INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

IJARIIT

ISSN: 2454-132X
Impact factor: 4.295
*(Volume 4, Issue 1)*
Available online at www.ijariit.com

# A Review of Various Ethanol Supplementation Techniques in Compression Ignition Operations on the Aspects of Performance, Combustion and Emission Characteristics

*Ishan Sharma*
sharmaishan1508@gmail.com
*University of Petroleum and Energy Studies, Dehradun, Uttarakhand*

*Karan Arora*
karanarora687@gmail.com
*University of Petroleum & Energy Studies, Dehradun, Uttarakhand*

*Satyam Dixit*
satyam.dixit25@gmail.com
*University of Petroleum and Energy Studies, Dehradun, Uttarakhand*

## ABSTRACT

***With the aggravating trends of Globalisation across the global circuit, it has certainly lead to the development of a vital sector more significantly – Transportation. To cater forth the growing demands of the growing population. With the growing demands, Sector had to opt for efficient and durable characteristics instilled with longevity which led to a complete reliance on the transportation industry onto the DIESEL Engines for Public & Commercial Transportation.***

**Keywords:** *Ethanol Supplementation Techniques, Ignition Operations, Performance, Combustion, and Emission.*

## 1. INTRODUCTION

With the aggravating trends of Globalisation across the global circuit, it has certainly lead to the development of a vital sector more significantly – Transportation. To cater forth the growing demands of the growing population. With the growing demands, Sector had to opt for efficient and durable characteristics instilled with longevity which led to a complete reliance on the transportation industry onto the DIESEL Engines for Public & Commercial Transportation. However, this had contributed & resulted in 26% increase of Greenhouse Gases Emissions alone by this sector (Vehicular Pollution) with its after-effects resulting in Global Warming[(1)]. Whereas on the Account of respirable suspended Particles, Diesel Fuelled vehicles are its major contributors to enlist upon[(2,3)] – Elemental Carbon, Organic Carbon, Inorganic ions are primary constituents of PM (Particulate Matter) Emission from the DIESEL Vehicles [(4,5,6)] which can lead to hazardous effects on the human health and had led to environment degradation in past which has been clinically proved by many research scholars around the globe [(7,8,9,10)] , numerous Studies have identified Vehicular Emission to be the Major Cause of cardiovascular health & respiratory problems including neurodegenerative disorders [(11,12)].Smog (Smoke + Fog) which is also majorly caused due to Emission caused by the vehicles which further mixes with the Fog [(13,14)].

With the increasing Vehicular Emissions, environment conservation from hazardous emissions has raised its bar with the Stringent Emission Norms and Standards in order to curb such emissions from diesel Engine Vehicles [(15)].With Stringent Emission norms in-effect has led to adoption of the 'Alternative Fuels and Sustainable Bio-fuels' such as – Biogas, Bio-Alcohol, Bio Diesel etc. [(16-21)] as progressive measures in the direction to meet the present emission norms [(22)] and with the dwindling fossil fuel stocks to has been claimed by the researchers about the existing stock to last for 40 years (Crude Oil)[(23-25)] , 62 years (Natural Gas)[(23-25)]& 219 years (Coal)[(23-25)] : As estimated at the End of 2013 [(23-25)]. Growing challenges for the availability of fossil fuels has been the major factor responsible for the increasing cost of the petroleum commodities across the global market – which has been the prevalent reason for Bio-fuels as Alternate Fuel adoption in the system with immediate effect. Among the bio-fuel sources are –

- Bio – Alcohol
- Bio Diesel
- Biogas
- Alcohol

Among all 4 Sources, Alcohol has prominently grabbed a Market-Eye with its promising characteristics to be the provident Alternative for the Future with its present counterparts - Fossil Fuels. Alcohol stands to be superior fuel on compared to Biogas &

 

Biodiesel Operation which have a High Pressure Operational requirement, Leakage Problem; Biodiesel production from non-edible sources with its commercial viability can only be produced through Large Scale Cultivation to provide adequate biomass for its Large Scale Production.

With dual fuel operation, Alcohol (OH) can be combined with diesel fuel by different operating techniques and conditions; with prominent ones are –

**A. Blending Process**

When DIESEL fuels are blended with Alcohols before it is being injected inside the combustion chamber with necessary additives to maintain the miscibility across its operation – which states to be the limiting condition for corrective % of alcohol usage in DIESEL vehicles in dual fuel operation mode.

**B. Fumigation Process**

It is simply defined as the pre-introduction of Alcohol (Ethanol/Methanol) into the Intake Manifold which would further get mixed with Intake air inside the manifold, this could be achieved by either carburetting, spraying or injecting inside the Intake Manifold which has proved to be the credential advantage with the total fuel supply. Modification required for its implementation – [26, 27]

- A Low-Pressure Fuel injector
- Separate fuel tank & controls

In Ethanol fumigation process, larger substitution with Ethanol could be made with its advantageous edge over blending of no-additive addition in comparison to blending which shows an evident improvement in performance characteristics by fumigation.

## 2. HISTORY: ALCOHOLS USAGE AS A SUPPLEMENT IN DIESEL ENGINES

Alcohols have been used in IC Engines ever since its invention. With its commercial usage roots-in from the Legendary Model-T by Henry Ford, Usage of Ethanol (Corn Alcohol) with Diesel in 1908.With a steep supply deficit which was conceded as an effect inadequate supply to meet the concurrent demands lead to the adoption of Bio-fuel like - Ethanol as an alternative [25].
With an Inadequate Supply rate, It is leading to a development of Supply-demand deficit which has certainly proved an indication to adopt Alternatives which could certainly decrease reliance over the fossils, also as the depletion rate is increasing, fuel such as biodiesel are being considered as alternate fuels. Alcohol holds to be the most lucrative option on the grounds of storage and handling, to be adopted as the most attractive alternative fuels [59]. However, The Ease of operation & availability of supply are the predominant parameters of fossil fuel to be the prominent transportation fuel in past whereas its hazardous emission's and its complex refining process are disadvantages o ponder upon over alcohols [28]. With the increasing awareness across the Globe for environment conservation from vehicular pollution has brought attention towards alcohol fuels as supplementary fuels.

