Chapter

Alcohol Contribution over Conventional Fuel

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Abstract

Biofuels have caught the eye of engine specialists as far back as the oil emergency and heightening expenses of petro-synthetic compounds cropped up in the 1970s. Ethanol and methanol were the most broadly inquired alcohols in IC engines. Higher alcohols are alluring second/third era biofuels that can be created from sugary, dull and lignocellulosic biomass feedstocks utilizing reasonable pathways. Developing worries of petroleum product consumption, oil-value variances, heightening vitality requests and stringent discharge guidelines are driving established researchers to discover elective sustainable biofuels for use in diesel engines. Among the biofuels like biogas, bioalcohol and biodiesel, alcohol is by all accounts generally appealing. Biogas requires high weight for its utilization in vehicle and its spillage can be risky. Biodiesel from consumable vegetable oil can cause insufficiency in sustenance supply. Everything being considered, the utilization of lower alcohols like methanol and ethanol in slow speed engines shows certain complexities because of their low cetane number, high inert warmth of vaporization and high protection from auto-start. Further the less calorific respect and poor miscibility with diesel limit their utilization in diesel motors.

Keywords: diesel engine, bioalcohols, butanol, pentanol, hexanol, octanol, performance and emission

1. Introduction

High-carbon bioalcohol with higher cetane number and higher vitality thickness than the prevalently looked higher alcohols makes it an appealing fuel for diesel engines [1]. Studies are quickly developing on high-yield biocombination of higher alcohols from glucose and lignocellulosic biomass feedstock utilizing built smaller scale creatures like *Escherichia coli* and *Clostridium* species [2]. Regardless of its good properties and promising prospects for creation in biorefineries, higher alcohol has been scarcely researched in engines. Higher alcohol is an advanced biofuel derived from lignocellulosic biomass, which is suitable for compression ignition technology with several properties closer to fossil diesel [3]. A few methods like alcohol fumigation, double infusion, alcohol-diesel mixes and alcohol-diesel emulsions have been utilized to manage these constraints of the alcohols as a diesel motor fuel [4]. From the wellbeing viewpoint, lower alcohols have low glimmer point (FP) and are delegated Class I fluids (FP beneath 37.8°C) alongside fuel by the National Fire Protection Association (NFPA) in the US. In the meantime, diesel fuel is arranged under Class II fluids (FP above 37.8°C). Yet, expansion of lower alcohols to diesel brings down the blaze point and would make the mix to fall under Class I fluids, subsequently requiring a similar framework as gas for capacity and taking care off [5]. Then again, there are some positive parts of alcohols that can be profitable in diesel engines. The decrease of smoke is firmly identified with the oxygen-substance of the mixes. Alcohols being oxygenated energize with a hydroxyl (OH) bunch increment the accessibility of oxygen amid burning and diminish smoke outflows in diesel engines particularly at high motor burdens [6]. Concerning the substance structure, it is affirmed that smoke decrease effectiveness is high in liquor and low in ether.

As of late higher alcohols have accumulated enthusiasm among the specialist sowing to their higher vitality thickness, higher cetane number, better mix dependability and less hygroscopic nature when contrasted with other generally considered lower alcohols like ethanol, methanol. Increment long of the carbon chains additionally improves the start nature of alcohol atoms. The term "higher alcohol" more often than not alludes to the arrangement of straight chain alcohols containing at least four carbon iotas, viz. butanol (C4), pentanol (C5), hexanol (C6), octanol (C8), dodecanol (C12), phytol (C20) and so on. Anyway propanol (C3) is additionally incorporated into this examination, as this three-carbon alcohol is used as a dissolvable to tie lower alcohols with diesel and moreover as a blending portion with diesel fuel in diesel engine [7]. **Table 1** presents a relationship of physical and substance properties of some lower and higher alcohols with diesel. It might be gotten from the table that higher alcohols (when appeared differently in relation to bring down alcohols like methanol and ethanol) have increasingly unmistakable potential outcomes to supersede fossil diesel totally or to some degree. Higher alcohols can mix with diesel with no stage detachment which is credited to their high carbon content, low extremity and less hygroscopic nature [8]. Subsequently no co-solvents or emulsifying operators would be required to keep up mix dependability when higher alcohols are utilized. The development of long carbon chain and the nonappearance of branches in liquor give high calorific regard, thickness and cetane number while sparing self-lighting credits less penchant to knock [9]. Higher alcohols have less dangerous movement on materials used in the fuel transport. Higher the water content in the alcohols, higher the ruinous action is higher alcohols are less hygroscopic and thusly can be less dangerous. Moreover alcohols with high subnuclear burdens are known to be less ruinous.

