + 1.5 Al) and (D + 1Al) by about 35.18 % and 29.62 % at full load , 30.67 % and 27 % at maximum BMEP , 14.48 % and 10.34 % and finally 28.57 % and 22.77 % at full load respectively .

Weiss et al. [2016] [13] , investigated the penetration of diesel spray using Schlieren – Mie techniques under diesel engine relevant conditions .The experiment was conducting in the high pressure combustion vessel " OptiVep " at FAU .A particular injector was manufactured for the studying by Continental Automotive GmbH based on transportation cars and supplied with three holes in order to enhanced optical access and visualization . An excessive Photrons Fastcam SA–Z M1 camera with a resolution of 408 X 384 pixels at 100,000 frame per second was used in order to capture a spray of 500 m/s speed .The authors showed that the merge between Schlieren and Mie techniques gave a composite phase of liquid and non-liquid phases .Also they showed that when taken off non-liquid fuel , the cone angle in the Schlieren signal was increased and they found that the non-liquid penetration followed the spray model from Hiroyasu and Arai .

Chaichan et al. [2017] [14] , studied experimentally the performance and emissions characteristics of a blend of nano - fluid (nano Al_2O_3 + water) and clear Iraqi diesel .The test engine was FIAT , 4 – cylinder, 4 – stroke, in line, DI, water cooled, natural aspired, compression ratio of 17 and ten nozzle holes of 0.48 mm diameter .The nano - AL_2O_3 (nano – alumina) of 51 diameter was used .Different weight ratios of this nano - particle were blended with water to form a nanoparticles emulsion .The weight fraction used were 1,3,5,7 and 10 % Then a fixed volume ratio of the resulting emulsion (10 %) was added to the diesel and well mixed .The authors showed that adding aqueous nano – alumina to diesel reduced the SFC for all loads at constant speed of engine . Also, they showed that the BTE for mixture was higher than that of clear diesel for all specified loads .The carbon monoxide , HC , NO_x , and PM were lowered when adding nano – alumina and the CO_2 was enhanced by adding of nano – alumina .

Kegl and Lešnik [2018] [16] , examined the macroscopic fuel spray features of conventional diesel and rapeseed oil biodiesel injected into a constant volume high pressure chamber . At lower spray pressure inside the combustion chamber , the figure of fuel spray seems to be more inclined and showed higher cavitation inside the nozzle hole . The following results were obtained :

1- The spray chamber pressure affects the inclinations of fuel spray and it was higher at low pressure of chamber because higher pressure inhibits cavitation in nozzle hole .
2- Mineral diesel showed stronger cavitation in comparison to biodiesel .
3- Penetration at high chamber pressure is shorter than at lower pressure for petroleum diesel and biodiesel because of the resistance during spray proceeding .
4- An altered mathematical correlation for tip penetration and angle of spray is developed . This new correlation had two parts and had results match with experiments along the part of spry development .The new or altered correlation for penetration and angle of spray are more close to the experimental data for both petroleum and biodiesel fuel .

Selvan and Rajan [2018][17] , studied experimentally the spray formation in enhanced pressure chamber through optical entrance . The material used to manufactured the boosted pressure chamber was cast iron and two glasses fitted at 90 degrees to each other in order to captured the photos of spray profile inside the chamber by utilizing high speed camera .Spray features were studied at different pressure chamber with a pressure amount from 1 to 10 bar .The viscosity impact and pressure in chamber lead to change in spray formation parameters .Penetration of spray decreased when there was an elevation in chamber pressure for clear diesel and palm oil methyl ester (POME) . Several parameters like cone angle, area, and width of spray were elevated with an elevation in chamber inside pressure .

Naser [2018] [19] , examined experimentally the impact of adding two types of nanoparticles in various dose to the conventional clear diesel fuel on it's physical properties, engine performance and emissions and finally the impact of this additives on heat release . The research was carried out on a single cylinder, water cooled, four strokes, DI diesel engine with a power of 3.7 kW at 1500 rpm. A common rail fuel injection system with a three hole injector of 0.2 mm diameter was used . Nano alumina (nano Al_2O_3) and nano titania (nano TiO_2) with four doses (25,50,100 and 150) ppm with a nominal diameter less 45 nm were used . The results were as follow :

1- There was an enhancement in the value of cetane number from 51.6 for clear diesel to 54.3 and 53.3 for DF + alumina and DF + titania respectively when the additives at dose of 150 ppm was used .
2- There was an increase in the flash point of fuel from 53 ˚C for clear diesel to 61 ˚ C and 60 ˚ C when adding alumina and titania to clear diesel respectively .

Giraldo et al. [2018] [20] , studied the impact of injection pressure and properties of the ambient gas on fuel spray penetration and fuel spray cone angle .The test was carried out with a multi-hole piezo electric injector in various ambient gases (N_2 , Co_2 , SF_6) under isothermal conditions , using the optical apparatus .The results showed that the ambient density was a critical criteria for the spray progressing . The two investigated important parameter, which are spray penetration and spreading angle, both were influenced considerably . The investigation also showed that the increase of ambient density inside the combustion chamber improved the spray spreading angle and shrank the spray penetration .

Abdullah et al. [2019] [22] , investigated the behavior of diesel spray specially the tip penetration in an inversed delta injection speed profile . The experiments were conducted at an enhanced density non-vaporizing state in a fixed volume chamber. Two available different injectors were straightly connected together. Injection speed profile was obtained with BOSCH long tube type method . The tests were performed in CVCC (constant volume combustion chamber) supplied with 35 mm diameter three quartz orifice. The peak speed of images was 30000 fps with 4 microsecond shuttering gate by utilizing a NAC MEMRE CAM HX-5 high speed camera supplied with Nikkor 105 mm f 2.8 mm lens . The results showed that smaller penetration is observed in inversed –

delta . The penetration of spray tip of rectangular fuel injection was related to time (t) of power of (0.5) while the penetration spray tip of inversed – delta kind of injection is related to time (t) of power (0.43) .

Adzmi et al. [2019] [23] , investigated experimentally the effects of nanoparticles blending with palm oil methyl easter (POME) on combustion features, performance of engine and emissions of exhaust gases .The test engine was YANMAR TF 120 M , single-cylinder , water cooled with rated power of 12 HP at 2400 rpm . Nano alumina (Al_2O_3) and nano silica (SiO_2) with an amount of 50 ppm and 100 ppm for each were mixed with POME. The results showed that (POME + SiO_2) and (POME + Al_2O_3) fuels increased maximum cylinder pressure by 16.5 % and 15.3 % at 28 Nm load and there was an improvement in HRR by 21.7 % at 21 Nm load . Also, the results showed a little enhancement in BTE for all test blends by matching with POME, while BSFC of (POME + 50 ppm Sio_2) and (POME + 50 ppm Al_2O_3) was enhanced by 15 % drop in fuel consumption . Emissions of (POME + SiO_2) and (POME + Al_2O_3) showed reductions for CO , CO_2 , NO_x by an average of 0.4 , 0.8 and 9.2% respectively .

Hoang and Le [2019] [24] , studied experimentally the configures of fuel spray using clear diesel fuel (DF) , Jatropha oil at 30˚C (SJ 030) and preheated to 90 ˚C Jatropha oil (PSJ 090) in a special tool rig .They found that the (SJ 030) fuel produced longer spray with narrow cone angle compared to DF , while the (PSJ 090) fuel produced approximately similar jet configuration to DF .This is due to the reduction in density, kinematic viscosity and surface tension when the Jatropha fuel is preheated .

Zhu et al. [2020] [25] , studied the effect of injector aging on spray configuration using optical engine .They used one new injector and one aged injector .They found that both injectors showed similar spray configuration .However the aged injector showed longer injection process and more fuel dribbling at end of injection.

Shi et al. [2020] [26] , studied the macroscopic features of liquid fuel blended with nanomaterial in a subsonic gaseous cross flow concentration on impact of breakup process . The influence of nanoadditives on the jet track and column breaking location were calculated . An additional constant was entered into the experimental relation of the column breaking location in order to understand the impact of the nanoadditives .The results showed that with small amount of nanoadditives, the surface tension of the blend was lightly enhanced , while the viscosity was enhanced greatly (about 30%) .These changes in the surface tension and viscosity had small impact on the breakup structure or stream path. Also, the researchers found that nanoadditives strengthened cavitation inside the liquid line. This resulted in an improvement in starting breakup mode for the nanofluid. Accordingly, the height of the column was reduced by about 20 % comparison to that of the clear fluid .

Dhahad et al. [2020] [27] , investigated the effects of adding nano particles of Al_2O_3 to Iraqi diesel ($C_{12.3}H_{22.2}$) with four mass fractions (25 , 50 , 100 and 150 ppm) on the several engine performance characteristics namely BTE, ignition delay period and peak pressure inside the combustion chamber .The test engine was a four strokes single cylinder water-cooled with three hole nozzle . The output power was 3.7 kW at rated speed of 1500 rpm and full rated load .The results showed great impression on the ignition and peak pressure inside the cylinder due to the addition of nano TiO_2 and nano Al_2O_3 . BTE increased from 18.9 % to 24.25 % and 20.45 % respectively , peak (maximum) pressure was raised to 60.4 bar and 63.2 bar respectively when the nanoparticles dose was 25 ppm .

Nouri et al. [2021] [29] , assessed the influence of mixing Fe_2O_3 and Al_2O_3 nanoparticles (30,60 and 90 ppm) and their hybrid with clear diesel fuel on combustion, performance and emissions of diesel engine. The test engine was air-cooled , single – cylinder, four stroke with rated power of 5.7 kW at 3000 rpm .The results showed increasing in power and torque up to 8 % and decreasing in BSFC up to 9 % because of addition of nano particles. Maximum pressure and HRR were enhanced by 4% and 15% respectively and the BTE was raised by up to 14% when adding the nanoparticles as compared to clear diesel fuel . Emissions of CO , NO_x and SO_2 were reduced by 21% , 24% and 23% respectively .

Kadem [2021] [30] , studied experimentally the velocity of the laminar stretched flame speed and laminar burning velocity of pre-mixed Iraqi Liquefied Petroleum gas (ILPG) with air at different equivalence ratios from 0.6 to 1.4 . A special rig was built in the labs of Mechanical Engineering Department in order to measure these two parameters .The results of the test showed that :

1- The maximum laminar stretched flame speed for ILPG happened at the stoichiometric mixture experimentally and numerically .
2- The maximum burning velocity for ILPG and Naphtha vapor at stoichiometric mixture equal to 35.5 cm/s and 49.45 cm/s respectively found by using program of ANSYS / FLUENT .

Gad et al. [2021] [31] , studied experimentally the effect of addition of Al_2O_3 nanoparticles (00 nm) to clear diesel on the engine combustion characteristics, emission and performance of a DI compression ignition engine .The test engine was a four cycle, air-cooled, single cylinder DEUTEZ diesel engine with 5.77 kW power output at rated speed of 1500 rpm with single injector .The dosing of Al_2O_3 nanoparticles is 20, 30 and 40 mg/l used with diesel fuel .The results showed that the SFC was decreased by about 5.5% at 40 ppm of AL_2O_3 at full load. Emissions of smoke, HC, Co_2 and NO_x was decreased to about 17% , 25% , 30% and 33% respectively using 40 ppm AL_2O_3 nanoparticles .

2.2 Theoretical Researches :

Berg et al. [2002] [2] , developed a primary breakup model based on resolved features of flow in the nozzle under cavitation flow . A combination of aerodynamic / turbulent procedure was utilized to calculate the breakup speed .The model gave the primary starting droplet size and speed distribution for the various droplet models .The model predicted the asymmetry of the spray configuration and the inhomogeneity of droplet dilution within the spray .They concluded that the model can predict spray behavior in more details near the nozzle . Validity of the model was approved by using practical data from AVL List GmbH Austria, AVL Powertrain Engineering Inc., MI, USA and Chalmers University of Technology, Sweden .

No [2007] [3] , studied the already available spray tip penetration models (before 1990's and the one reported lately) for maximum injection pressure and other fuel sprays . He also studied the correlations of diesel spray penetration with connection of liquid–phase penetration. He divided the existing theoretical correlations into seven groups : Fuel spray models, jet mixing model, cone model, two - phase flow model , quasi–jet model, momentum flux conservation model and non–dimensional parameters model. He divided the empirical relationships into two groups which are jet breakup model and breakup time and length model. He found that all the relations studied included the same factors like ambient gas density, time after the start of injection, pressure drop, diameter of nozzle orifice with different weight of each. He also found that the spray angle had been considered in all the theoretical correlation except the jet mixing model and the non – dimensional parameters model. So that choosing the right correlation for spray angle had affected the expectation of spray penetration .

No [2008] [4] , reviewed the available equations for prediction of maximum liquid core length of spray in vaporizing diesel engine conditions and suggested the future research. The author discussed and grouped the existing equations of liquid phase spray. The author reveled that the already found equations and models showed that the maximum liquid – phase diesel fuel penetration was a function of fuel, in-cylinder pressure and injection characteristics. Also the author classified the already existed models of liquid – phase diesel fuel penetration into three groups which are :

i. The zero – dimensional (empirical) models.
ii. The multidimensional models.
iii. The Other models.

The study showed that the maximum liquid – phase fuel penetration was influenced by the orifice diameter nozzle, volatility of fuel, injection pressure, ambient pressure of gas, fuel temperature and the density of gas inside the constant volume chamber.

Arai [2012] [8] , reviewed physical approaches about spray behavior and classified the parameters that are effected it into two groups which are :

1- Macroscopic parameters :
i. Spray angle . ii. Breakup length . iii. Core of spray .

iv. Spray penetration .

2- Microscopic parameters :

i.	Size distribution of spray .	iii.	Mean diameter of spray .
ii.	Spatial diameter of spray .	iv.	Turbulence .

He showed that the laminar liquid jet is driven by the two main forces which are : liquid force deformation caused by Rayleigh instability and shear force caused by high speed movement . He also expressed a formula for the spray tip penetration at first stage and the time and length of breakup and after breakup then introduced the non – dimensional scales of time and length of penetration . He gave many suggestion for enhancement of diesel engine and scientific advancements like atomization and two–phase jet flow. He gave a very specified information on phenomena like cavitation and breakup. He suggested several topics to be studied in the future.

Liu et al. [2018] [18] , had developed a zero–dimensional fuel spray modal to predict the spray penetration after the end of injection (EOI) for the varying injection ratio . They concluded that :

1- The effect of injection velocity which is the ratio between momentum flux and fuel mass flow rate on the tip spray cross–sectional area is an effective parameter with variable injection ratio
2- The effect of injection velocity after end of injection was gradually come to constant value named as target injection velocity after EOI
3- They suggested the following formula to calculate the target injection velocity after EOI .

$$U_{EOI} = (1- R_{IV} * t_{decay} / t_{inj}) * U_{max} \quad (2\text{-}1)$$

Where :

U_{EOI} = Injection velocity at the end of injection .

R_{IV} = A dimensionless ratio between the time ratio (t_{de}/t_{decay}) and the time ratio (t_{decay}/t_{inj}) .

t_{de}/t_{decay} = The decay extent of the injection velocity .

t_{decay}/t_{inj} = The proportion of the decay period in the injection duration .

t_{de} = Time from start of decay to the defined injection termination .

t_{decay} = The period that injection velocity decays .

t_{inj} = The injection duration .

4- The model of zero – dimensional spray had the ability to catch the propagation of fuel head penetration with time as compared to experimental data .

Arai [2018] [21] , developed a modified spray tip penetration equation to replace the empirical equation developed previously from experimental data obtained from the jerk pump injection system . Since the jerk pump injection system is replaced now days by the common rail injection system which operates under higher pressure than jerk injection system a new equation is required to calculate the spray penetration to account for the change .The new equations were as follows :

$$L_b = \alpha\,(\rho_l / \rho_a)^{1/2} . D_n = K_{bl} . (\rho_l / \rho_a)^{1/2} . D_n . \qquad (2-2)$$

$$t_b = (\alpha\,\rho_l\,D_n) / c_v\,(2\,\rho_a\,\Delta p)^{1/2} = (K_{bl} / (2)^{1/2} .K_v) * (\rho_l\,D_n / (\rho_a\,\Delta p)^{1/2})$$

$$= K_{bt} * (\rho_l\,D_n) / (\rho_a\,\Delta p)^{1/2} \qquad (2-3)$$

At $0 < t < t_b$

$$\check{S} = U_{inj} . t = K_v . (2\,\Delta p / \rho_l)^{1/2} . t \qquad (2-4)$$

$$\check{U} = U_{inj} = K_v . (2\,\Delta p / \rho_l)^{1/2} \qquad (2-5)$$

At $t_b < t$

$$S = K_p . (D_n)^{1/2} . (\Delta p / \rho_a). (t)^{1/2} \qquad (2-6)$$

$$U = dS/dt = 1/2 . K_p . (D_n)^{1/2}. (\Delta p / \rho_a)^{0.25} . (1 / t^{0.5}) \qquad (2-7)$$

$$\Theta\,[deg] = 0.0143\,(\rho_f / \rho_a)^{-0.25} * \{ (2.\Delta p.D_n . \rho_f) / (\rho_f . \mu_a)^{0.5} \}^{0.5} .$$

$$\Theta\,[deg] = 0.017\,\{ (D^2_n . \rho_a .\Delta P)/ \mu^2_a \}^{0.25} \qquad (2-8)$$

Yusof et al. [2020] [28] , recapped the novel researches results related to the effect of nanoparticles of the fuel specifications and combustion efficiency .Various kind of additives mixture with different fuel . Properties are also analyzed .The highs and lows of utilizing nanoparticles as an additives to the clear fuel are recapped for future studies suggestions .