**Alcohol Fuel**

**ETHANOL ($C_2H_5OH$) ($CH_3$-$CH_2$-OH)**

**Sources**

- Cellulosic feed stocks
- Waste Wood* Note – Ethanol when produced from a Biomass-Based production like - waste wood can reduce $CO_2$emissions leading to an Eco-friendly, thus, helping to curb the effects of $CO_2$ Emissions which further contributed towards Global Warming [30,31].

**Production**

By fermentation and distillation process of starch crops after they are converted into simple sugars.
In India, Ethanol production majorly relies on Molasses based production, Molasses is a by-product of Sugarcane Industry. With India among the major consumer of Sugar, Ethanol based production using molasses certainly put pressure over the current stock to meet the consumption of Sugar in the nation. Certainly, Ethanol production commercially has to be encouraged so that added pressure due to ethanol production could be nullified with immediate effect.

**Characteristics/Property**

i. Ethanol has great mix ability with water ($H_2O$)
ii. It has a strong corrosive action against metals like aluminum, brass, and copper etc.
iii. It also results in clogging across fuel pipes on its reaction with rubber.

Note – It is advised fluorocarbon in place of rubber.

**Advantages**

I. Safer for transportation
II. Safer for Storage

Ethanol can help achieve peak power on comparable values as that of a gasoline engine in some case a lot more than its counterparts – Gasoline Engines [29, 30]. Ethanol can be used in IC Engine in 2 ways either as a fuel or by producing biodiesel [71].

 

**METHANOL ($CH_3OH$)**

**Sources***

- Organic sources such as Bio Mass etc.
- Most produced from Coal & Natural Gas (Bio Methanol production)
  - *(32-33)

**Production**

**Properties**

- It is colorless, light flammable liquid.
- Its chemical composition doesn't have to sulphur neither of any organic compounds.
- It produces higher thermal efficiency with lower emission levels.

**Advantages**

With its HIGH Octane Number, methanol suits to be the prominent choice of fuel for engine s having High Compression ratios.

**Disadvantage**

Low CV & Density prompts a need for large storage tank to be installed in vehicles

**Physiochemical Properties of Alcohol**

In CI Engines [34-35] – Ethanol and methanol are the most providential alternatives for the alternate fuels over fossil fuels i.e. Petroleum.

- **Viscosity**

When estimating kinematic viscosity of the alcohol it is probably less than that of D100 i.e. of Neat Diesel Sample. Kinematic Viscosity of Ethanol lies in between 1.09-2.02 centistokes [81] (1.41 centistokes at room temperature conditions [81]) on compared with Diesel that lies in the range of 1.3-4.1Centistokes [82] at 40$^{o}$C respectively

- **Oxygen ($O_2$) Percentage**

$O_2$ content is relatively high in alcohol fuels leading to HIGHER (A/F) Ratios than the Stoichiometric Ratios which in-turn provides better breathability to CI Engines for proper & effective combustion, High Hydrocarbon content and low Sulphur Content emits fewer emissions.

- **Heat of Vaporization**

With the addition of Alcohol, leads to a COOLING EFFECT across the combustion chamber. This is due to the High Heat of Vaporization, which certainly leads to COOLING EFFECT during the INTAKE & COMPRESSION Stroke. Thus, helping in increasing the Volumetric Efficiency.

- Laminar Flame propagation speed leading to combustion process getting finished & completed earlier [36,37]
- Alcohols have higher octane numbers thus, making it compatible to achieve higher compression ratios (CR) in CI Engines before the emergence of Knocking, which ensures efficient and economic power supply from the engine.

**Techniques Used for OH & Diesel Fuel Operation in CI Engines**

- ALCOHOL FUMIGATION TYPE [38-43]

Alcohol fuel is introduced via intake manifold by spraying or carburizing.

- ALCOHOL DIESEL BLEND TYPE [44-49]

A pre-mixed combination of Alcohol & Diesel fuel is made maintaining their homogeneity of the mixture.

- ALCOHOL DIESEL EMULSIFICATION TYPE [50-53]

In this technique to maintain phase stability across the solution, An Emulsifier is added to the fuels to prevent phase separation across the given fuel sample.

- DUAL INJECTION TYPE [54-55]

Where upon an independent injection for Alcohol fuel and Diesel Fuel is equipped independently?

Among all the methods discussed above for Alcohol and Diesel Dual fuel operation- Alcohol Diesel blend & Fumigation are widely used techniques with Ethanol &Methanol

 

**ALCOHOL-SUPPLEMENTED CI OPERATION VS. NEAT CI OPERATION**

Diesel consumption decreases when the ethanol percentage increases at the same load. It is observed that there is a decrease in fuel consumption at higher engine loads. It is due to substitution of Diesel with Ethanol for which Consumption is higher during zero and partial loads as compared to higher engine load conditions. When the incoming air and ethanol mixture in combustion chamber mixes with the diesel fuel due to surface tension difference (As Ethanol has a lower surface tension than that of diesel) thus at lower loads more amount of ethanol substituted. But at higher speeds, this surface tension factor reduces as the substitution is not high and diesel has to generate the energy at higher speeds. A maximum of 46% substitution was achieved by fumigation.

## 3. BLENDING VS. FUMIGATION

**BLENDING**

Large Supply of OH (Alcohol) is limited.[56-57]

Reason –Poor Miscibility with Alcohols

Blends aren't stable, extra additives needed to be added to maintain their stability & homogeneity across its composition [56-57]

Ethanol diesel blend is the easiest method to introduce ethanol to a diesel engine. But this is limited to ethanol only as lower alcohol methanol has a low solubility in diesel [75].

**FUMIGATION**

Fumigation is also a prevalent technique used for Ethanol substitution with the Diesel, in this process, Alcohols (Ethanol) in its vapour state is made to mix with the Intake air stream across the intake manifold, thus helping to prevent the immiscibility character due to phase separation, which is recurrent in Ethanol – Diesel blends. Alcohols (Ethanol) can be introduced either by vaporization or direct injection. This can be done via Manifold Injection or Direct port injection technique. Even Carburizing unit could be equipped to comprehend the process of fumigation but with carburetion units discontinued this technique is moreover obsolete due to its certain limitations.

By the fumigation process, it leads to decrease in intake mixture temperature and thus, enabling in increasing its density. Thus by this process, there is the availability of provident amount of air for complete combustion to take place which would yield increased power, if the composition of the fumigated mixture is produced leads to complete & effective combustion across the chamber.

**ADDITIONAL REQUIREMENTS FOR FUMIGATION PROCESS**

- Additional Carburettor
- Additional Vaporizer

Or

The fumigation process requires a separate apparatus where-in 1. A Separate Injection System with a separate fuel tank for the Ethanol to be stored, this would certainly help to revert back to primary operations (Single Fuel) without any inconvenience. This also provides the user with the choice for Single fuel operation and dual fuel operation.

Advantage

- By this process, it has been observed by researchers that, a larger amount of air can be delivered and a greater amount of power can be harness if the corrective amount of fuel is added into the chamber [59].
- No Need for addition of additives for further stability as it is premixed with intake air leading to improved miscibility of OH (Alcohol) & Diesel fuel.

Researchers have critically reviewed with their experimentation that fumigation mode can replace about 50% Diesel fuel with Alcohol [58]

As a Result, Researchers have found on experimentations that Blending (25%) supplies less amount of Alcohol Energy as on compared to fumigation (50%-60%) [58]

## 4. PREVIOUS EXPERIMENTATIONS

**Effect of Fumigation**

Experimental Researchers performed with Fumigation process by

a. Ajav. Et.al [60] in a modified CI Engine using Diesel & Ethanol (Vaporized) as a supplementary fuel.

**Operating Conditions**

MODE – I (Temperature (Ambient) = 20ºC)

MODE – II (Air (Pre-heated) at 50ºC before injection)

b. [61] Atomization technique in Diesel Engine with Ethanol fumigation. (Engine Speed ranges from 1000rpm to 2400rpm)

c. Chang. [63] – Experimentation with Biodiesel with 10% Methanol Fumigation Concentrations at 1800 Rev/Min.
d. Tsang. [62]Analysed its experimentation at 5%, 10%, 15% & 20% concentration ethanol fumigation.

## 5. OBSERVATIONS

- **Combustion Characteristics [80] -**

The researcher observed that at higher engine loads the achieved pressure values of fumigation were maximum at about 1.22kg/hr [59] whereas an inferential study across the combustion parameters infer with maximum cylinder pressures at 12.4$^o$ (Crank Angle position at TDC) [59]. With Bioethanol with above 30% concentration of oxygen across the mixture, it certainly leads to rapid pressure rise and peak cylinder pressure [59].

On Experimentation with the fumigation process, it was found that the Heat Release Rate (HRR) as compared to Neat Diesel operation is Higher by 5-15 J/$^o$CA, it was also found that this phenomenon was visible at the retarded operating range, with maximum retardation of about 2-4$^o$ at full load conditions[59]. With bioethanol, HRR is more due to the availability of more oxygen and shorter combustion duration which provide enhanced combustion. [59]
Apparently, With Equivalence ratio tending to be higher as compared to Normal CI operations which lead to a reduction in any type of Ignition delay (ID) to follow forth. [59]

- **Performance Characteristics**

  - BSFC

(Brake Specific Fuel Consumption)

It is defined as Mass flow Rate of Fuel divided with the Brake Power (BP) and is inversely proportional to Brake Thermal Efficiency (BTE)

**Inferences**

Fumigation lead to increased BSFC levels with Maximum BSFC = 285g/KWh@2400rpm (50% ENGINE Load Conditions) [61]

With 10% Methanol Fumigation with Biodiesel also led to increasing in BSFC & SFC due to Lower CV (Calorific Value) of the fuel.

Tsang. [62]Analysed BSFC 250.5g/KWh & 255.8g/KWh at 10% & 20% concentrations respectively which are 7% & 9% higher than the Neat operations of the Engine in-reference.

In Bioethanol Fumigation process, the overall fuel consumption i.e. specific fuel consumption (SFC) has drastically decreased with the Global Equivalence Ratio. [60][80]

**Summary**

Increased BSFC Level which is majorly attributed due to Lower CV Levels in the fumigation process.

With alcohol addiction, across the combustion chamber leads to a cooling effect, which is due to the fact, 'Alcohols having Higher Heat of Vaporization' which further requires more fuel to support complete combustion.

  - BTE

(Brake Thermal Efficiency)

It is defined as Brake Power (BP) divided by the fuel energy supplied. An inverse dependence over BSFC.Hansdah et.al[80]At $\Phi$ = 0.85, $\Phi$ = 0.88, $\Phi$ = 0.90 and $\Phi$ = 0.74, the brake thermal efficiency of four flow rates of bioethanol fumigation is found to be higher by about 2–7% compared to that diesel at full load[80]

**Summary**

BTE (Brake Thermal Efficiency) gets degraded at lower Engine Loads [67, 68] and increased BTE Levels have been observed at Medium & Higher Engine Loads [63, 66, 67, 68, 70] as at lower Engine Loads, Excess Air concentrations is very high leading to a very lean fumigated mixture for combustion thus deterioration in the combustion efficiency is observed. Also, Homogenous Air/Alcohol Mixture burns faster hence, provides more premixed combustion which tends to increase BTE. It is providently found by some researchers that due to lower Cetane Number (CN) of Alcohols it leads forth a phenomenon wherein the energy is released within a very short span leading to an increase to Ignition Delay (ID).