2.3 Experimental and Theoretical Researches :

Ghasemi et al. [2012] [7] , studied experimentally and numerically through CFD simulations using the Eulerian – Lagrangian multiphase approach , the breakup process associated with the collision achieved by two jets interacted each other. Injection pressure reached about 300 MPa , while the ambient pressure was about 1.27 MPa inside constant volume chamber. A single hole nozzle with diameter of 160 μm and length of 1.2 mm were used in order to inject diesel fuel in fixed volume chamber with a jet injection pressure of 300 Mpa. The density of the ambient air inside the combustion chamber was 15 kg/m^3. The density of fuel was 830 kg/m^3, the viscosity was 3.36 mm^2/s at 30 ˚C, the surface tension was 25.5 mN/m, cetane number was 55 and the heating value was 43 .1 MJ/kg . The authors showed that the increasing of nozzle separation distance caused an enhancement in jet tip penetration and SMD but there was a reduction in the angle of spray cone. In addition, increasing the incidence angle caused diminishing of the angle of the spray cone, SMD and penetration.

Buchholez et at. [2017] [15] , examined experimentally the impact of fuel specifications on the behavior of diesel spray utilizing a common rail injection system of a medium speed diesel engine. The tests were conducted with two types of diesel which are conventional diesel fuel (EN-590) and heavy fuel oil (RMG 180) in a constant volume chamber at ordinary ambient temperature. The results showed that the heavy fuel oil (RMG 180) had penetrated longer in the constant volume cell, but the diesel fuel had a wider cone angle than the other. The authors put the bases for further advancing of the one–dimensional model to predict the penetration by taking the fuel properties and temperature in consideration. The assessment showed that the fuel properties impacted the spray breakup, spray penetration and spray spread angle. They modified and used an existing model in order to find the spray penetration with a heavy fuel oil (HFO). This model is basically performed for diesel spray from high pressure injectors and is constructed on two theories controlled the action of spray. The results demonstrated that the impact of gas density on the spray length is unrelated to the fuel type .The findings were very well compatible with the measurements attained from experiments.

2.4 Scope of present work :

The scope of this work is to study the influence of adding nanoparticles namely nano - SiO_2 , nano - Al_2O_3 and nano - TiO_2 with three different mass fractions namely (25 , 50 and 100) ppm with a nominal diameter of 50 nm for each of them on diesel fuel spray characteristics . The fuel spray characteristics investigated are : Fuel Spray Tip Penetration and Spray Cone Angle and how they change with Time . High Speed Photography Technique will be used .

CHAPTER THREE

EXPERIMENTAL SETUP AND PROCEDURE

Chapter Three

Experimental Setup and Procedure .

3.1 INTRODUCTION

In this experimental work , the effect of addition of nanoparticles to Traditional Iraqi diesel fuel on spray jet penetration and cone angle are studied .Three types of nanoparticles (nano-SiO_2 , nano-Al_2O_3 and nano-TiO_2) with different doses (25 , 50 and 100) ppm are used . The prevailing conditions are 297 K and 1 atm .The detailed description of the set up is given in section 3.2 , The procedure to prepare nanofuel is given in section 3.3 , while the procedure of carrying out the experiment is explained in section 3.6 .

3.2 Description of the Experimental Setup .

The setup of the rig is made of the following units fig (3.1) :

1. Injection Vessel .
2. Fuel Pumping and Injection Unit.
3. Fuel Pumping and Injection Control unit .
4. Capturing Unit .

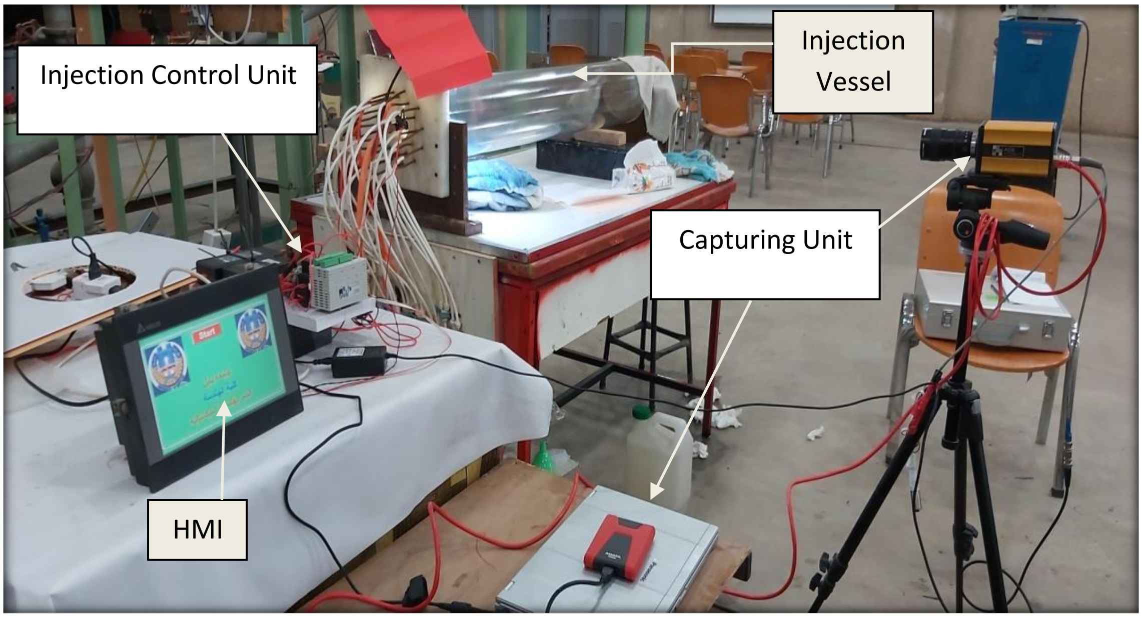


Fig. (3.1) : Photograph of the apparatuses used in the research .

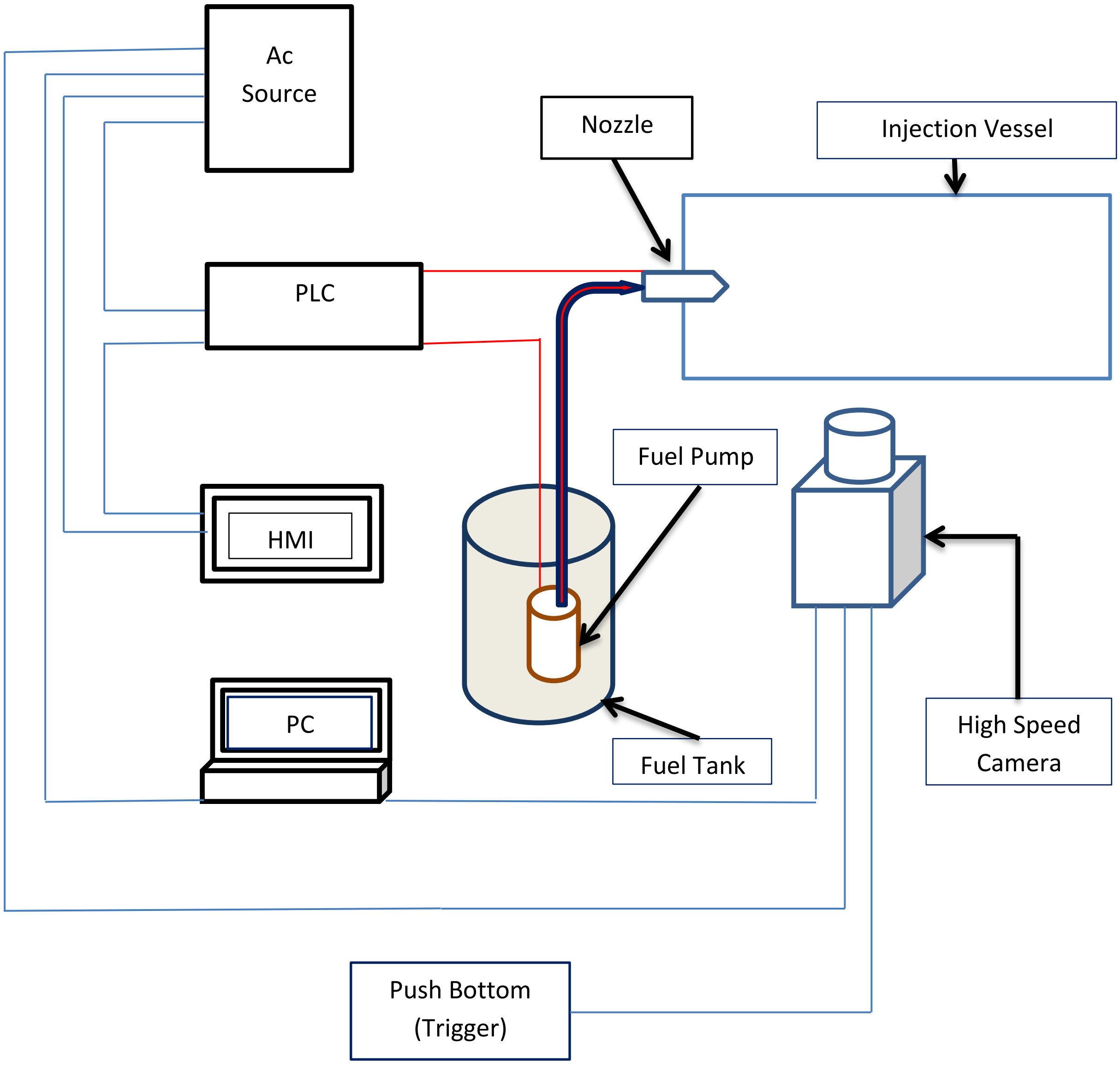


Fig. (3.2) : Schematic diagram of the components of the experimental

3.2.1 Injection Vessel .

The present work used a cylindrical Pyrex vessel which is heat resistant up to (1000 ˚C), with (170 mm) inner diameter, (5 mm) wall thickness and (1.3 m) long .The cylinder is installed horizontally and fixed on the metal table by two pieces of wood as shown in fig. (3.3) .The cylinder is closed at one end by a Teflon flange , on which the fuel injector is installed , and opened at the other end as shown in fig. (3.4) .

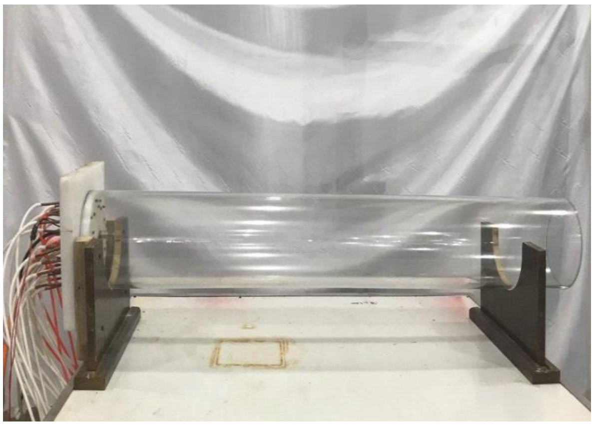


Fig. (3.3) : Photograph of the horizontal Pyrex spray vessel connected to Teflon Flange [19].

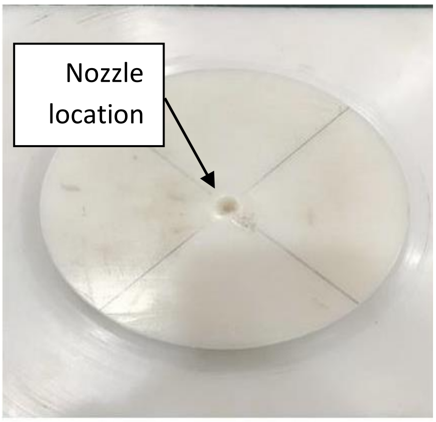


Fig. (3.4) : The Teflon Flange .

3.2.2 Fuel Pumping and Injection Unit .

- **Fuel Pump .**

An electrical submerged fuel pump Type Rifox Global is used in this present work as shown in fig. (3.5). The fuel pump specifications are

1. Operating voltage 12V DC .
2. Operating pressure between 300 and 450 kPa (3-6 bar) .
3. Fuel supply rate between 60 and 200 l/h at rated voltage .

The fuel pump is connected to the electric timer (PLC) in order to control the amount of fuel supply to be injected inside the spray chamber by controlling the duration time (time of opening the injector in millisecond which was 20 ms throughout the whole experiments) and the frequency of repeating the spray injection process in second which was 45 injections per second (throughout the whole experiments) .

Fig (3.5) : Photograph of the electric fuel pump .

- **Fuel Injector .**

An electrical injector fig. (3.6) used to inject the (clear diesel and nano-diesel) inside the chamber . The fuel is supplied from the fuel tank by the electrical fuel pump shown in fig. (3.5) .The injector is installed on the Teflon Flange fig.(3.4) and connected to a Programmable Logic Controller system (PLC) showed in fig. (3.7) to be opened for pre-specified time and for pre-specified time between two successive injected sprays (i.e. the frequency of repeating the spray injection process in one second) .The injector specifications shown in table (3.1)

Fig. (3.6) The fuel Injector .[30]

Table 3.1 : Injector specifications [30] .

Operating Voltage	12 DC volt
Injector duration to spray fuel	20 ms
Number of holes	1 holes
Diameter of hole	0.24 mm
Pressure of fuel back of the injector	4-6 bar gauge
Frequency (maximum speed for open)	22.2 HZ 45 ms between two successive sprays)
Max. temperature	150 ˚C
Min. temperature	0 ˚C
Normal operation temperature of the electrical injector	85 ˚C

3.2.3 Fuel Supply Control Unit .

This unit consists of the following parts :

- **Programmable Logic Controller (PLC) .**

It receives information from connected Human Machine Interface , processes the data and triggers outputs current to the injector and the fuel pump in a specified time . PLC 's are a flexible control solution used in almost any application . PLC circuit used in our experiment consists of one input line and two output lines as shown in fig. (3.7) .The input power is connected to an AC source to operate the PLC circuit .
The two output lines are to supply DC power to the fuel pump and the fuel injector .

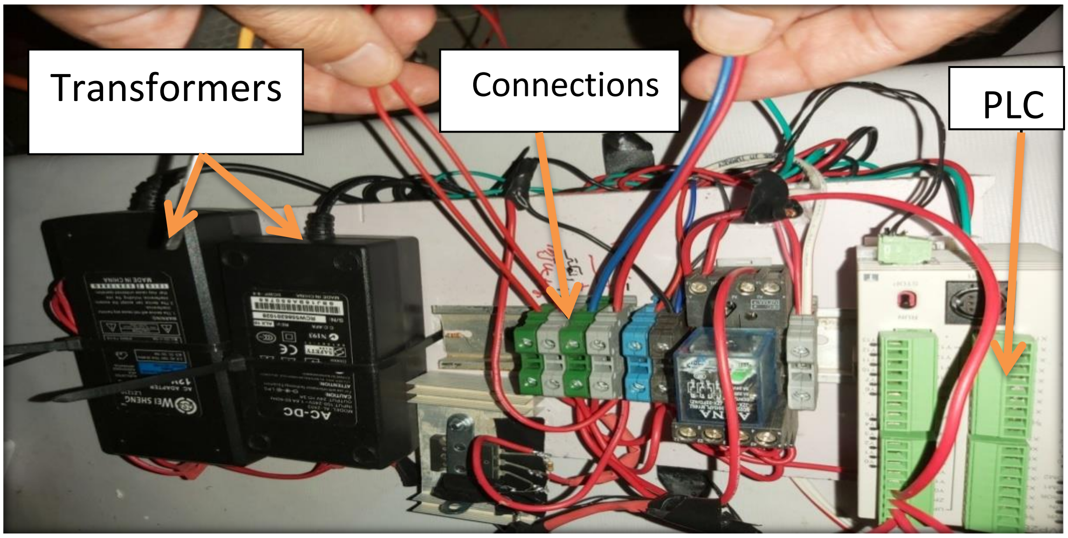


Fig. (3.7) : Photograph of Fuel Supply Control Unit or PLC Unit .

Table (3.2) : PLC specifications .

MODEL	DVP28SA211T
INPUT DC	24 V dc 2.1 W
OUTPUT MODULE	0.5 A 30V dc RES LOAD
SERIAL NOMBER	28SA 211TW21120010

- **Human Machine Interface (HMI) .**

It is a unit of exchanging data between the operator and the PLC unit in order to control the time of duration of injection (20 ms) and the time between two successive injections which is (45 ms) or the frequency of repeating the injection process in one second of our whole experiment , and also to supply the current necessary to trigger the fuel pump .This unit is also fabricated specially for this project fig. (3.8) .

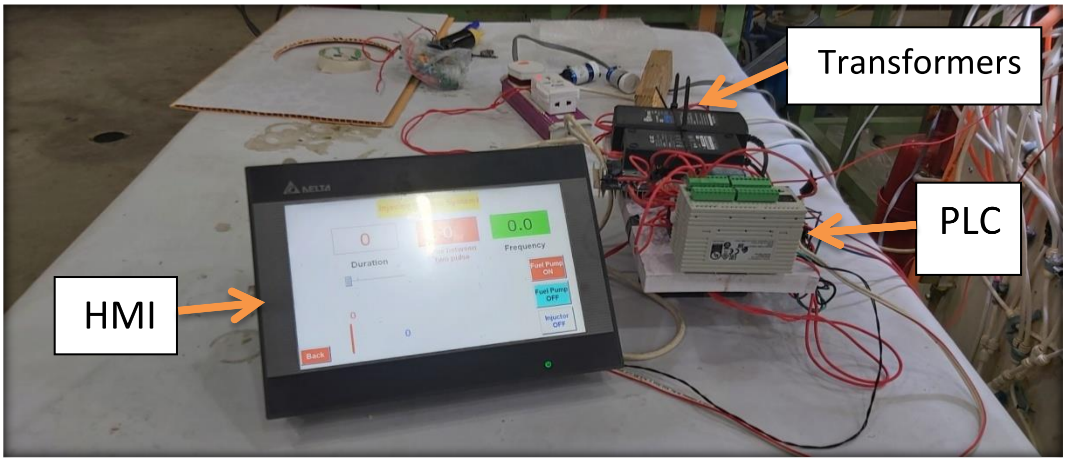


Fig. (3.8) : Photograph of the HMI and PLC Unit

Table (3.3) : HMI specification

MODEL	DOP – B15S411
INPUT DC	+ 24 Class 2/270 mA
Type	4 X for Indoor use only
SERIAL NOMBER	B10S4116 W 16090030

.