- EMISSION CHARACTERISTICS

  - EXHAUST TEMPERATURE

When ethanol substitution increases exhaust gas temperature decreases. When ethanol fumigation is done using carburettor due to atomization and high latent heat of evaporation there is a decrease in temperature. Due to this exhaust as temperature decreases. Researchers [59] on experimentation observed that at full load with Ethanol substitution with diesel increases across its composition it leads to decrease in overall exhaust temperatures. Quantitatively, Temperature decrease at lower substitution ranges is less evident whereas a steep decrease is observed at higher ethanol substitution ranges.

- $NO_X$ (Mono Nitrogen Oxides)

A NO & $NO_2$ family emissions and among the most hazardous emissions which are emitted among other CI Engines pollutants. Relatively observed that NOx formation does not take place until the flame temperature is over 2800F

FORMATION OF $NO_X$

They are produced when Nitrogen reacts with Oxygen during combustion process which leads to their high dependent on in-cylinder temperatures. Factors which affect their production are –

- Injection Timing
- Engine Load Conditions
- The rate of formation of NOx increases with increasing combustion chamber temperatures [72, 73, 74].

Its formation is governed by Zeldovich Mechanism.

**Summary**

Decreased NOx Emissions were observed in experimentations at Higher and Medium Engine Loads whereas a significant increase in NOx Emissions was seen at Lower Engine Loads as NOx Emissions being a temperature dependent phenomenon along with its dependence on concentrations of Oxygen ($O_2$) present at the time of combustion. With the Higher global equivalence ratio ranges, BSNO (NO Emissions) is found to be lower by about 5% minimally with a maximum 24% reduction as observed [80].
Specifically, As Alcohol possess Higher Levels of Latent Heat of Vaporization which leads to lower HEAT Release Rate Levels thus decreasing combustion chamber temperature which on brings a reduction in NOx Levels.
On Contrary facts, some researchers found a significant increase in NOx emissions and on further treating it with A EGR based system no significant change in observations were recorded with Post & Pre -Ethanol Fumigation.

- ❖ Poor Auto-Ignition properties leading to an increase of fuel burnt in pre-mixed mode, thus, increasing combustion temperature [63-67].
- ❖ A decrease in temperature is seen through carburettor at ongoing ethanol due to atomization. $NO_X$ emission decreases as ethanol substitution is increased because it depends upon the combustion temperature [59].
- ❖ Due to low pressures and reduction in combustion temperatures lower loads are limited to a small energy substitution by ethanol. So at lower loads $NO_X$ emission may be higher even after adding ethanol [59].

- UNBURNED HYDROCARBON (HC) EMISSIONS

Due to poor fuel distribution, an excessive amount of air lower exhaust temperatures at no or partial loads lean fuel-air mixtures may escape exhausting increasing HC emissions [78, 79].

The rate of Unburnt Hydrocarbon emission increases linearly with Ethanol addition across the diesel mixture, as with the ethanol addition across the chamber leads to increased substitution in the overall mixture which leads to poor combustible conditions leading to incomplete/ineffective combustion cycles across its operation.

At 70% and full loads till 11% ethanol fumigation HC emission increases and decreases till 18% subject to better combustion at higher loads. HC emissions remain constant after 18% [59].

It was found as an experimental observation to the experiment that at lower range limit of the global equivalence ratio, the BSHC emission at four different flow rates is found to be higher by about 24–43% when compared to neat diesel operation at ambient temperature conditions [80].

- CO (CARBON MONOXIDE)

These emissions are produced as a result of incomplete combustion in the combustion chamber which happens due to insufficient in-cylinder temperatures during combustion to support the transformation of CO to $CO_2$ [62,63,66,67,68,69].
Emission of CO depends upon the air-fuel ratio relative to stoichiometric proportion. Invariable amount of CO produced in the rich mixture as the deviation from stoichiometric is nearly linear [76].

The local rich mixture can be developed if an excess of air is developed in the combustion chamber leading to lower temperatures and resulting in lower temperature and resulting in improper combustion of fuel and CO emissions [77].

Considering lean mixture, the BSCO (Brake Specific Carbon Monoxide) for 0.24 and 0.48 Kg/h was found to be lower about 6.2% and 6.1% respectively. For 0.96 and 1.22 Kg/h it was found to be higher by about 12.8% and 9% respectively, compared to diesel [80].

**Summary**

CO & HC emission was reported a credential decrease in their concentration's at Higher Engine Loads and increased at Lower Engine Loads. It is majorly caused as at the time of combustion Air/Alcohol (OH) mixture gets trapped in Crevices, deposits and quench layers.

 

With alcohol, it leads to a lower in-cylinder gas temperature which is not enough to ignite Trapped alcohol in the crevices during the Expansion stroke leading to CO Emission increase at Lower Engine Loads.

Another reason to look forth could be the Rapid burning of vaporized Alcohol, which further assists Combustion Quenching caused by High Latent Heat of Vaporization of Alcohols with subsequent cooling as it after-effects decreases in-cylinder temperature, further leads to incomplete combustion.

- $CO_2$ (Carbon dioxide)
  A Primary Greenhouse gases emitted as a pollutant in CI Engine operations.
  Dependent Factors –
  - Combustion Temperature
  - Availability of Oxygen ($O_2$)

Researchers observed a decreased in $CO_2$ emission levels post Alcohol Fumigation [59, 63, 65, 68].

With Alcohol fumigation, BTE levels decreased which leads to increased fuel consumption discarding the CO2 reduction potential with the use of Alcohol Fuels.

In their respective experimental study, the researchers observed that at Zero load conditions, CO increases up to 30%. At 20% or 45% load CO decreases 20%. At 70% fuel load CO decreases until 15% ethanol fumigation and then increases with ethanol percentage. At Zero load conditions, $CO_2$ is constant. At 20 or 45% load $CO_2$ decreases as ethanol percentage decreases [59].

**Summary**

$CO_2$ emissions levels observations have outlaid a mixed review from all the experimentation process being carried by many researchers , majorly pointing out to decrease in $CO_2$ emission levels due to reduce in-cylinder temperatures leading to incomplete oxidation of CO to $CO_2$ during their respective Expansion Stroke thus resulting in increased CO Emission levels and decrease in $CO_2$ Emission levels whereas on contrary notes [68,69], Results observed displayed an increase in $CO_2$ levels with EGR system whereas some found NO Considerable changes in HOT EGR system with or without fumigation process.

- SMOKE & PARTICULATE MATTER
  Particulate matter consists of solid particles + liquid particles suspended in Air droplets which combined constitute towards PM (Particulate Matter) Emissions. Elemental Carbon or soot, adsorbed hydrocarbons and inorganic compounds, these all constituents contribute towards the PM (Particulate Matter) Emissions majorly.

**Summary**

A Significant decrease in SMOKE & PARTICULATE MATTER levels was reported. It was observed that with increased Alcohol Fumigation levels reported a steady decrease in PM levels. As by this less concentration of diesel fuel is burnt in diffusion mode which combusts together with homogenous Alcohol Air Mixture, which has a tendency to burn more swiftly with higher availability of $O_2$ (Oxygen) proving it to be a major reason for the reduction in PM Levels.
The darkness of smoke due to the carbon content which blocks the light is called smoke opacity. As ethanol fumigation increases smoke opacity decreases. At 70% and 100% loads up to 14% ethanol fumigation opacity decreases sharply then lightly. $O_2$ which is present in ethanol help in the better combustion reducing smoke opacity [59].

An Increase in ID (Ignition Delay) was observed with Fumigation process which enhances the mixing of Diesel fuel with Alcohol Air mixture thus leads to proper utilisation of air = Reduction in SMOKE Levels [55,56,58,61,65]
At $\Phi = 0.85$, $\Phi = 0.88$, $\Phi = 0.90$ and $\Phi = 0.74$, the smoke opacity for 0.24, 0.48, 0.96 and 1.22 kg/h flow rates, is found to be lower by about 4.2%, 5.5%, 12.5% and 25% respectively, compared to that of diesel operation[129].

Higher smoke is produced by higher molecular weight fuel, but bioethanol is lower molecular weight fuel as compared to diesel, therefore, lower smoke emission is obtained [80].

## 6. REFERENCES

[1] Dalkmann h., brannigan C... Transport and climate change. A sourcebook for policy-makers in developing cities: module 5e gesellschaft für technische zusammenarbeit—gtz eschborn; 2007.
[2] Lal s., Patil r.s. Monitoring of atmospheric behavior of nox from vehicular traffic. Environmental monitoring and assessment 2001; 68:37–50.
[3] Li n, xia t, nel ae. The role of oxidative stress in the ambient particulate matter- induced lung diseases and IT'S implications in the toxicity of engineered nanoparticles. Free radical biology and medicine 2008; 44:1689–99.
[4] Cheung kl, ntziachristos l, tzamkiozis t, schauer jj, samaras z, moore kf, et al. Emissions of particulate trace elements, metals and organic species from gasoline, diesel, and biodiesel passenger vehicles and their relation tooxidative potential. *Aerosol science and technology* 2010; 44:500–13.
[5] Stayner l, dankovic d, smith r, steenland k. Predicted lung cancer risk among miners exposed to diesel exhaust particles. American journal of industrial medicine 1998;34:207–19.
[6] Lloyd ac, cackette ta. Diesel engines: environmental impact and control. Journal of the air& waste management association 2001;51:809–47.
[7] Harrod ks, jaramillo rj, berger ja, gigliotti ap, seilkop sk, reed md. Inhaled diesel engine emissions reduce bacterial clearance and exacerbate lung disease to pseudomonas aeruginosa infection in vivo. Toxicological sciences 2005;83:155–65.