3.2.4 Capturing Unit .

In this experiment, the AOS Technologies AG, Q – PRI , High Speed camera manufactured in Switzerland with ultra-high image resolution of (3 Mega Pixel), (1.3 GB) internal memory and (16,000 FPS) is used to record the spray propagation as shown in figure (3.8).The setting used in the experiment is (500*400 pixels) for (4000 FPS), sequence length of 6000 , shutter speed of 450 and the total time of recording is 1.1 sec . A 10% of the time is set as pre-triggering to ensure that all the process is recorded when the trigger is pressed .The camera is shon in fig (3.9) . App. D1 shown the Calibration of high Speed Camera .

Fig. (3.9) : AOS - Q PRI High-Speed Camera .

3.3 Nano-fuels preparations procedure .

Three type of nanoparticles namely nano-Alumina (nano-Al_2O_3) , nano-Silica (nano-SiO_2) , and nano-Titania (nano-TiO_2) with three doses for each type , which are 25, 50, and 100 ppm are to be prepared .The nano-particles size is 50 nm .

1. Calculate the mass of each kind of nano particles required for the dose .
2. Measure the mass of each kind of nano particles, for each dose required by a high sensitive digital balance shown in fig (3.10) .

Fig. (3.10) : High Sensitive digital balance .[19]

3. Add the prepared mass of nano particles of each kind to a liter of clear Iraqi diesel fuel ($C_{12.3}H_{22.2}$) [19] from table (3.7) in a jar as shown below in fig. (3.11) and fig. (3.12) .

Fig. (3.11) : Jars contain clear diesel prepared for mixing with nano particles of one kind which is Silica (SiO2) .

4. Mixed the nano fluid mechanically for about one hour by a mean of stirrer (portable drilling machine with special drill) in order to assure the distribution of nano particles in a diesel fuel and not to accumulated in the bottom of jar .
5. Put the prepared mixture of all types in the Ultrasonic Cleaner bath and setting its Generator shown in the fig. (3.13) for about six hours .

Fig. (3.12) :The nine jars of all kind of nanofuel used in experiment .

Fig. (3.13) : Photograph of Ultrasonic Cleaner Bath Generator .

Table 3.4: Specifications of the Ultrasonic Generator Unit .

Specifications of Ultrasonic Mixture		
1	Ultrasonic Frequency	40 k Hz
2	Ultrasonic Power	720 W
3	Capacity	54 litter
4	Temperature control range	< 90 ˚C

6. After six hour , the nano-fuel are ready now to be used in the tests fig (3.14) .
7. Add the nano-fuel to the fuel tank to start the test .
8. Repeat steps (1 – 7) for other types of nano-fuels .

Fig. (3.14) : Photograph of the nine jars of nanofuel after mixing in ultrasonic Bath .

3.4 Calculation of Density and Viscosity of Nano-fuel .

The Nano-fuel density and viscosity of the three types and for the three mass fractions of each type are in the table (3.5) according to the two relations bellow :

$$\rho_{nf} = (1 - \varphi) * \rho_f + \varphi * \rho_P \qquad (3 – 1)$$

$$\mu_{nf} = (1 + 2.5 * \varphi) * \mu_f \qquad (3 – 2)$$

where : ρ_{nf} : Density of nanofuel , μ_{nf} : Viscosity of nanofuel .

Table (3.5) below showed the calculated physical properties of the three types of nanofuel and for the three mass fractions of each ..

Table 3.5 : Calculated physical properties of the three nanofuel .

Volume Ratio ppm	m_p (g)			ρ_{nf} (kg/m^3)			μ_{nf} (kg / m . s)*10^{-3}		
	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel
25	0.06	0.099	0.11	829.0	829.1	829.1	2.778	2.778	2.778
50	0.12	0.199	0.21	829.1	829.2	829.2	2.778	2.778	2.778
100	0.24	0.397	0.42	829.2	829.3	829.3	2.78	2.78	2.78

3.5 Measurements of Physical Properties of Nano-fuel

- **Measurement of Density .**

We measured the density of SiO_2 at the labs of the College of Material Engineering fig. (3.15) . The model of apparatus is GP-120S and it's precision of liquid mode is 0.0001 g /cm^3 .The density of other two type of Nano-fuel are taken from [19] . The measurement are repeated three times in order to achieve an accurate results . The resulted data are shown in table (3.6)

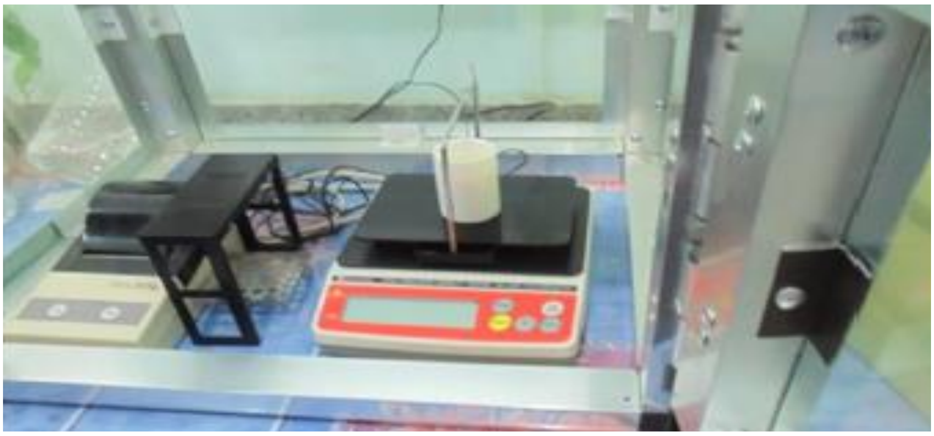


Fig. (3.15) : Photograph of the Density apparatus .[19]

- **Measurement of Viscosity .**

We measured the viscosity of SiO_2 at the labs of the College of Material Engineering by an instrument called a Viscometer , [brookfield digital viscometer model DV-E][19] fig. (3.16) . The viscosity of the other two types of nanofuel are taken from [19] . Three prepared samples with the three doses of SiO_2 nanofuel are tested .The measurement are repeated three times to have an accurate results .The resulted data are shown in table (3.6) .

Fig. (3.16) : Photograph of the Viscosity apparatus .[19]

Table 3.6 : Physical Properties Measured at the labs of the College of Material Engineering.

Volume Ratio ppm	ρ_{nf} (kg/m^3)			μ_{nf} (kg / m . s)*10^{-3}			ν_{nf} (m^2/s)*10^{-6}		
	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel	Nano-SiO_2fuel	Nano-Al_2O_3fuel	Nano-TiO_2fuel
25	798.9	849.8	849.9	2.78	2.80	2.78	3.32	3.295	3.271
50	818.3	856.3	857.1	2.79	2.805	2.791	3.34	3.2757	3.256
100	828.9	861.2	862.2	2.81	2.821	2.815	3.35	3.2756	3.265

3.6 Experimental Procedure .

1. Fill the fuel tank with the 1st type of nanofuel (which was nano-silica + ID) .
2. Setting the PLC (Through the HMI) in order to program the nozzle to be open for 20 ms and for a time of 45 ms between two successive sprays .
3. Setting the High Speed Camera on this numbers : width = 500 , height = 400 , frame per second = 4000 , Sequence length = 6000 Pre-trigger = 1.1 second .
4. Trigger the fuel pumps .
5. Trigger the injector to start the injection process .
6. After several sprays trigger the camera button to captured the movie of propagation of spray and for several sprays .
7. Save this videos in an exterior hard memory at two extensions one as a video (name.avi) and the other as a photo (name.jpg)
8. After finishing the capturing process , empty the fuel tank from the nanofuel and filled it with a clear diesel and start to trigger the fuel pump and injector for about 3 minute continuously in order to be sure that the whole pipes and fuel pump are clear from the previous nanofuel .
9. Refilling the fuel tank with a next mass fraction which is 50 ppm from nano SiO_2 .
10. Repeat the same procedure above (from 4 to 7) .
11. Repeat point 8 .
12. Repeat the same procedure with a next type of nanoparticles (which was Al_2O_3) of a mass fractions 25 , 50 and 100 ppm respectively .
13. Repeat the same procedure with a next type of nanoparticles (which was TiO_2) of a mass fractions 25 , 50 and 100 ppm respectively .
14. Repeat the same procedure with the Clear Iraqi Diesel Fuel with the specifications showed in table (3.7) .

15. Process the photos that had been captured with High Speed Camera by using the photo visualization software namely ACDsee Photo Manager 12 in order to visualize the photos .
16. Measure the spray tip penetration of each frame (the time for each frame is 0.25 ms) for almost 12 frames (from 0 to 2.75 ms) .
17. Measure the spray cone angle at 3 frames namely (0.5 , 0.75 and 1) ms.
18. Take the whole measurement to Microsoft Excel 10 spread sheets in order to analyze and draw them in a several graphs .

Table3.7 : Clear diesel fuel specifications . [19]

	Properties	Diesel
1	Chemical formula	$C_{12.3}H_{22.2}$
2	Molecular weight	169.8
3	Density at 16 ˚C and 1.01 bar (kg / m^3)	833 - 881
4	Specific gravity	0.84 – 0.88
5	Kinematic viscosity (m^2 / s)	3.29×10^{-7}
6	Dynamic viscosity (kg / m .s)	2.778×10^{-3}
7	Thermal conductivity (W / m .K)	0.145
8	Flammability limits (volume % in air)	0.7 – 5
9	Auto ignition temperature (K)	530
10	Stoichiometric air fuel ratio on mass basis	14.5
11	Low heating value (MJ / kg)	44.08
12	Cetane number	51.6
13	Specific heat (kJ / kg .K)	2.2
16	Pour point (˚C)	-35 to -15
17	Cloud point (˚C)	-15 to -5

CHAPTER FOUR

RESULTES AND DISCUSION

CHAPTER FOUR

RESULTES AND DISCUSION

4.1 Introduction .

In this chapter the results are presented and discussed . The results are divided into two parts which are :

Spray penetration results and spray cone angle results . And each of them is subdivided into two categories which are :

The effect of nanoparticles type and the effect of nanoparticle mass fraction .

4.2 Repeatability Test

The experiment is repeated for three times at different dates which are at Nov. 14 , 17 and 25 , 2021 . Fig. (4.1) bellow shows the clear Iraqi diesel spray tip penetration achieved from the three times . The maximum difference between the three experiments was 7.75 % at a time equal to 1.5 ms .While, the minimum difference between the three experiments was 0.34 % at a time equal to 2.5 ms .The photo of the spray is shown in fig (4.2) . See App. B1 .

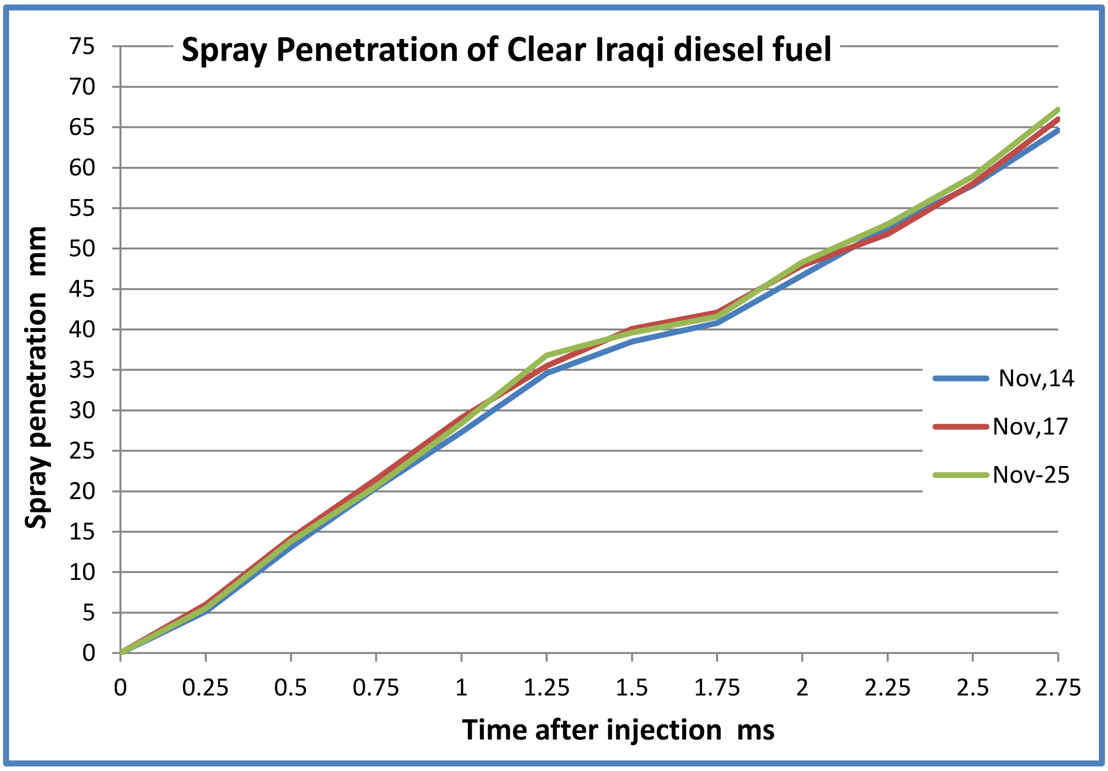


Fig.(4.1) : Spray Penetration for clear Iraqi diesel .

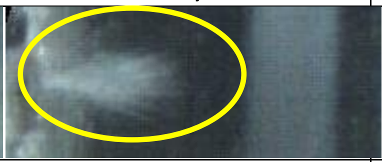
Nov. 14,2021	Nov. 17,2021	Nov. 25,2021
		
Time after injection = 0.75 ms	Time after injection = 0.75 ms	Time after injection = 0.75 ms

Fig. (4.2) : Photos of clear diesel fuel spray at 0.75 ms after injection for different dates .

4.3 Effect of Nanoparticles on Spray Tip Penetration .

4.3.1 Effect of Nanoparticle Type .

Fig (4.3) shows the variation of spray penetration with time for different types of diesel fuel , including clear Iraqi diesel and nano-diesel at a mass fraction of 25 ppm .The figure starts from 0.25 ms after injection . It shows that for all types of fuel , the spray tip penetration increases with time and reaches maximum penetration of 70.9 mm at 2.75 ms . The maximum difference between the three types of nano-diesel and the clear Iraqi diesel taken place at the time of 1.75 ms after injection . It is shown that the titania nano-particles has the largest effect on fuel penetration followed by alumina and silica since titania has the largest density (see table 1.1) .Therefor the titania nano-diesel spray has the highest momentum .The same trends are shown in fig.(4.5) and fig.(4.7) for 50 and 100 ppm . The increases of the dose increase the fuel spray penetration for all types of nano-particles for the same reason mentioned above . For example the titania nano-fuel has 70.9 , 72.3 and 74.4 mm penetration for 25 , 50 and 100 ppm doses respectively at 2.75 ms after start of injection . Fig.(4.4) , fig (4.6) and fig (4.8) show photos of fuel spray of three doses for each of the three kinds at 0.5 ms after start of injection . (See App. A2 to A10 and App. B2 to B 4) .

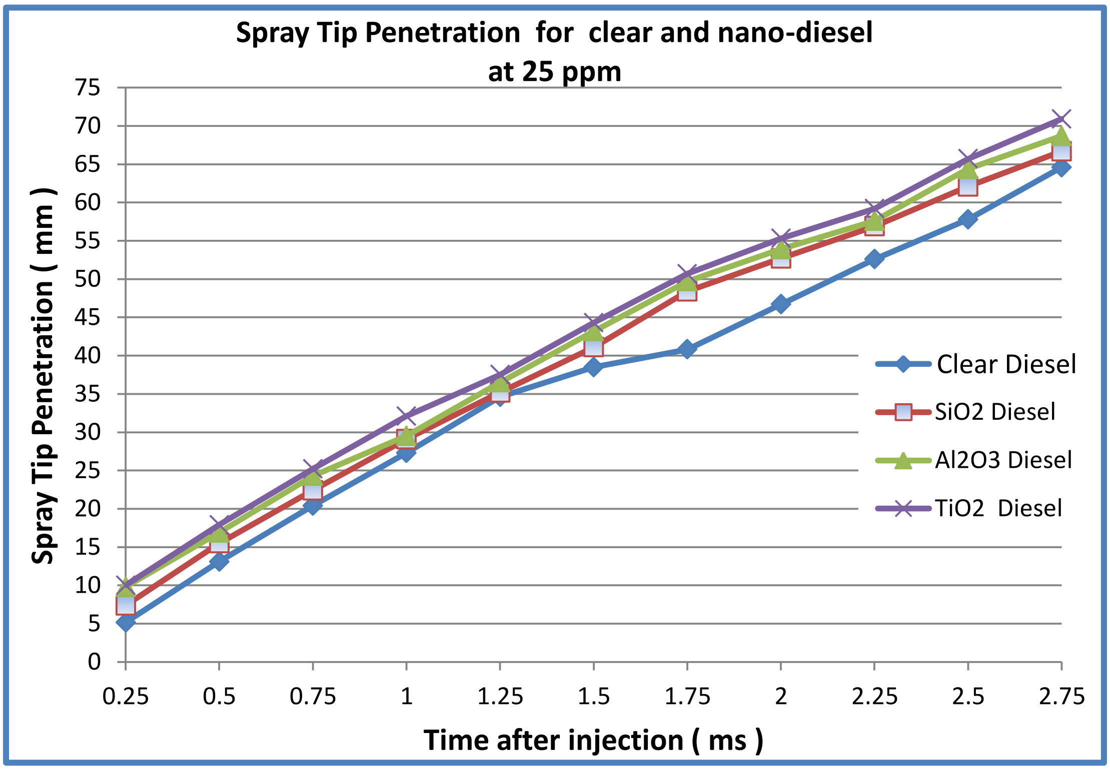


Fig. (4.3) : Spray Penetration for clear and nano-diesel at 25 ppm .

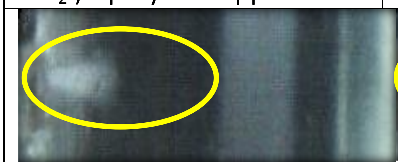
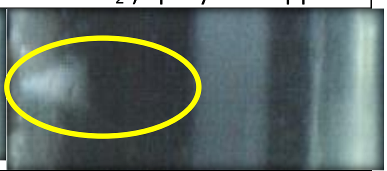
Silica nano-diesel (ID + nano SiO_2) spray at 25 ppm	Alumina nano-diesel (ID + nano Al_2O_3) spray at 25 ppm	Titania nano-diesel (ID + nano TiO_2) spray at 25 ppm
		
Time after injection = 0.5 ms	Time after injection = 0.5 ms	Time after injection = 0.5 ms

Fig. (4.4) : Photos of fuel spray at 0.50 ms after injection for different nano-fuels .

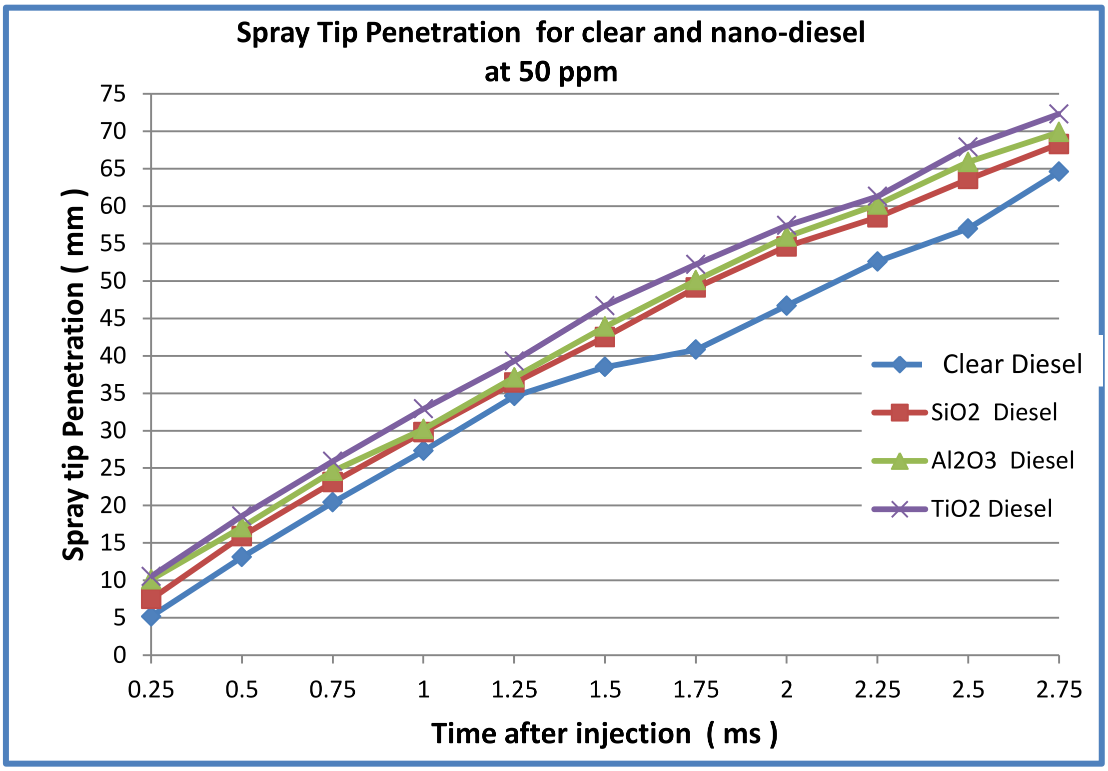


Fig. (4.5) : Spray Penetration for clear and nano-diesel at 50 ppm .

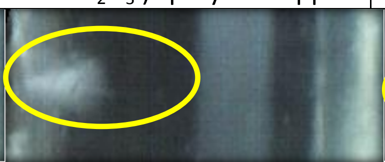
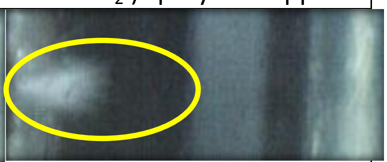
Silica nano-diesel (ID + nano SiO_2) spray at 50 ppm	Alumina nano-diesel (ID + nano Al_2O_3) spray at 50 ppm	Titania nano-diesel (ID + nano TiO_2) spray at 50 ppm
		
Time after injection =0.5 ms	**Time after injection = 0.5 ms**	Time after injection = 0.5 ms

Fig. (4.6) : Photos of fuel spray at 0.50 ms after injection for different nano-fuel .

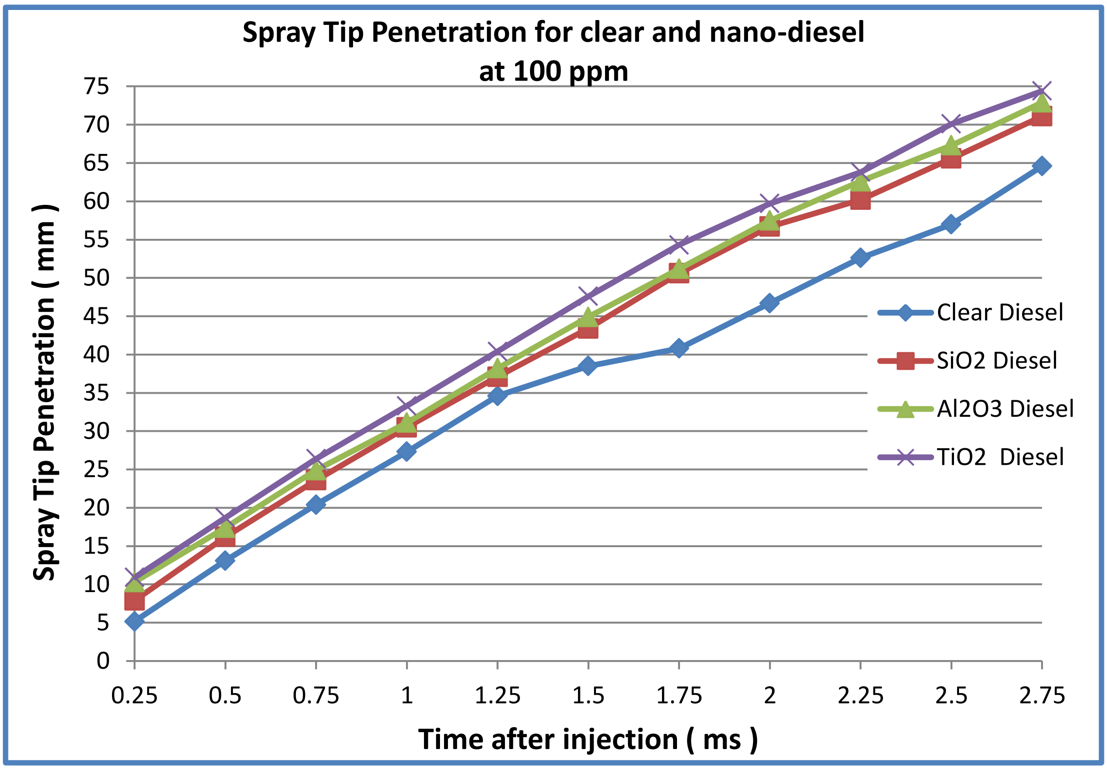


Fig. (4.7) : Spray Penetration for clear and nano-diesel at 100 ppm .

Silica nano-diesel (ID + nano SiO_2) spray at 100 ppm	Alumina nano-diesel (ID + nano Al_2O_3) spray at 100 ppm	Titania nano-diesel (ID + nano TiO_2) spray at 100 ppm
		
Time after injection =0.5 ms	**Time after injection = 0.5 ms**	Time after injection = 0.5 ms

Fig. (4.8) : Photo of fuel spray at 0.50 ms after injection for different nano-fuel .

4.3.2 Effect of Nanoparticles Mass Fraction

Fig. (4.9 – 4.14) show the variation of fuel spray penetration with time after injection for different nano-diesel fuels . It's shown that the 100 ppm dose has the largest effect on tip penetration . This is due to the increase in fuel spray momentum as the dose increases . For example after 2.75 ms from start of injection the spray penetration is 71.1 , 72.9 and 74.7 mm for 25 , 50 and 100 ppm respectively see (App. B5 to B7) .

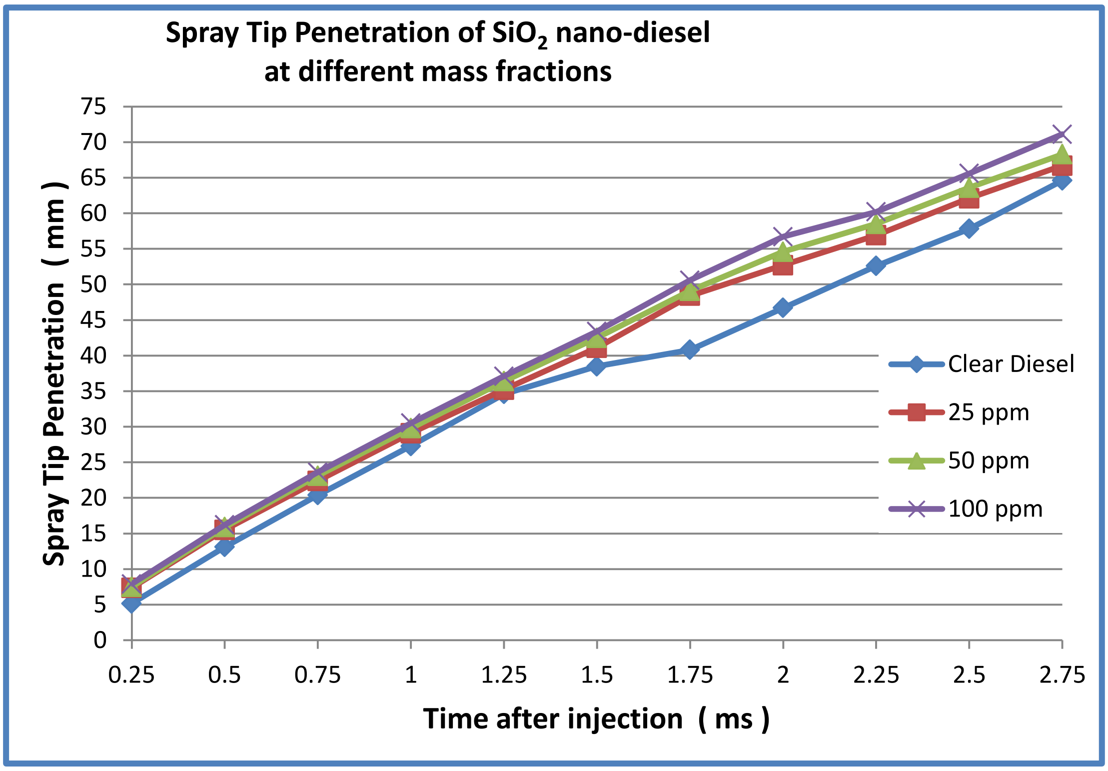


Fig. (4.9) : Spray Tip Penetration of clear and SiO_2 nano-diesel at three mass fractions .

Silica nano-diesel (ID + nano SiO_2) spray at 25 ppm	Silica nano-diesel (ID + nano SiO_2) spray at 50 ppm	Silica nano-diesel (ID + nano SiO_2) spray at 100 ppm
		
Time after injection =0.5 ms	**Time after injection = 0.5 ms**	Time after injection = 0.5 ms

Fig. (4.10) : Photo of fuel spray at 0.50 ms after injection for silica nano-diesel at three doses

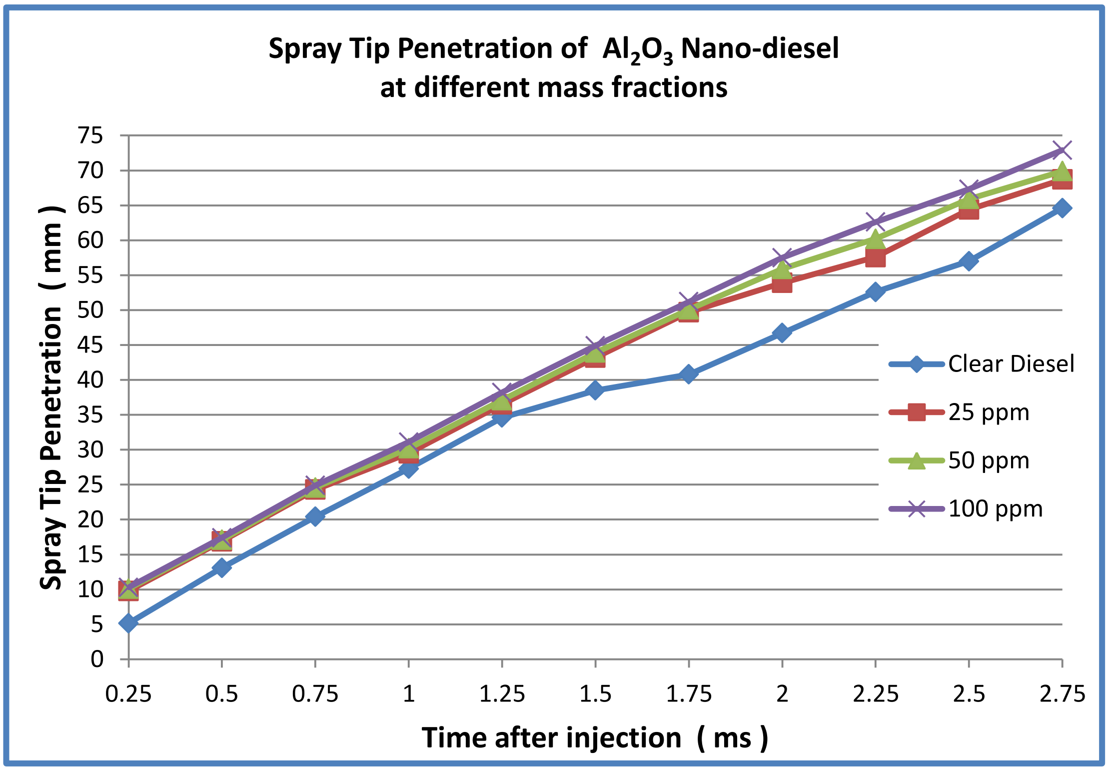


Fig. (4.11) : Spray Penetration of clear and Al_2O_3 nano-diesel at three mass fractions .

Alumina nano-diesel (ID + nano Al_2O_3) spray at 25 ppm	Alumina nano-diesel (ID + nano Al_2O_3) spray at 50 ppm	Alumina nano-diesel (ID + nano Al_2O_3) spray at 100ppm
		
Time after injection =0.5 ms	**Time after injection = 0.5 ms**	**Time after injection = 0.5 ms**

Fig. (4.12) : Photo of fuel spray at 0.50 ms after injection for Alumina nano-diesel at three doses .

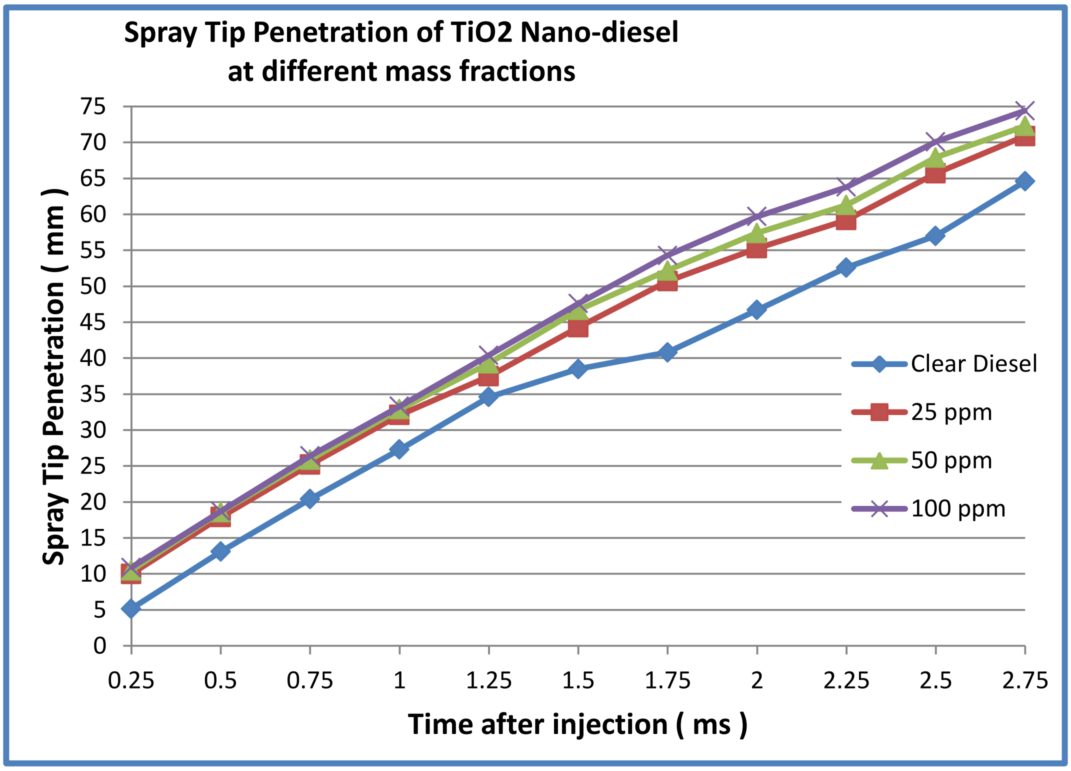


Fig. (4.13) : Spray Penetration of clear and TiO_2 nano-diesel at three mass fractions .