[8] SEAGRAVE JC, MCDONALD JD, BEDRICK E, EDGERTON ES, GIGLIOTTI AP, JANSEN JJ, ET AL. LUNG TOXICITY OF AMBIENT PARTICULATE MATTER FROM SOUTHEASTERN US SITES WITH DIFFERENT CONTRIBUTING SOURCES: RELATIONSHIPS BETWEEN COMPOSITION AND EFFECTS. ENVIRONMENTAL HEALTH PERSPECTIVES 2006;114:1387.
[9] MCDONALD JD, REED MD, CAMPEN MJ, BARRETT EG, SEAGRAVE J, MAUDERLY JL. HEALTH EFFECTS OF INHALED GASOLINE ENGINE EMISSIONS. INHALATION TOXICOLOGY 2007;19:107–16.
[10] GAUDERMAN, W., JAMES, V., MCCONNELL, H., ROB, B., GILLILAND, K., THOMAS, F., ET AL. EFFECT OF EXPOSURE TO TRAFFIC ON LUNG DEVELOPMENT FROM 10 TO 18 YEARS OF AGE: A COHORT STUDY. THE LANCET 2007;369:571–7.
[11] PETERS A, VERONESI B, CALDERÓN-GARCIDUEÑAS L, GEHR P, CHEN LC, GEISER M, ET AL. TRANSLOCATION AND POTENTIAL NEUROLOGICAL EFFECTS OF FINE AND ULTRAFINE PARTICLES A CRITICAL UPDATE. PARTICLE AND FIBRE TOXICOLOGY 2006;3:1–13.
[12] KREYLING W, SEMMLER-BEHNKE M, MÖLLER W. HEALTH IMPLICATIONS OF NANOPAR- TICLES. JOURNAL OF NANOPARTICLE RESEARCH 2006;8:543–62.
[13] ECKERLE WA, LYFORD-PIKE EJ, STANTON DW, LAPOINTE LA, WHITACRE SD, WALL JC. EFFECTS OF METHYL ESTER BIODIESEL BLENDS ON NOXEMISSIONS.*SAE INTERNATIONALJOURNAL OF FUELS AND LUBRICANTS* 2009;1:102–18.
[14] VARATHARAJAN K, CHERALATHAN M, VELRAJ R. MITIGATION OF NOX EMISSIONS FROM A JATROPHA BIODIESEL FUELLED DI DIESEL ENGINE USING ANTIOXIDANT ADDITIVES. FUEL 2011; 90:2721–5.
[15] MOFIJUR M, ATABANI AE, MASJUKI HH, KALAM MA, MASUM BM. A STUDY ON THE EFFECTS OF PROMISING EDIBLE AND NON-EDIBLE BIODIESEL FEEDSTOCKS ON ENGINE PERFORMANCE AND EMISSIONS PRODUCTION: A COMPARATIVE EVALUATION. RENEW- ABLE AND SUSTAINABLE ENERGY REVIEWS 2013;23:391–404.
[16] WANG WG, CLARK NN, LYONS DW, YANG RM, GAUTAM M, BATA RM, ET AL. EMISSIONS COMPARISONS FROM ALTERNATIVE FUEL BUSES AND DIESEL BUSES WITH A CHASSIS DYNAMOMETER TESTING FACILITY. ENVIRONMENTAL SCIENCE& TECHNOLOGY 1997; 31:3132–7.
[17] LEUNG DYC, LUO Y, CHAN TL. OPTIMIZATION OF EXHAUST EMISSIONS OF A DIESEL ENGINE FUELLED WITH BIODIESEL. ENERGY& FUELS 2006;20:1015–23.
[18] LIAQUAT AM, MASJUKI HH, KALAM MA, VARMAN M, HAZRAT MA, SHAHABUDDIN M, ET AL. APPLICATION OF BLEND FUELS IN A DIESEL ENGINE. ENERGY PROCEDIA 2012;14: 1124–33.
[19] MOFIJUR M, MASJUKI HH, KALAM MA, HAZRAT MA, LIAQUAT AM, SHAHABUDDIN M, ET AL. PROSPECTS OF BIODIESEL FROM JATROPHA IN MALAYSIA. RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 2012; 16:5007–20.
[20] SHAHABUDDIN M, KALAM MA, MASJUKI HH, BHUIYA MMK, MOFIJUR M. AN EXPERIMENTAL INVESTIGATION INTO BIODIESEL STABILITY BY MEANS OF OXIDATION AND PROPERTY DETERMINATION. ENERGY 2012;44:616–22.
[21] SHAHABUDDIN M, MASJUKI HH, KALAM MA, MOFIJUR M, HAZRAT MA, LIAQUAT AM. EFFECT OF ADDITIVE ON PERFORMANCE OF C.I. ENGINE FUELLED WITH BIO DIESEL. ENERGY PROCEDIA 2012;14:1624–9.
[22] IEA. TECHNOLOGY ROADMAP: BIOFUELS FOR TRANSPORT. PARIS: INTERNATIONAL ENERGY AGENCY; 2011. P. 52.
[23] KESSEL DG. GLOBAL WARMING—FACTS, ASSESSMENT, COUNTERMEASURES. JOURNAL OF PETROLEUM SCIENCE AND ENGINEERING. 2000;26:157–68.
[24] GOLDEMBERG J, JOHANSSON TB, REDDY AKN, WILLIAMS RH. ENERGY FOR THE NEW MILLENNIUM. AMBIO: A JOURNAL OF THE HUMAN ENVIRONMENT 2001;30: 330–337.
[25] GILBERT R, PERL A. ENERGY AND TRANSPORT FUTURES. A REPORT PREPARED FOR NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY. UNIVERSITY OF CALGARY; 1–96.
[26] POPA M., NEGURESCU N., PANA C., RACOVITZA A. RESULTS OBTAINED BY METHANOL FUELLING DIESEL ENGINE. SAE PAPER 01-3748; 2001.
[27] UDAYAKUMAR R., SUNDARAM S., SIVAKUMAR K.. ENGINE PERFORMANCE AND EXHAUST CHARACTERISTICS OF DUAL FUEL OPERATION IN DI DIESEL ENGINE WITH METHANOL. SAE TECHNICAL PAPER 01-0096; 2004.
[28] AGARWAL AK, KUMAR AVINASH. BIOFUELS (ALCOHOLS AND BIODIESEL) APPLICATIONS AS FUELS FOR INTERNAL COMBUSTION ENGINES. PROGRESS IN ENERGY AND COMBUSTION SCIENCE 2007;33:233–71.
[29] FUERY R.L.P.K.. COMPOSITION AND REACTIVITY OF FUEL VAPOR EMISSIONS FROM GASOLINE-OXYGENATE BLENDS. SAE PAPER 912429; 1991.
[30] DAVID W, NAEGELI PIL, ALGER MATTHEW J.,DENNIS L.. SURFACE CORROSION IN ETHANOL FUEL PUMPS. SAE PAPER 971648; 1997.
[31] BEER T, GRANT T. LIFE-CYCLE ANALYSIS OF EMISSIONS FROM FUEL ETHANOL AND BLENDS INAUSTRALIAN HEAVY AND LIGHT VEHICLES. JOURNAL OF CLEANER PRODUCTION 2007;15:833–7.
[32] SUNTANA AS, VOGT KA, TURNBLOM EC, UPADHYE R. BIO-METHANOL POTENTIAL IN INDONESIA: FOREST BIOMASS AS A SOURCE OF BIO-ENERGY THAT REDUCES CARBON EMISSIONS. APPLIED ENERGY 2009;86(SUPPL. 1):S215–21.
[33] DEMIRBAS A, GULLU D. ACETIC ACID, METHANOL AND ACETONE FROM LIGNOCELLULOSES BY PYROLYSIS. ENERGY EDUCATION SCIENCE AND TECHNOLOGY 1998;1:111–5.
[34] KISENYI J, SAVAGE C, SIMMONDS A. THE IMPACT OF OXYGENATES ON EXHAUST EMISSIONS OF SIX EUROPEAN CARS. SAE TECHNICAL PAPER 940929; 1994.
[35] DI Y, CHEUNG CS, HUANG Z. EXPERIMENTAL STUDY ON PARTICULATE EMISSIONOFA DIESEL ENGINE FUELED WITH BLENDED ETHANOL–DODECANOL–DIESEL. *JOURNALOF AEROSOL SCIENCE* 2009;40:101–12.
[36] WAGNER TOGD, ZARAH BY, KOZINSKI AA. PRACTICALITY OF ALCOHOLS AS MOTOR FUEL. SAE PAPER NO. 790429; 1979.
[37] ADELMAN H. ALCOHOLS IN DIESEL ENGINE. SAE PAPER NO. 790956; 1979.
[38] HAYES TK, SAVAGE LD, WHITE RA, SORENSON SC. THE EFFECT OF FUMIGATION OF DIFFERENT ETHANOL PROOFS ON A TURBOCHARGED DIESEL ENGINE. SAE PAPER NO. 880497; 1988.
[39] AJAV EAS, BACHCHAN BTK. THERMAL BALANCE OF A SINGLE CYLINDER DIESEL ENGINE OPERATING ON ALTERNATIVE FUELS. ENERGY CONVERSION AND MANAGEMENT 2000;41:1533–41.