Titania nano-diesel (ID + nano TiO_2) spray at 25 ppm	Titania nano-diesel (ID + nano TiO_2) spray at 50 ppm	Titania nano-diesel (ID + nano TiO_2) spray at 100 ppm
		
Time after injection =0.5 ms	**Time after injection = 0.5 ms**	Time after injection = 0.5 ms

Fig. (4.14) : Photo of fuel spray at 0.50 ms after injection for titania nano-diesel at three doses .

4.3.3 Spray Tip Penetration of Nano-diesel at 1 ms after injection .

Fig (4.15) shows a comparison of fuel spray penetration at 1 ms after start of injection for different types of nano-particles and different doses (different mass fractions). The comparison shows that the titania has the largest effect since it has the largest density as mentioned earlier. See App. B8 .

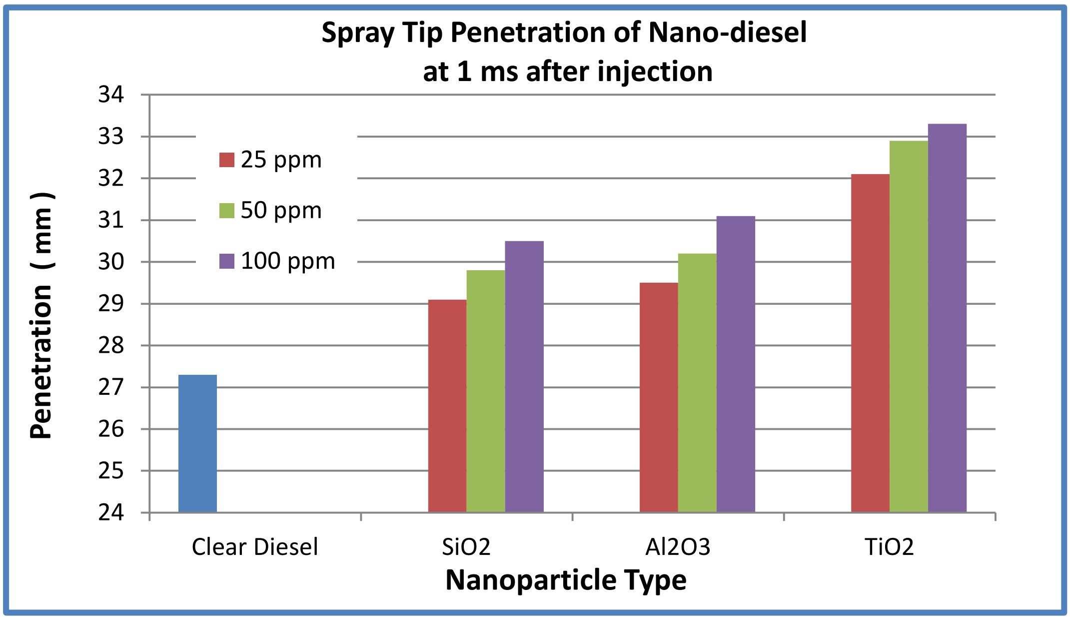


Fig. (4.15) : Spray Penetration of clear and nano-diesel at 1 ms after injection for all types and mass fractions .

4.4 Effect of Nanoparticles on Spray Cone Angle .

4.4.1 Effect of Nano-diesel Type on Spray Cone Angle .

Fig (4.16 – 4.18) shows the effect of nano-particles type on spray cone angle for clear and different nano-diesel fuel . It is show that the addition of nano-particles to diesel fuel reduces the cone angle .The titania nano-fuel spray has the smallest cone angle followed by alumina and then silica .This is due to the effect of nano-particles density which affects spray momentum .For example the clear diesel cone angle is 14 deg while it becomes 12.2 deg and 12.7 deg for titania and silica nano-fuels respectively . See App. C1-C6 .

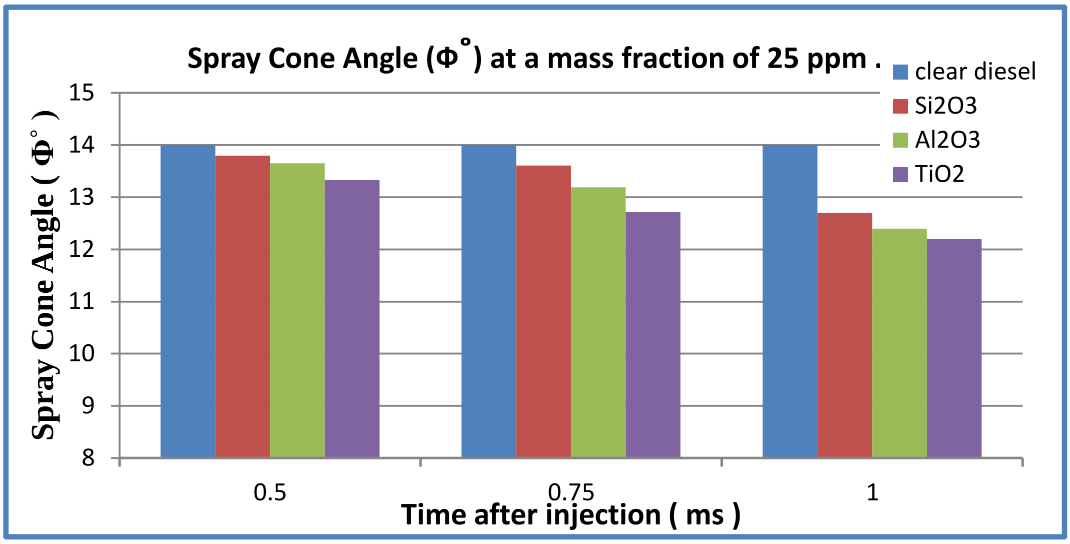


Fig. (4.16) : Spray Cone Angle at a mass fraction of 25 ppm .

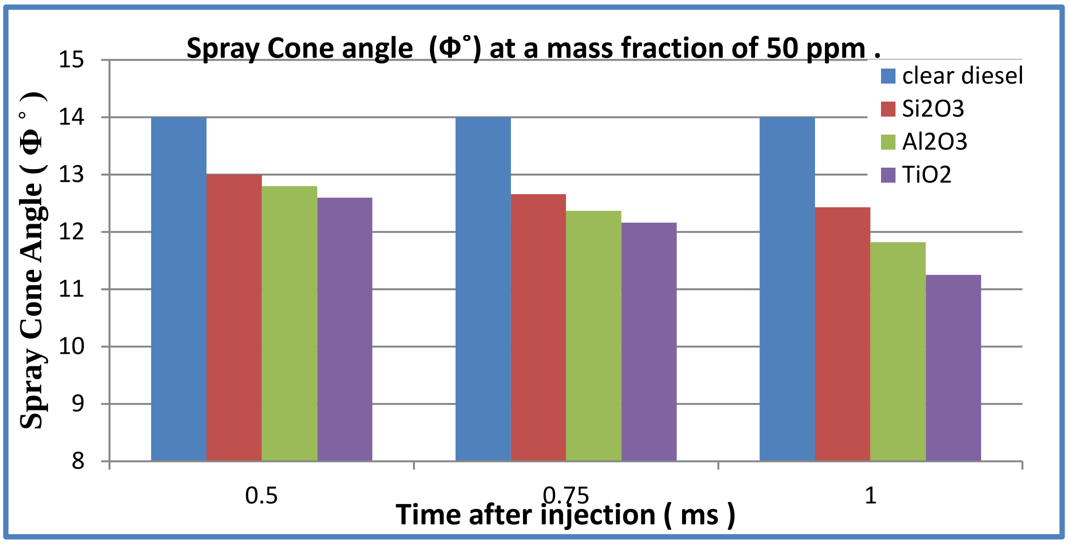


Fig. (4.17) : Spray Cone angle at a mass fraction of 50 ppm .

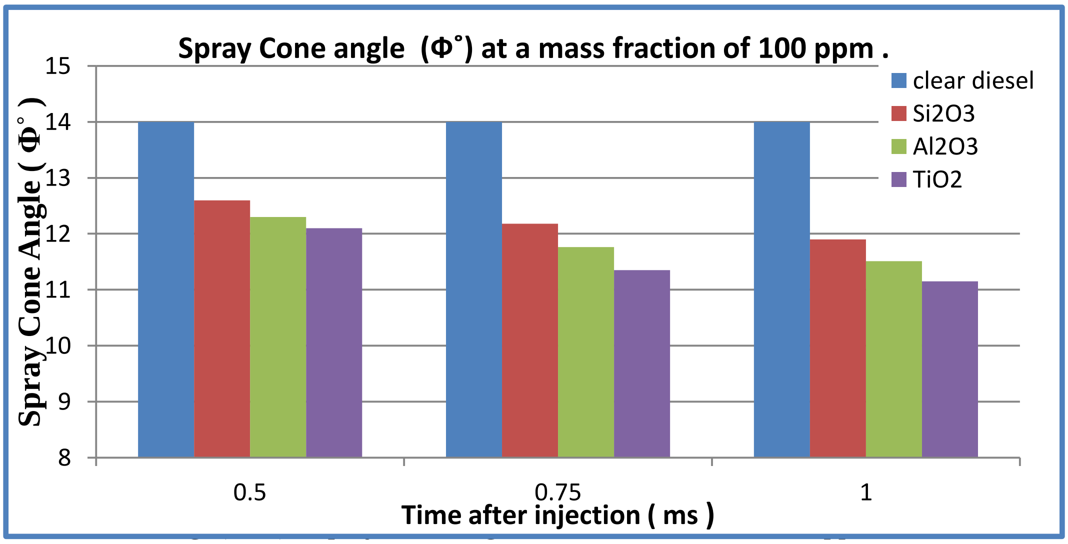


Fig. (4.18) : Spray Cone Angle at a mass fraction of 100 ppm .

4.4.2 Effect of Nano-diesel Mass Fraction on Spray Cone Angle .

Fig. (4.19 – 4.21) show the effect of nano-particles dose on spray cone angle for different nano-fuels and clear diesel .The figures show that larger doses reduce the cone angle since the fuel spray penetrates further due to it's larger momentum . The same trend is shown for all types of nano-fuels .For example the cone angle for clear diesel is 14 deg while it becomes 13.3 deg, 12.6 deg and 12.1 deg for 25 , 50 and 100 ppm respectively for titania nano-fuel . See App. C4 – C6.

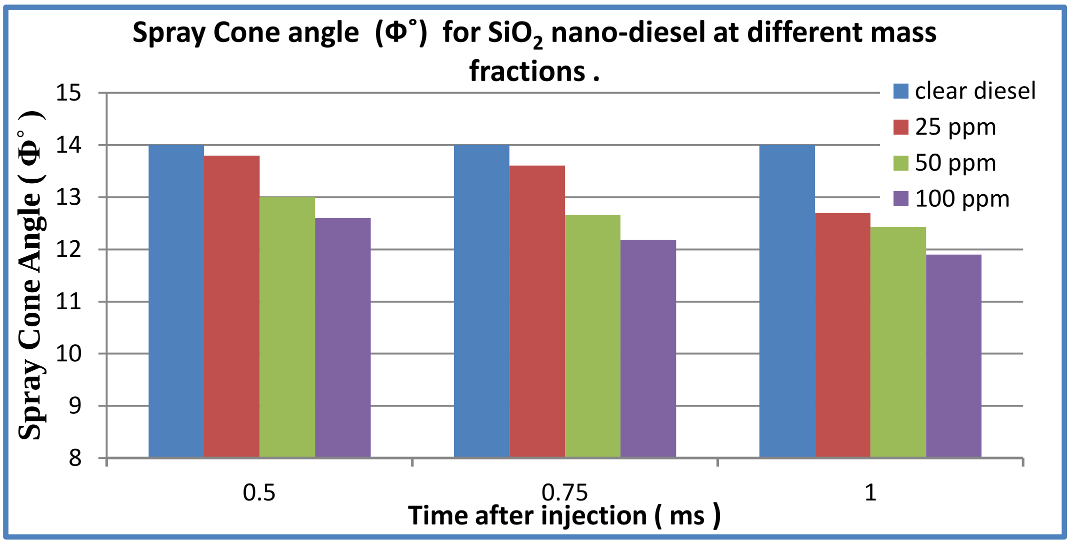


Fig. (4.19) : Spray Cone Angle for SiO_2 nano-diesel at different mass fractions .

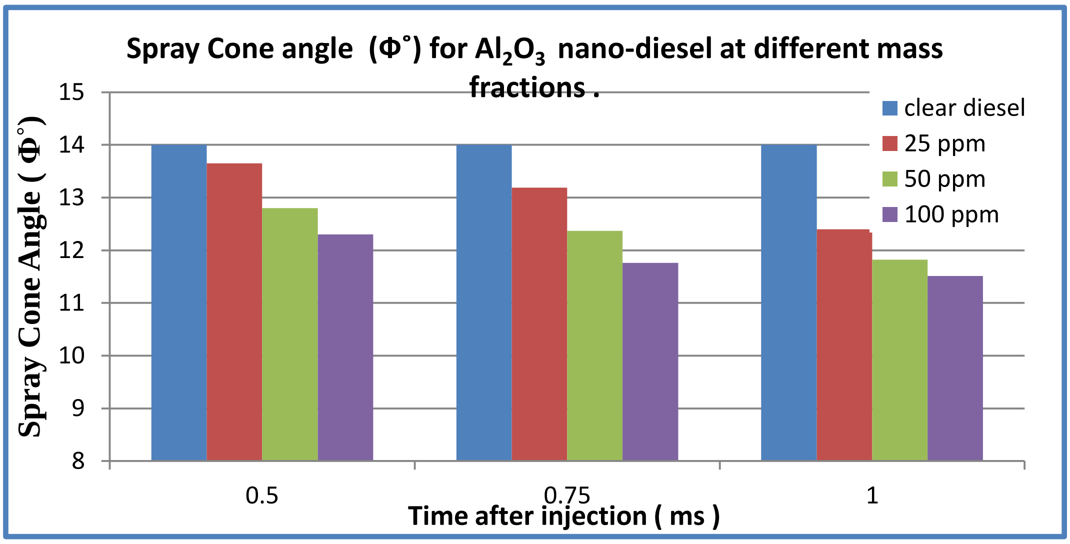


Fig. (4.20) : Spray Cone Angle for Al_2O_3 nano-diesel at different mass fractions .

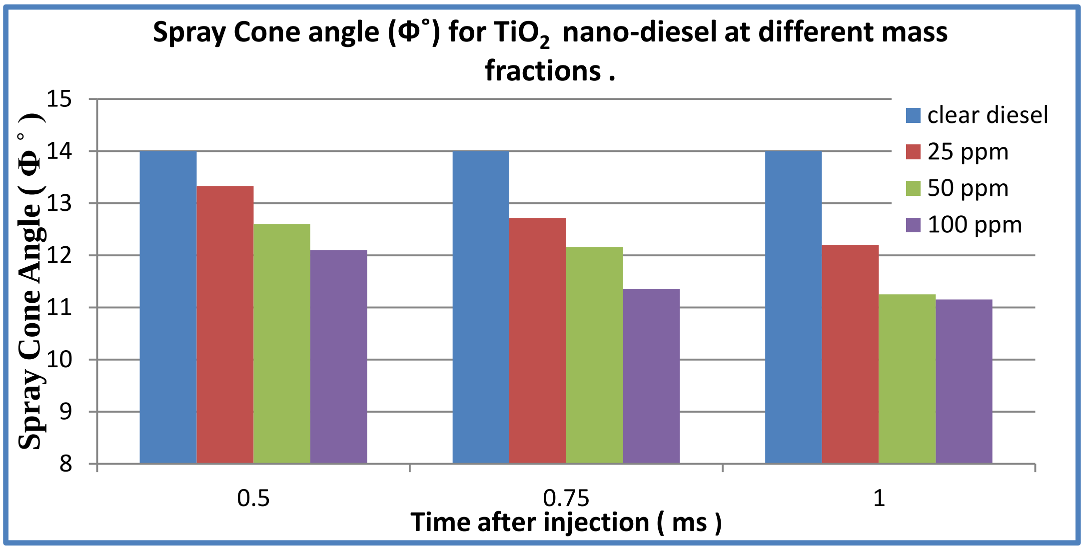


Fig. (4.21) : Spray Cone Angle for TiO_2 nano-diesel at different mass fractions .

CHAPTER FIVE

CUCONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

CHAPTER FIVE

CUCONCLUSIONS AND FUTURE WORKS

5.1 Conclusions :

The present research focuses on the impact of three nanoparticles mixed at three mass fractions with clear Iraqi obtained diesel on two spray macroscopic properties. According to the results of present research, the following conclusions can be drawn :

1- Spray penetration increases with time after injection .
2- Addition of nano-particles increases spray penetration .
3- Addition of nano-particles decreases spray cone angle .
4- The increase of mass fraction of nano-particles of the same kind increases the spray penetration .
5- The increase of mass fraction of nano-particles of the same kind decreases the spray cone angle .

5.2 Suggestions for future works :

1- Using higher mass fractions (doses) for the same nano-particles used in this study like (150 , 175 and 200) ppm .
2- Using another kind of nano-particles like FeO , ZnO , CuO .
3- Using hybrid nano-diesel consists of two or more kind of nano-particles .
4- Using biomaterial nano-particles .
5- Study the characteristics that affect the stability of the physical properties of diesel fuel and nano-particles to avoid the agglomeration of it in pipes and injector .
6- Use higher injection pressure .
7- Injecting into higher chamber pressure and temperature .

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Profile " . Journal of Automobile Engineering , Vol. 233 (11), PP : 2780-2790, 2018 .

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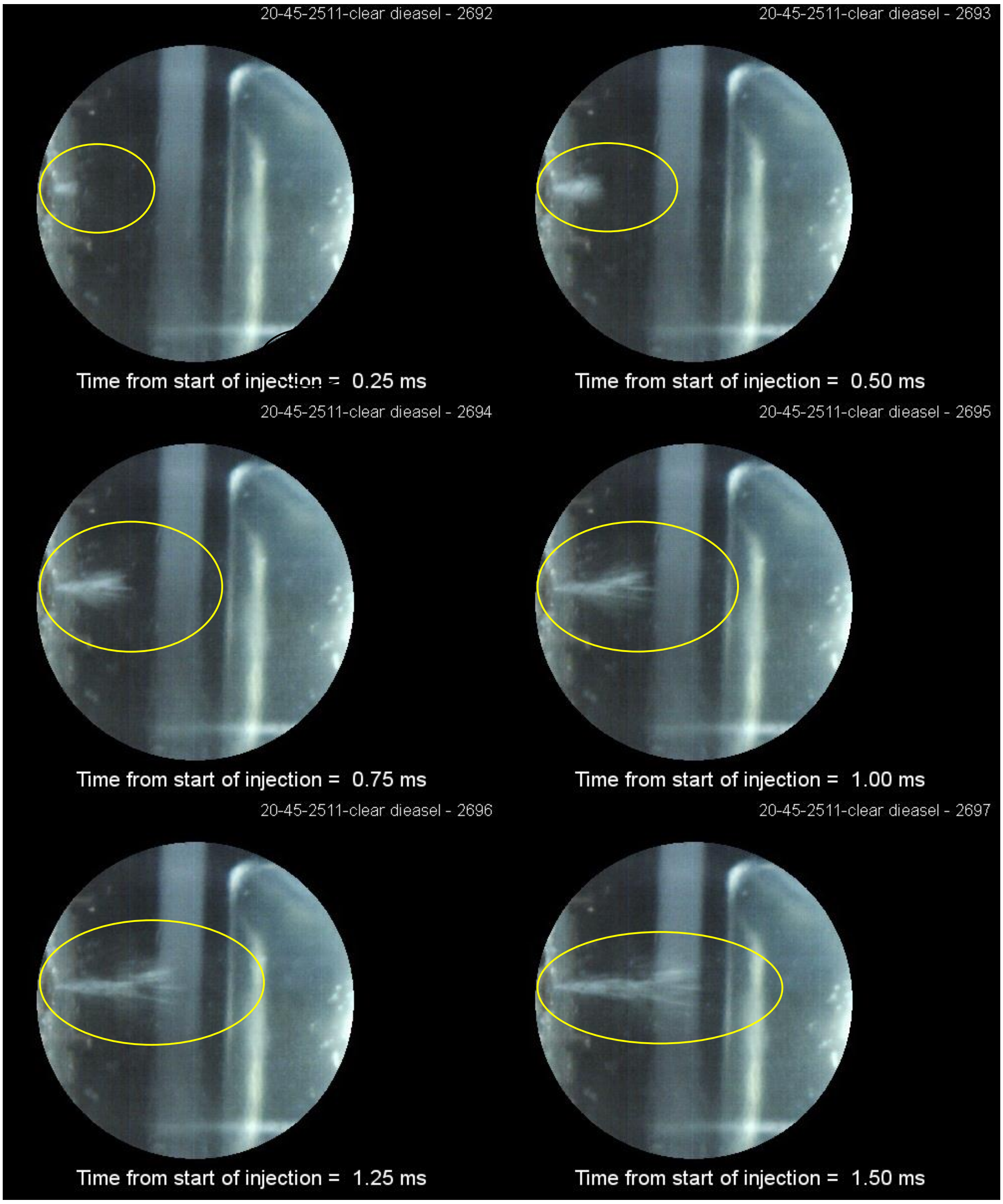
Appendices

Appendix A

Appendix A1

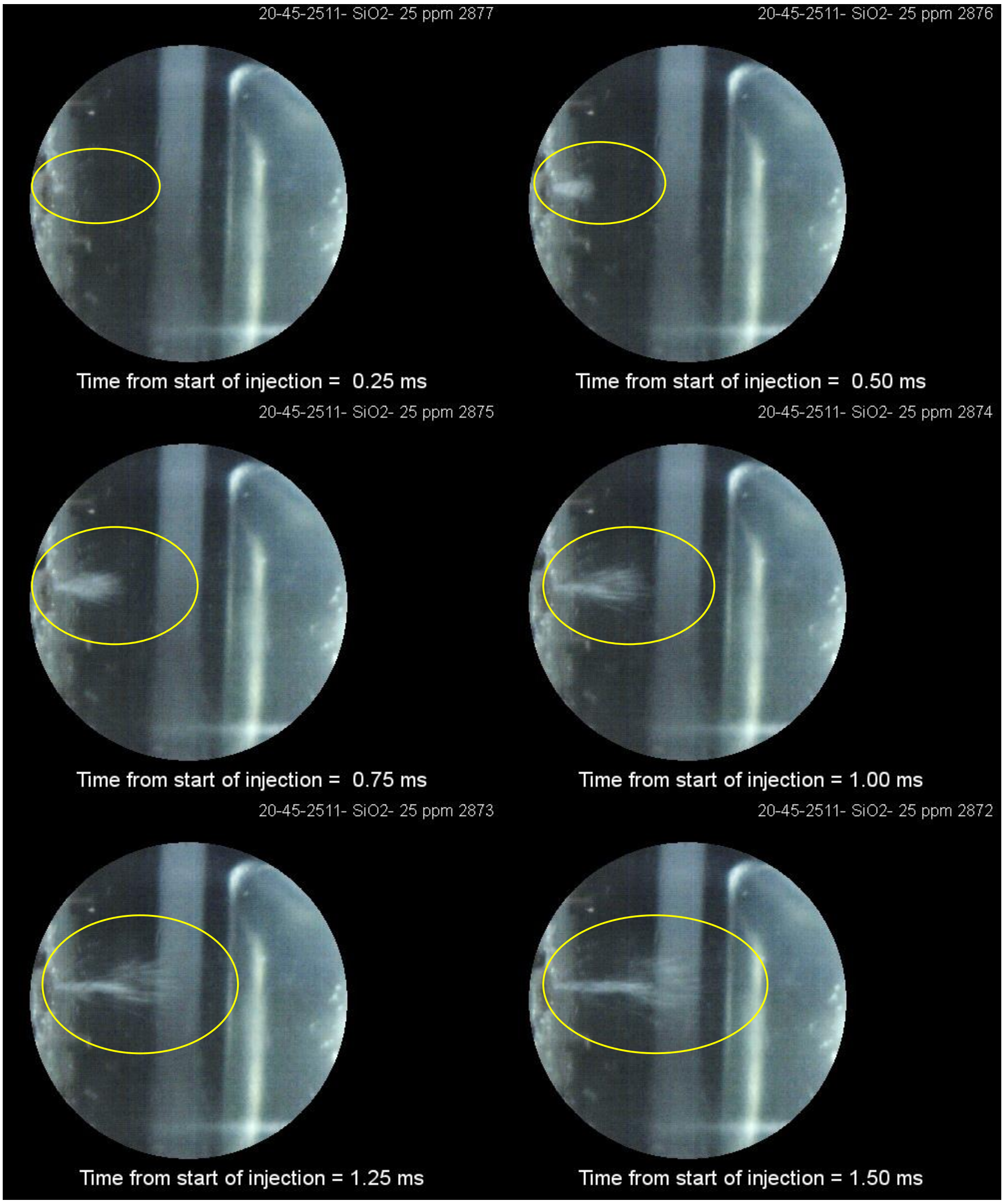
Photos for Propagation of Spray of clear Diesel .



Appendix A2

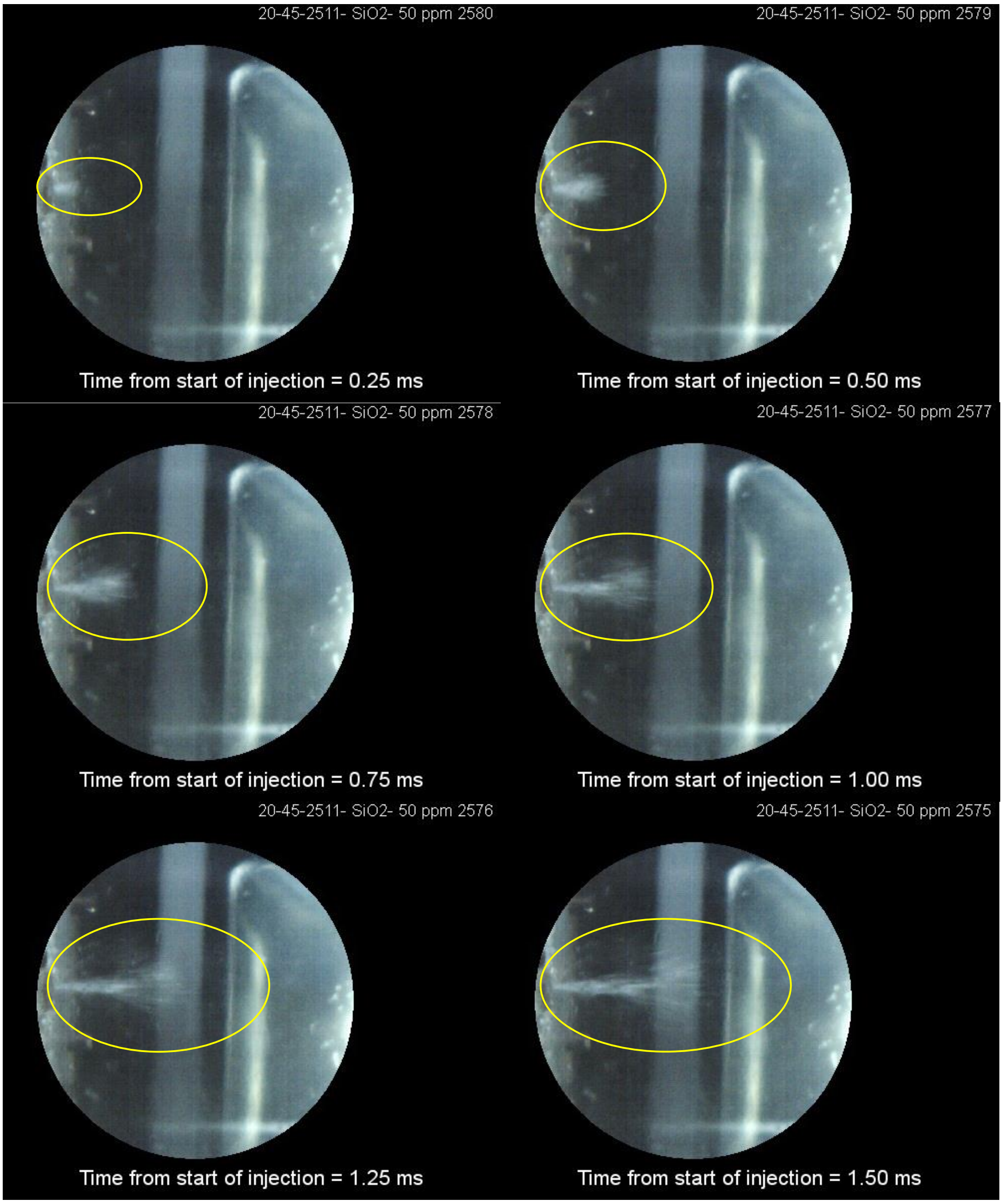
Photos for Propagation of Spray of SiO_2 nano-diesel (ID + SiO_2)

At 25 ppm .



Appendix A3

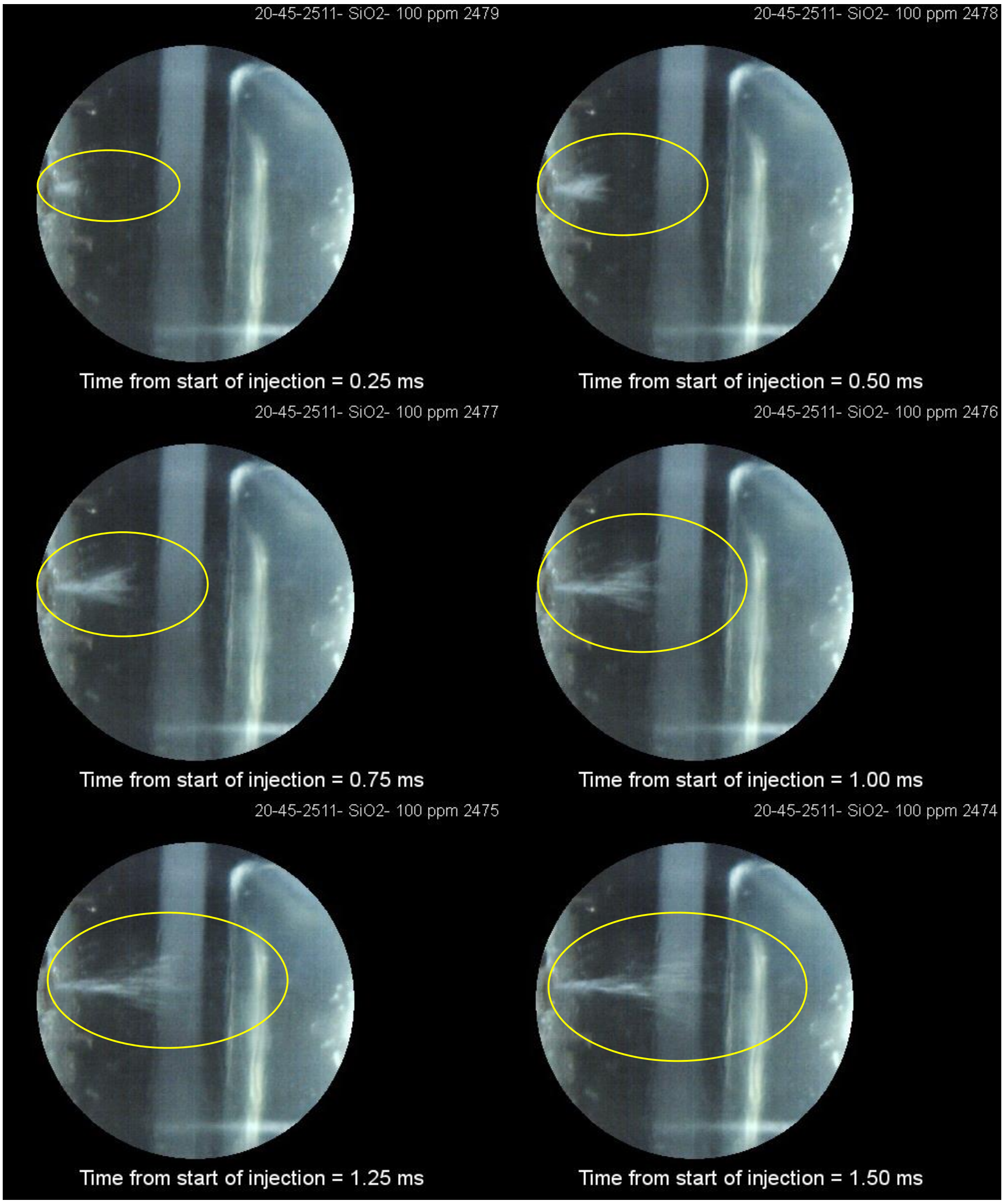
Photos for Propagation of Spray of SiO_2 nano-diesel (ID + SiO_2)
At 50 ppm .