 

[40] Gao xb g, foster d, ye z. Ignition delay and heat release analysis of an ethanol fumigated turbocharged diesel-engine. In: 6th annual energy sources technology and exhibit asme; 1983. 83-dgp-1.
[41] Walker jt. Diesel tractor engine performance as affected by ethanol fumiga- tion. Transactions of the asae 1984;27(1):49.
[42] Shropshire gj, bashford ll. Comparison of ethanol fumigation systems for a diesel engine. Agricultural engineering (united states) 1987;65(5):17–24.
[43] Chaplin j, janius rb. Ethanol fumigation of a compression-ignition engine using advanced injection of diesel fuel. Transactions of the asae 1987;30(3): 610–4.
[44] He b-q, shuai s-j, wang j-x, he h. The effect of ethanol blended diesel fuels on emissions from a diesel engine. Atmospheric environment 2003;37: 4965–71.
[45] Bilgin a, durgun o, sahin z. The effects of diesel–ethanol blends on diesel engine performance. Energy sources 2002;24:431–40.
[46] Lapuerta m, armas o, herreros jm. Emissions from a diesel–bioethanol blend in an automotive diesel engine. Fuel 2008;87:25–31.
[47] Kim h, choi b. Effect of ethanol–diesel blend fuels on emission and particle size distribution in a common-rail direct injection diesel engine with warm- up catalytic converter. Renewable energy 2008;33:2222–8.
[48] Rakopoulos dc, rakopoulos cd, kakaras ec, giakoumis eg. Effects of ethanol–diesel fuel blends on the performance and exhaust emissions of heavy duty di diesel engine. Energy conversion and management 2008;49:3155–62.
[49] Xing-cai l, jian-guang y, wu-gao z, zhen h. Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel. Fuel 2004;83:2013–20.
[50] Xiao zln, zhao h. The effect of aromatic hydrocarbons and oxygenates on diesel engine emissions. Proceedings of the institution of mechanical engineers part d: *journal of theautomobile engineering*2000;214 (d3):307–32.
[51] Fahd mea, wenming y, lee ps, chou sk, yap cr. Experimental investigation of the performance and emission characteristics of direct injection diesel engine by water emulsion diesel under varying engine load condition. Applied energy 2013;102:1042–9.
[52] Boruff pa, schwab aw, goering ce, pryde eh. Evaluation of diesel fuel– ethanol micro-emulsions. Transactions of the asae 1982;25:47–53.
[53] Satgé de caro p, mouloungui z, vaitilingom g, berge jc. Interest of combining an additive with diesel–ethanol blends for use in diesel engines. Fuel 2001;80:565–74.
[54] Shropshire gj, goering ce. Ethanol injection into a diesel engine. Transac- tions of the asae (united states) 1982;25(3):570–5.
[55] Noguchi n, terao h, sakata c. Performance improvement by control of flow rates and diesel injection timing on dual-fuel engine with ethanol. Bioresource technology 1996;56:35–9.
[56] Abu-qudais m, haddad o, qudaisat m. The effect of alcohol fumigation on diesel engine performance and emissions. Energy conversion and manage- ment 2000;41:389–99.
[57] Surawski nc, miljevic b, roberts ba, modini rl, situ r, brown rj, et al. Particle emissions, volatility, and toxicity from an ethanol fumigated compression ignition engine. Environmental science& technology 2009;44:229–35.
[58] Ecklund ee, bechtold rl, timbario tj, mccallum pw. State-of-the-art report on the use of alcohols in diesel engines. Paper no. 840118. Warrendale, pa: society of automotive engineers, inc.; 1984.
[59] Chauhan bs, kumar n, pal ss, du jun y. Experimental studies on fumigation of ethanol in a small capacity diesel engine. Energy 2011;36:1030–8.
[60] Ajav ea, singh b, bhattacharya tk. Performance of a stationary diesel engine using vapourized ethanol as supplementary fuel. Biomass and bioenergy 1998;15:493–502.
[61] Janousek gs. Evaluation of ethanol and water introduction via fumigation on efficiency and emissions of a compression ignition engine using an atomiza-tion technique [dissertations, theses, and student research]. University of nebraska at lincoln, biological systems engineering; 2010. P. 9.
[62] Tsang ks, zhang zh, cheung cs, chan tl. Reducing emissions of a diesel engine using fumigation ethanol and a diesel oxidation catalyst. Energy& fuels 2010;24:6156–65.
[63] Cheng ch, cheung cs, chan tl, lee sc, yao cd, tsang ks. Comparison of emissions of a direct injection diesel engine operating on biodiesel with emulsified and fumigated methanol. Fuel 2008;87:1870–9.
[64] Zhang zh, tsang ks, cheung cs, chan tl, yao cd. Effect of fumigation methanol and ethanol on the gaseous and particulate emissions of a direct- injection diesel engine. Atmospheric environment 2011;45:2001–8.
[65] Cheung cs, cheng c, chan tl, lee sc, yao c, tsang ks. Emissions character- istics of a diesel engine fueled with biodiesel and fumigation methanol. Energy& fuels 2008;22:906–14.
[66] Zhang zh, cheung cs, chan tl, yao cd. Experimental investigation of regulated and unregulated emissions from a diesel engine fueled with euro v diesel fuel and fumigation methanol. Atmospheric environment 2010;44: 1054–61.
[67] Cheng ch, cheung cs, chan tl, lee sc, yao cd. Experimental investigation on the performance, gaseous and particulate emissions of a methanol fumigated diesel engine. The science of the total environment 2008;389: 115–24.