Appendix A4

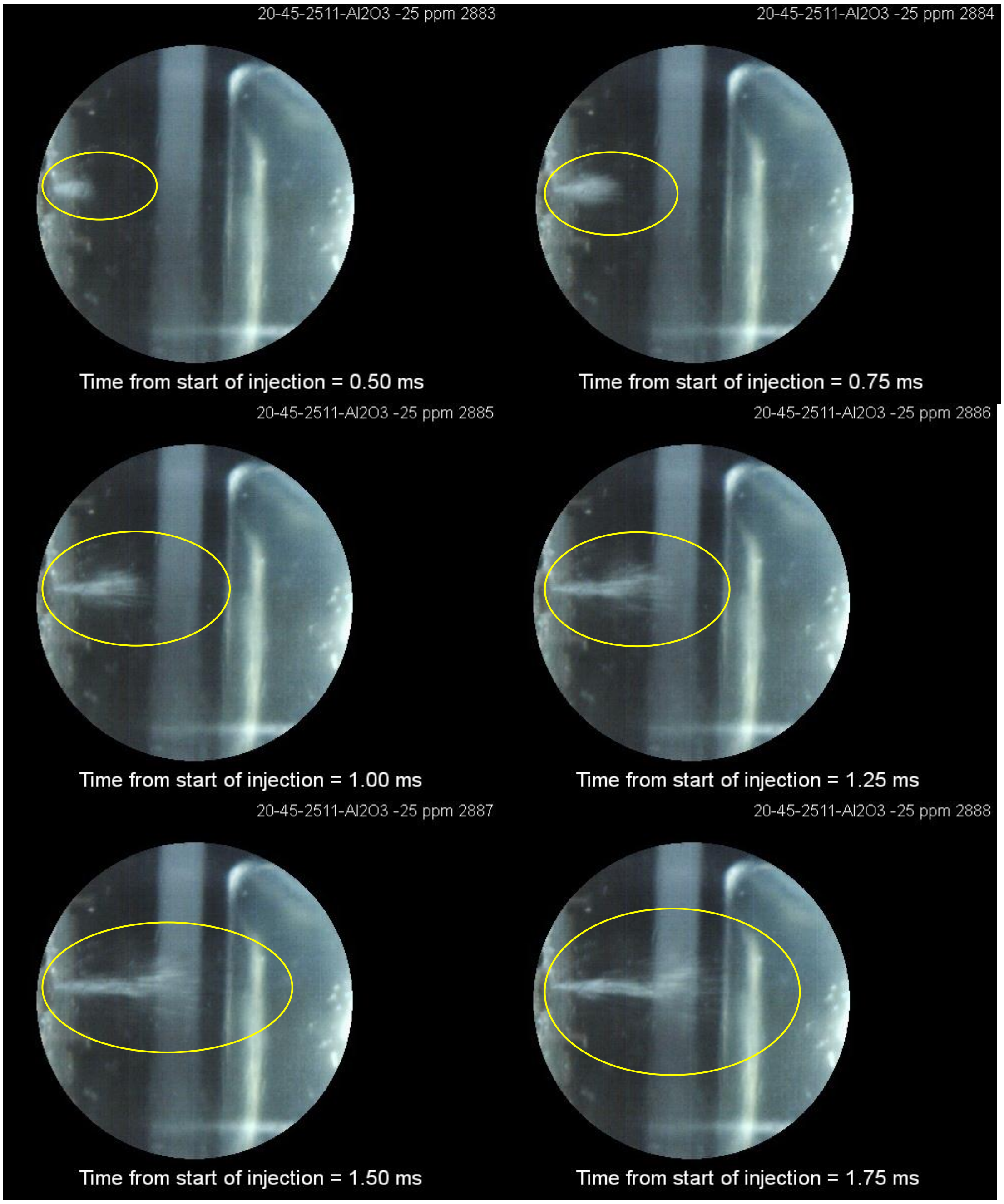
Photos for Propagation of Spray of SiO_2 nano-diesel (ID + SiO_2)

At 100 ppm .



Appendix A5

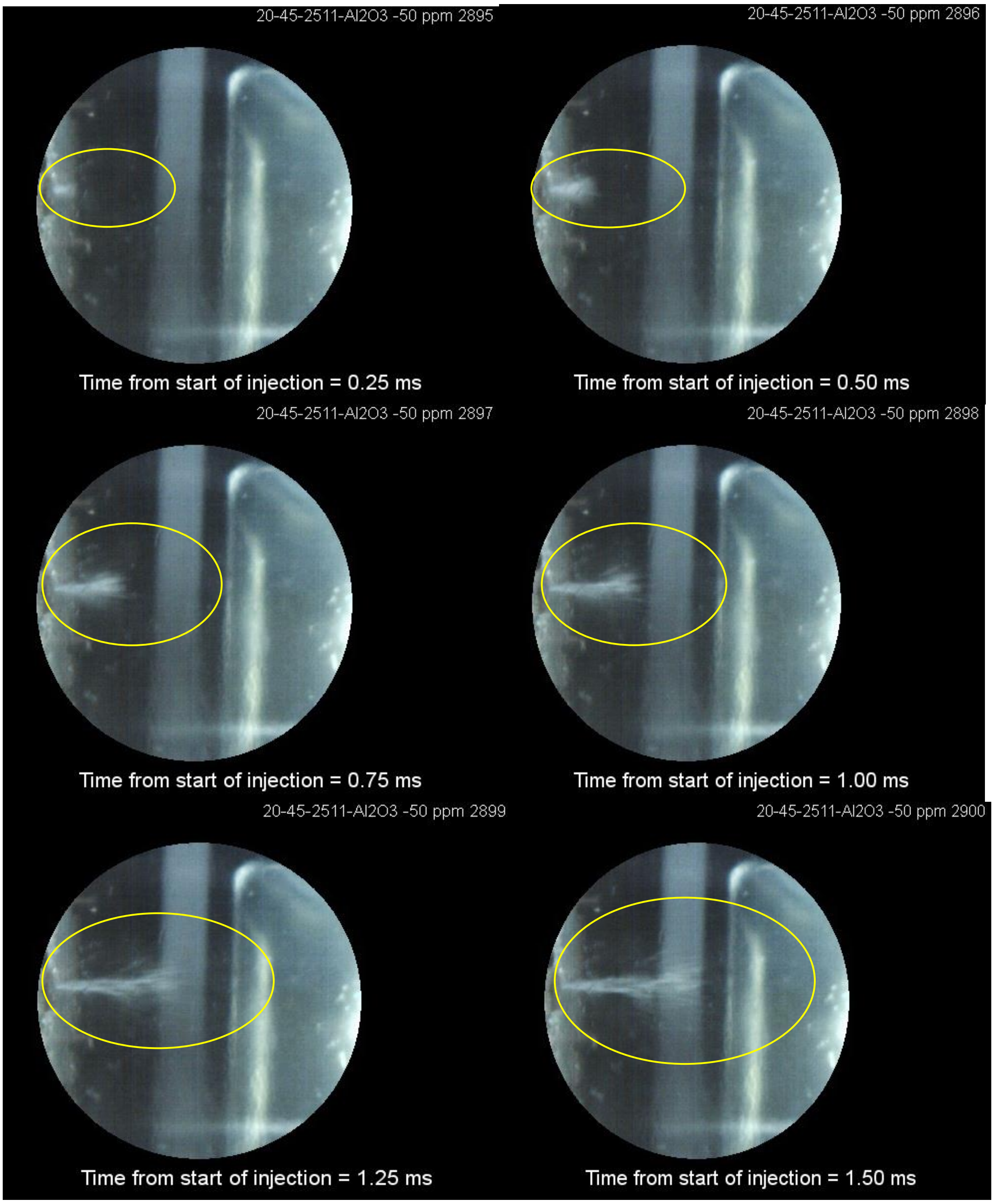
Photos for Propagation of Spray of Al_2O_3 nano-diesel (ID + Al_2O_3)
At 25 ppm .



Appendix A6

Photos for Propagation of Spray of Al_2O_3 nano-diesel (ID + Al_2O_3)

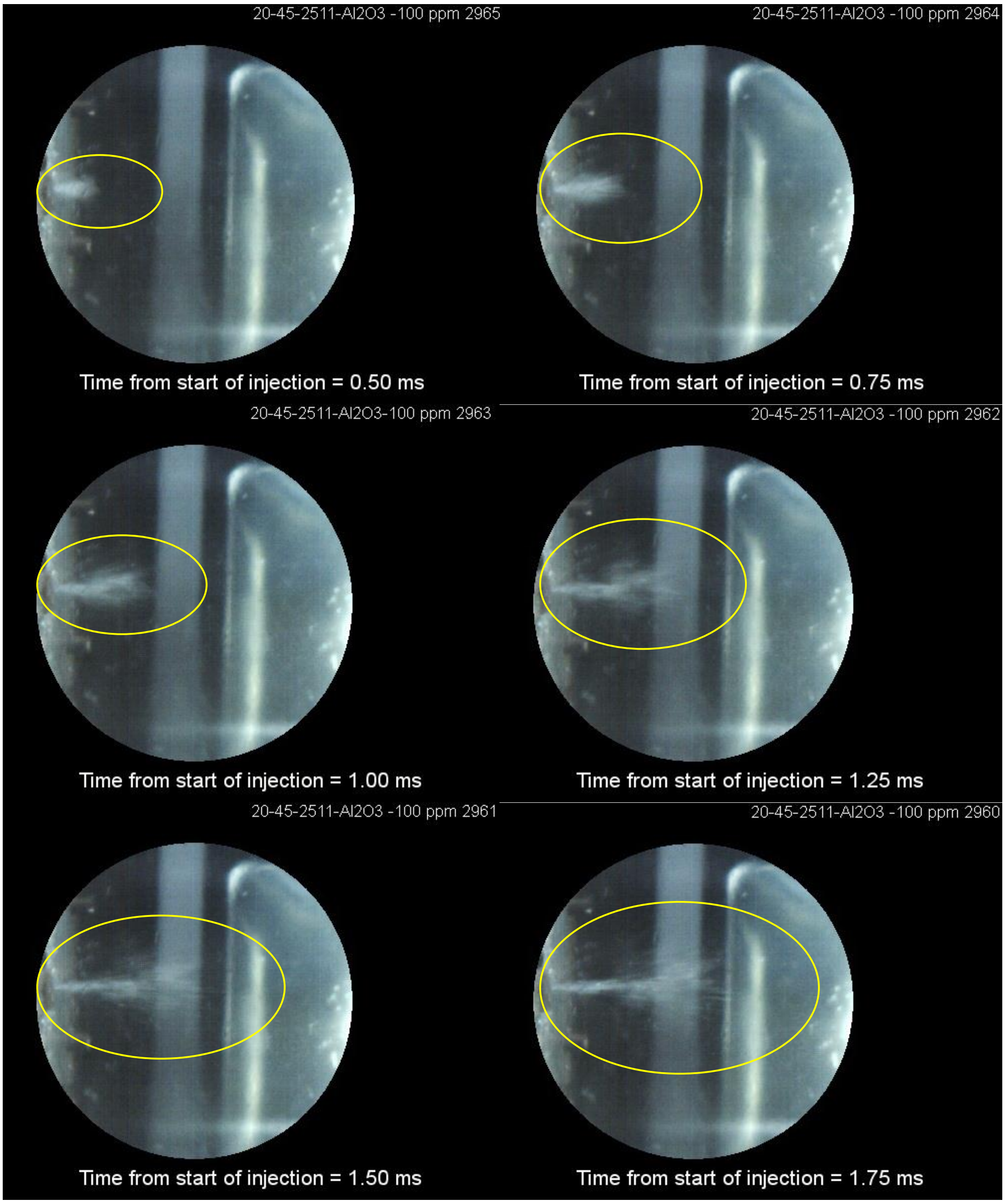
At 50 ppm .



Appendix A7

Photos for Propagation of Spray of Al_2O_3 nano-diesel (ID + Al_2O_3)

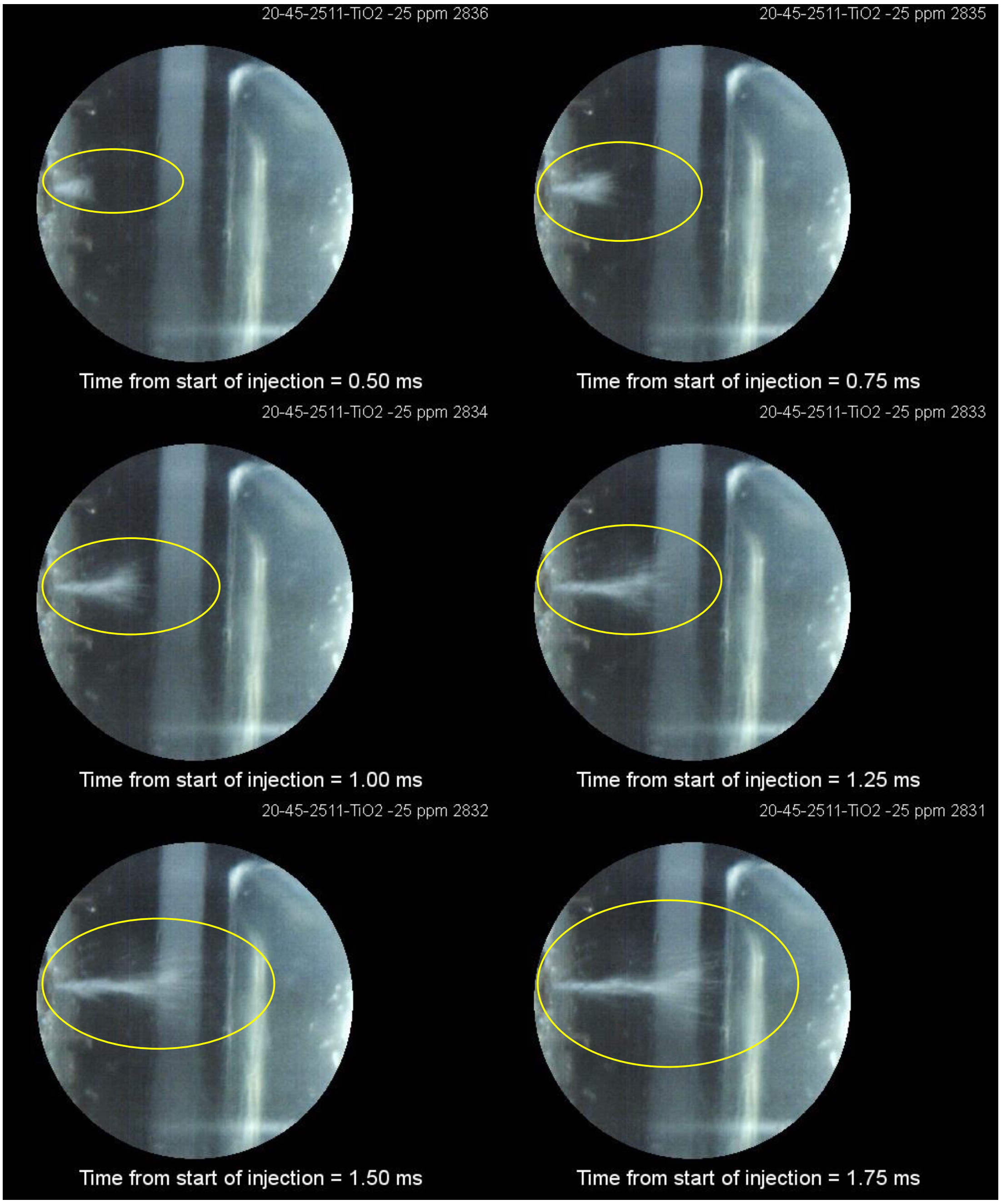
At 100 ppm .



Appendix A8

Photos for Propagation of Spray of TiO_2 nano-diesel (ID + TiO_2)

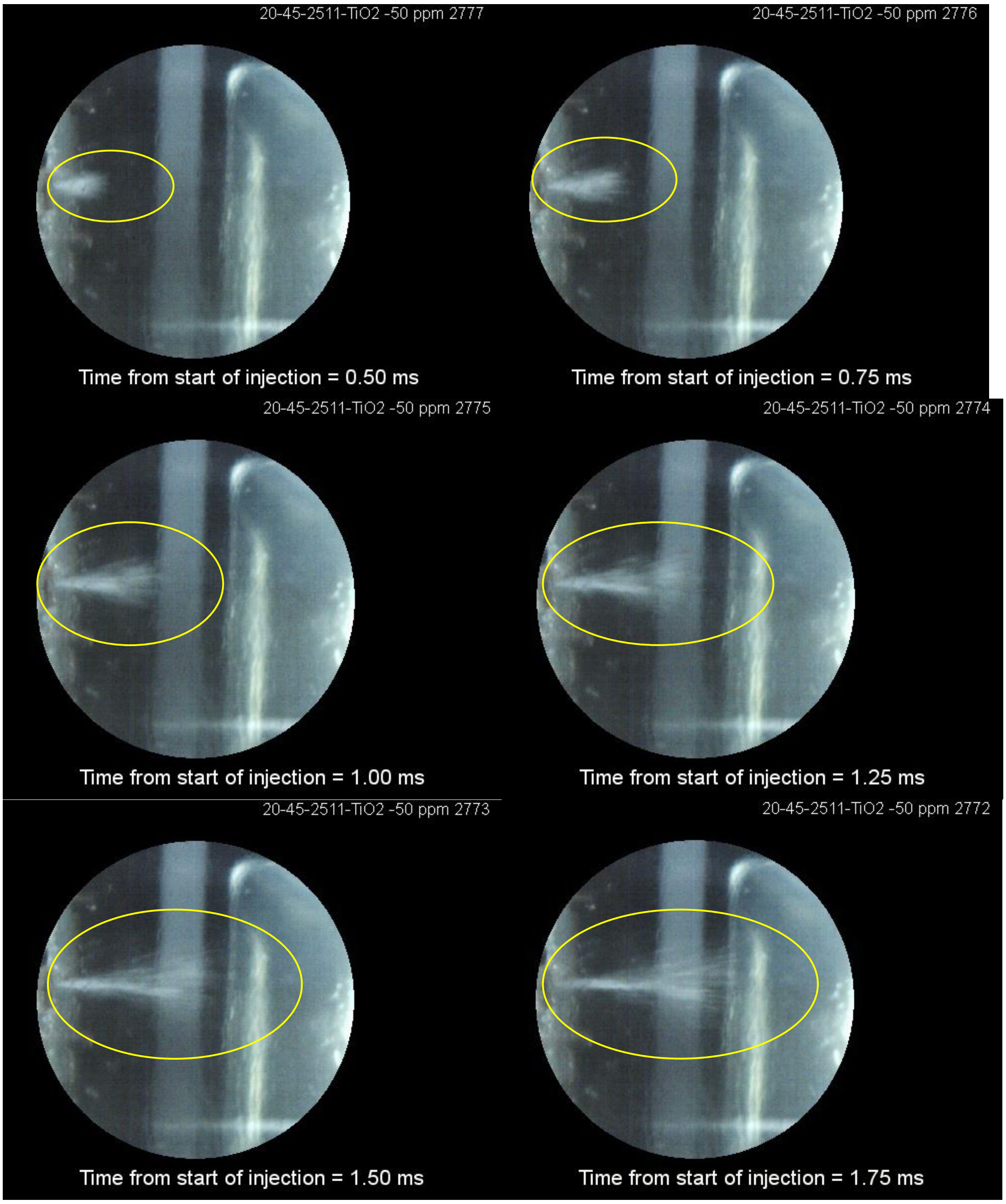
At 25 ppm .