 

[68] ZHANG ZH, CHEUNG CS, CHAN TL, YAO CD. EMISSION REDUCTION FROM DIESEL ENGINE USING FUMIGATION METHANOL AND DIESEL OXIDATION CATALYST. THE SCIENCE OF THE TOTAL ENVIRONMENT 2009;407:4497–505.
[69] HEISEY JB, LESTZ SS. AQUEOUS ALCOHOL FUMIGATION OF A SINGLE-CYLINDER DI DIESEL ENGINE. SAE TECHNICAL PAPER 811208; 1981. 4271/811208.
[70] HOUSER KR, LESTZ SS, DUKOVICH M, YASBIN RE. METHANOL FUMIGATION OF A LIGHT DUTY AUTOMOTIVE DIESEL ENGINE. SAE PAPER 801379; 1980.
[71] HEYWOOD JB. INTERNAL COMBUSTION ENGINE FUNDAMENTALS. NEW YORK: MC GRAW- HILL; 1988 2002.
[72] HOEKMAN SK, ROBBINS C. REVIEW OF THE EFFECTS OF BIODIESEL ON NOX EMISSIONS. FUEL PROCESSING TECHNOLOGY 2012;96:237–49.
[73] PALASH SM, KALAM MA, MASJUKI HH, MASUM BM, RIZWANUL FATTAH IM, MOFIJUR M. IMPACTS OF BIODIESEL COMBUSTION ON NOX EMISSIONS AND THEIR REDUCTION APPROACHES. RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 2013;23:473–90.
[74] RIZWANUL FATTAH IM, MASJUKI HH, LIAQUAT AM, RAMLI R, KALAM MA, RIAZUDDIN VN. IMPACT OF VARIOUS BIODIESEL FUELS OBTAINED FROM EDIBLE AND NON-EDIBLE OILS ON ENGINE EXHAUST GAS AND NOISE EMISSIONS. RENEWABLE AND SUSTAINABLE ENERGY REVIEWS 2013;18:552–67.
[75] EUGENE EE, BECHTOLD RL, TIMBARIO TJ, MCCALLUM PW. STATE OF THE ART REPORT ON THE USE OF ALCOHOLS IN DIESEL ENGINES. SAE PAPER; 1984:40118
[76] JIANG J, OTTIKKUTTI P, GERPEN JV, METER DV. THE EFFECT OF ALCOHOL FUMIGATION ON DIESEL ENGINE AND STUDY OF TEMPERATURE AND EMISSIONS. SAE PAPER; 1990:900386.
[77] ABDELRAHMAN AA. ON THE EMISSIONS FROM INTERNAL COMBUSTIONENGINES.*INTERNATIONAL JOURNAL OF ENERGY RESEARCH* 1998;22:483E513.
[79] CANAKCI M. IDEALIZED ENGINE EMISSIONS RESULTING FROM THE COMBUSTION OF ISOOCTANE SUPPLEMENTED WITH HYDROGEN. MSC THESIS 1996.
[80] WHITTEN GZ, REYES S. AIR QUALITY AND ETHANOL IN GASOLINE. PROCEEDINGS OF NINTH ANNUAL ETHANOL CONFERENCE, POLICY AND MARKETING 2004: 8E16.
[81] Hansdah d, murugan s (2014) bioethanol fumigation in a di diesel engine. Fuel 130:324–333. Doi:10.1016/j.fuel.2014.04.047
[80] Nikiforov m.yu.; kondratev e.a.; alper g.a.: viskosität binärer chloroform- und acetonitrilhaltigen nichtelektrolyt-lösungen. Viniti (1986) 1-7
[82] Oluwafunmilayo a. Aworanti, samuel e. Agarry* , ayobami o. Ajani : a laboratory study of the effect of temperature on densities and viscosities of binary and ternary blends of soybean oil, soy biodiesel and petroleum diesel oil. Advances in chemical engineering and science, 2012, 2, 444-452.