Appendix A9

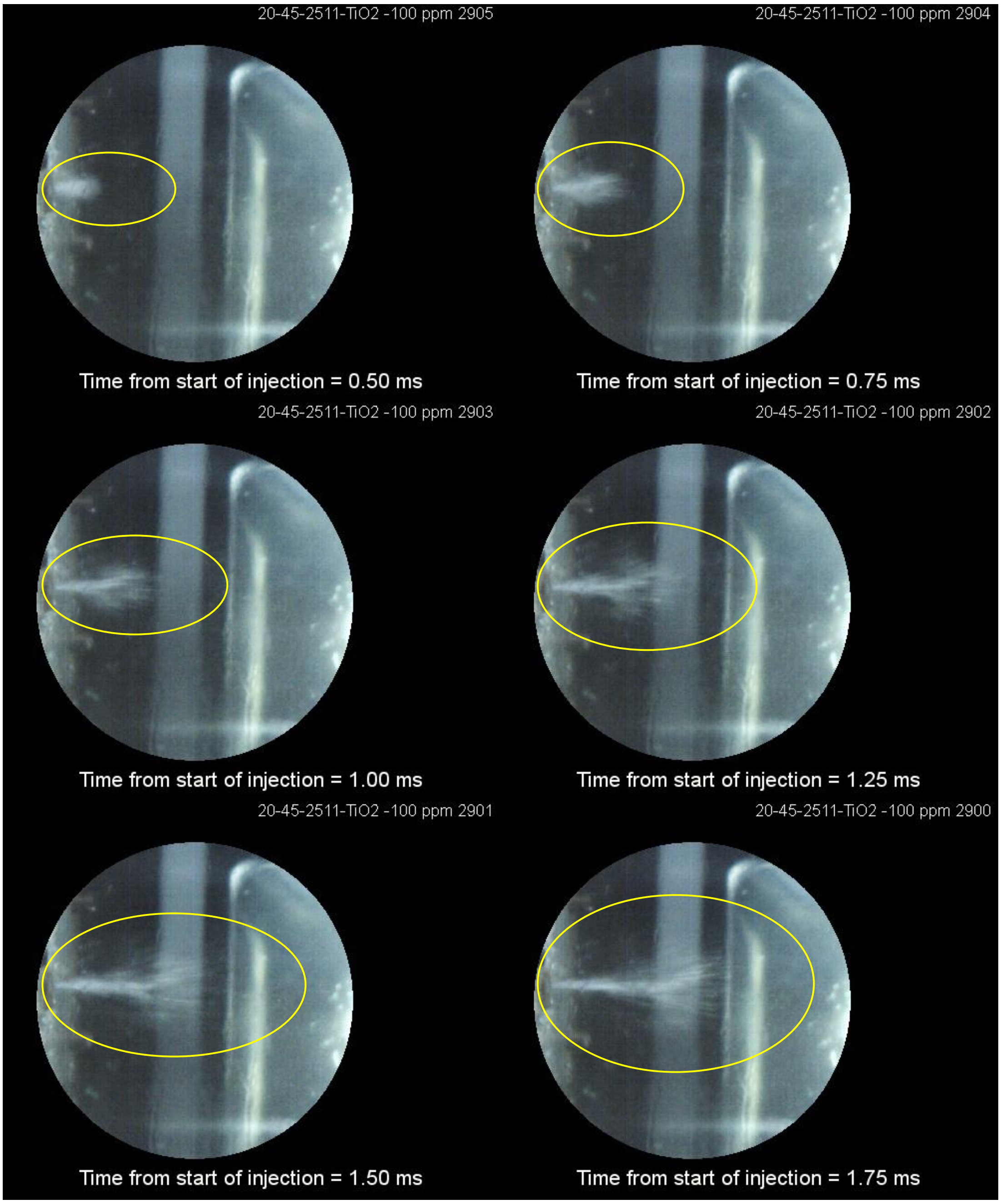
Photos for Propagation of Spray of TiO_2 nano-diesel (ID + TiO_2) .

At 50 ppm .



Appendix A10

Photos for Propagation of Spray of TiO_2 nano-diesel (ID + TiO_2) .
at 100 ppm .



Appendix B

Appendix B1

Penetration of clear Iraqi diesel fuel at three different dates .
Database of fig (4.1)

ms	Nov,14	Nov,17	Nov-25	
0	0	0	0	
0.25	5.16	6	5.53	0.84
0.5	13.1	14.2	13.8	1.1
0.75	20.4	21.5	20.6	1.1
1	27.3	29.1	28.4	1.8
1.25	34.6	35.5	36.8	0.9
1.5	38.5	40.1	39.6	1.6
1.75	40.8	42.1	41.6	1.3
2	46.7	47.9	48.3	1.2
2.25	52.6	51.8	53	-0.8
2.5	57.8	58	58.9	0.2
2.75	64.6	66	67.2	1.4

Appendix B2

SiO_2 , Al_2O_3 and TiO_2 Nano-diesel Spray Penetration (mm) at a mass fraction of 25 ppm . Database of Fig. (4.3) .

Time after injection ms	Clear Diesel mm	Nano-SiO2 fuel mm	Nano-Al2O3 fuel mm	Nano-TiO2 fuel mm
0.25	5.16	7.36	9.8	10
0.5	13.1	15.5	16.9	17.9
0.75	20.4	22.4	24.3	25.2
1	27.3	29.1	29.5	32.1
1.25	34.6	35.2	36.5	37.5
1.5	38.5	41.1	43.2	44.3
1.75	40.8	48.4	49.7	50.7
2	46.7	52.7	53.9	55.3
2.25	52.6	56.9	57.6	59.2
2.5	57.8	62.1	64.4	65.7
2.75	64.6	66.7	68.7	70.9

Appendix B3

SiO_2 , Al_2O_3 and TiO_2 Nano-diesel Spray Penetration (mm) at a mass fraction of 50 ppm . Database of Fig. (4.5) .

Time after injection ms	Clear Diesel mm	Nano-SiO_2 fuel mm	Nano-Al_2O_3 Fuel mm	Nano-TiO_2 fuel mm
0.25	5.16	7.5	10.1	10.5
0.5	13.1	15.9	17.1	18.6
0.75	20.4	23.1	24.6	25.9
1	27.3	29.8	30.2	32.9
1.25	34.6	36.4	37.1	39.3
1.5	38.5	42.5	43.9	46.7
1.75	40.8	49.1	50.1	52.2
2	46.7	54.6	55.9	57.4
2.25	52.6	58.5	60.2	61.3
2.5	57	63.6	65.9	67.9
2.75	64.6	68.3	69.9	72.3

Appendix B4

SiO_2 , Al_2O_3 and TiO_2 Nano-diesel Spray Penetration (mm) at a mass fraction of 100 ppm . Database of Fig. (4.7) .

Time after injection ms	Clear Diesel mm	Nano-SiO_2 fuel mm	Nano-Al_2O_3 fuel mm	Nano-TiO_2 fuel mm
0.25	5.16	7.9	10.3	10.9
0.5	13.1	16.2	17.4	18.7
0.75	20.4	23.6	24.9	26.4
1	27.3	30.5	31.1	33.3
1.25	34.6	37.1	38.2	40.4
1.5	38.5	43.4	44.9	47.6
1.75	40.8	50.6	51.2	54.3
2	46.7	56.7	57.5	59.7
2.25	52.6	60.2	62.6	63.8
2.5	57	65.6	67.3	70.1
2.75	64.6	71.1	72.9	74.4

Appendix B5

SiO_2 nano-diesel Spray Penetration (mm) at (25 , 50 and 100) ppm . Database of Fig. (4.9) .

Time after injection ms	Clear Diesel mm	At 25 ppm mm	At 50 ppm mm	At 100 ppm mm
0.25	5.16	7.36	7.5	7.9
0.5	13.1	15.5	15.9	16.2
0.75	20.4	22.4	23.1	23.6
1	27.3	29.1	29.8	30.5
1.25	34.6	35.2	36.4	37.1
1.5	38.5	41.1	42.5	43.4
1.75	40.8	48.4	49.1	50.6
2	46.7	52.7	54.6	56.7
2.25	52.6	56.9	58.5	60.2
2.5	57.8	62.1	63.6	65.6
2.75	64.6	66.7	68.3	71.1

Appendix B6

Al_2O_3 Nano-diesel Spray Penetration (mm) at (25 , 50 and 100) ppm . Database of Fig. (4.11) .

Time after injection ms	Clear Diesel mm	At 25 ppm mm	At 50 ppm mm	At 100 ppm mm
0.25	5.16	7.36	7.5	7.9
0.5	13.1	15.5	15.9	16.2
0.75	20.4	22.4	23.1	23.6
1	27.3	29.1	29.8	30.5
1.25	34.6	35.2	36.4	37.1
1.5	38.5	41.1	42.5	43.4
1.75	40.8	48.4	49.1	50.6
2	46.7	52.7	54.6	56.7
2.25	52.6	56.9	58.5	60.2
2.5	57.8	62.1	63.6	65.6
2.75	64.6	66.7	68.3	71.1

Appendix B7

TiO_2 Nano-diesel Spray Penetration (mm) at (25 , 50 and 100) ppm . Database of Fig. (4.13) .

Time after injection ms	Clear Diesel mm	At 25 ppm mm	At 50 ppm mm	At 100 ppm mm
0.25	5.16	10	10.5	10.9
0.5	13.1	17.9	18.6	18.7
0.75	20.4	25.2	25.9	26.4
1	27.3	32.1	32.9	33.3
1.25	34.6	37.5	39.3	40.4
1.5	38.5	44.3	46.7	47.6
1.75	40.8	50.7	52.2	54.3
2	46.7	55.3	57.4	59.7
2.25	52.6	59.2	61.3	63.8
2.5	57	65.7	67.9	70.1
2.75	64.6	70.9	72.3	74.4

Appendix B8

Spray Penetration (mm) at 1ms after Injection for the three types and the three mass fractions .
Database of Fig. (4.15) .

Mass Fractions ppm	Clear Diesel mm	SiO_2- nano fuel mm	Al_2O_3- nano fuel mm	TiO_2- nano fuel mm
25	27.3	29.1	29.5	32.1
50	27.3	29.8	30.2	32.9
100	27.3	30.5	31.1	33.3

Appendix C

Appendix C1

Spray Cone Angle (**Φ** degree) of the three types of Nano-diesel at 25 ppm . Database of Fig. (4.16) .

Time after injection ms	Clear Diesel deg	Nano-SiO_2 Fuel deg	Nano-Al_2O_2 fuel deg	Nano-TiO_2 Fuel deg
0.5	14	13.8	13.65	13.33
0.75	14	13.61	13.19	12.72
1	14	12.7	12.4	12.2

Appendix C2

Spray Cone Angle (**Φ** degree) of the three types of Nano-diesel at 50 ppm . Database of Fig. (4.17) .

Time after injection ms	Clear Diesel deg	Nano-SiO_2 Fuel deg	Nano-Al_2O_3 fuel deg	Nano-TiO_2 Fuel deg
0.5	14	13	12.8	12.6
0.75	14	12.66	12.37	12.16
1	14	12.43	11.82	11.25

Appendix C3

Spray Cone Angle (**Φ** degree) of the three types of Nano-diesel at 100 ppm . Database of Fig. (4.18) .

Time after injection ms	Clear Diesel deg	Nano-Si2O3 Fuel deg	Nano-Al2O3 Fuel deg	Nano-TiO2 fuel deg
0.5	14	12.6	12.3	12.1
0.75	14	12.18	11.76	11.35
1	14	11.9	11.51	11.15

Appendix C4

Spray Cone Angle (Φ degree) of SiO_2 Nano-diesel with the three mass fractions . Database of Fig. (4.19) .

Time after injection ms	clear diesel deg	25 ppm deg	50 ppm deg	100 ppm deg
0.5	14	13.8	13	12.6
0.75	14	13.61	12.66	12.18
1	14	12.7	12.43	11.9

Appendix C5

Spray Cone Angle (Φ degree) of Al_2O_3 Nano-diesel with the three mass fractions . Database of Fig. (4.20) .

Time after injection ms	clear diesel deg	25 ppm deg	50 ppm deg	100 ppm deg
0.5	14	13.65	12.8	12.3
0.75	14	13.19	12.37	11.76
1	14	12.4	11.82	11.51

Appendix C6

Spray Cone Angle (Φ degree) of TiO_2 Nano-diesel with the three mass fractions . Database of Fig. (4.21) .

Time after injection ms	clear diesel deg	25 ppm deg	50 ppm deg	100 ppm deg
0.5	14	13.33	12.6	12.1
0.75	14	12.72	12.16	11.35
1	14	12.2	11.25	11.15

Appendix D1

The Calibration of High Speed Camera :

AOS Technologies AG

Baden-Daettwil, 30th November 2021

To whom it may concern

CERTIFICATE OF CALIBRATION

We confirm that the delivered

Q-PRI camera with serial# 2121011648

has the following factory installed calibration files, which are valid and loaded in the camera:

2121011648_calib-coefficients_low.coeff
2121011648_calib-coefficients_high.coeff

Manufacturer
AOS Technologies AG

Stephan Trost
Managing Director

AOS Technologies AG, Taefernstrasse 20
5405 Baden – Daettwil, Switzerland
Tel: +41 56 483 34 88
info@aostechnologies.com

الخلاصة

تم اجراء هذا البحث التجريبي لدراسة تأثير اضافة مواد متناهية الصغر (المواد النانوية) على خاصيتين من خواص عملية البثق (على المستوى الماكروسكوبي) لوقود الديزل وهما طول وزاوية البثق . تم تحضير ثلاثة انواع من الديزل النانوي وهي الديزل + النانوسيلكا والديزل + النانوالومينا واخيرا الديزل + النانوتيتانيا . تم استخدام ثلاثة نسب وزنية للمواد النانوية وهي 25 و 50 و100 جزء من المليون . ولذلك فقد تم تجهيز اربعة انواع من الوقود ثلاثة منها متكونة من الديزل العراقي مخلوط مع المواد النانوية والرابع هو الديزل الاعتيادي بدون اي اضافات . استخدمت الكاميرا فائقة السرعة لدراسة تأثير اضافة المواد النانوية على خاصيتي طول وزاوية البثق . تم حقن الوقود في غرفة اسطوانية الشكل موضوعة بشكل افقي ومصنوعة من الزجاج الحراري لتسهيل عملية التصوير . بينت عملية التصوير بان طول البثق يزداد بتأثير اضافة المواد النانوية بينما تقل زاوية البثق بتأثير هذه الاضافات . هذا التغيير يعتمد على كثافة المواد النانوية المضافة الى الديزل . بالنسبة الى طول البثق فان مزيج الديزل + التيتانيا النانوية صاحب الزيادة الاكبر وحسب النسب الاتية (16.74 % و 21.03 % و 34.66 %) للنسب الوزنية للإضافات (25 و 50 و 100) جزء من المليون على الترتيب . بينما كان مزيج الديزل + السليكا النانوية تمتع بنسب الزيادة الاقل (8.94 % و 12.11 % و 15.5 %) للنسب الوزنية (25 و 50 و 100) جزء من المليون على الترتيب . اما فيما يخص التغير في زاوية البثق فان خليط (الديزل + نانو تيتانيا) تعاني النقصان الاكبر وحسب النسب الاتية (8.92 % و 14.26 % و 17.62 %) للنسب الوزنية (25 و 50 و 100) جزء من المليون بينما عانى خليط (الديزل + السليكا النانوية) من النقصان الاقل وحسب النسب (4.5 % و 9.31 % و 12.66 %) للنسب الوزنية (25 و50 و100) جزء من المليون . ان تاثير اضافة النسبة الوزنية 100 جزء من المليون لكل نوع من الانواع الثلاثة اكثر تاثير من اضافة النسبة الوزنية 25 جزء من المليون وللخاصيتين مدار او موضوع البحث.

الجمهورية العراقية
وزارة التعليم العالي والبحث العلمي
جامعة بابل / كلية الهندسة
قسم الهندسة الميكانيكية

دراسة تجريبية لتأثير اضافة حبيبات متناهية الصغر (نانوية) على إختراق بثق الوقود وزاوية المخروط

رسالة مقدمة الى قسم الهندسة الميكانيكية / كلية الهندسة / جامعة بابل
وهي جزء من متطلبات نيل درجة الدبلوم العالي في الهندسة الميكانيكية
(هندسة القدرة)

من قبل

ياسر فاضل عبود محمد

بكالوريوس هندسة ميكانيكية 1996

باشراف

الأستاذ الدكتور هارون عبد الكاظم شهد

2022 A.D. 1443 A. H.