Properties	Diesel	Methanol	Ethanol	n-Butanol	n-Pentanol	n-Hexanol	n-Octanol
Molecular weight (kg/kmol)	191 - 212.7	32.0	46.1	74.1	88.1	102.2	130.2
C *(% by wt.)*	86.1	37.5	52.3	64.8	68.2	70.6	73.8
H *(% by wt.)*	13.9	12.6	13.0	13.6	13.6	13.7	13.8
O *(% by wt.)*	0	49.9	34.7	21.6	18.2	15.7	12.4
Cetane number	51-57	5-7	8-9	16-18	18.5– 20.1	23	39
Lower heating value (kJ/Kg)	42500	19580	26830	33090	34650	39100	39940
Density (kg/m^3) at 15°C	834	791.4	789.5	809.6	814.7	821.6	827.2
Viscosity at 40°C (mm/s^2)	2.72	0.58	1.13	2.22	2.89	5.32	-
Latent heat of vaporization (kJ/kg)	270-375	1162.64	918.42	581.4	508.05	486	466
Vapor pressure (mmHg)	0.45	127	55	7	6	1	0.08
Self-ignition temperature (°C)	254-302	464	421	349	302	287	271
Boiling point (°C)	180 - 360	64.6	78.2	117.4	137.8	157.2	195.3
Solubility (g/L)	0	Miscible	Miscible	78	21	7.9	4.5
Flash point (°C)	Above 55	11-12	17	35-37	49	59	81

Table 1.
Properties of alcohols [4].

Flashpoints of higher alcohols are very high which makes them more secure to store, handle and convey in the current circulation foundation. The lower vapor weights of higher alcohols likewise results in lower evaporative discharges. In spite of the fact that more drawn out chain alcohols have less oxygen content, they can in any case upgrade the premixed burning stage with their generally longer start delay permitting adequate blending of air/fuel and furthermore improve the dissemination ignition stage. In addition, alcohols with longer carbon chains consume lesser essentialness in the midst of its age when appeared differently in relation to other lower alcohols since the regular method of isolating far reaching macromolecules can stop prior [10]. The use of higher alcohols was before frustrated by high age costs, gainful use in sustenance industry and compelled creation from nonoil resources [11]. The latest decade has seen a reestablished energy for higher alcohols (as pragmatic vehicle fills) which resuscitated many research social events and bio-development associations to grow the yield of higher alcohols like butanol and pentanol from cellulose by flow development structures using new strains of *Clostridium* species and by biosynthesis from glucose utilizing hereditarily designed smaller scale living beings like *Escherichia coli*, *Cyanobacteria* and *Saccharomyces cerevisiae*. There is likewise an elective course in which biomass can be gasified or steam improved or somewhat oxidized to create blend gas (CO, H2 and CO_2) which can be chemically changed over in to higher alcohols by a procedure called Higher alcohol amalgamation (HAS). Higher alcohols can likewise be created by direct electromicrobial transformation or photosynthetic reusing of carbon-dioxide. This strategy can in reality help reusing CO_2 (an ozone depleting substance) into higher alcohols without the need to deconstruct biomass. Further, select biochemical pathways for broad scale business making of higher alcohols are being made by biofuel producers to diminish the stunning costs included like Gevo and Butamax [12]. The U.S. Boundless Fuel Standard (RFS) program requires blending of forefront biofuels in growing aggregates with fossil transportation fuel every year which should raise up to 36 billion gallons by 2022 [13]. According to this program, each endless fuel characterization ought to convey lower greenhouse gas releases appeared differently in relation to petroleum product or diesel it replaces. In this one of a kind circumstance, higher alcohols can be used to meet these targets as they qualify as bleeding edge biofuels that can be gotten from lignocellulose [14]. The essential focus of this examination is to give an expansive overview of composing related to the usage of higher alcohols in diesel motor and their effects on the start, execution and spreads of diesel motors. Various analysts and experts have mulled over the use of higher alcohols running from 3-carbon propanol to 20 carbon phytolin different extents with diesel to evaluate their appropriateness as a fuel in the current CI engines [15]. The on-going examinations and the past discoveries about the substitution (entire or incomplete) of fossil diesel fuel with higher alcohols in diesel engines were observed to be commonly fruitful in light of the fact that they diminished directed outflows with improved proficiency other than expanding the inexhaustible portion in the fuel.

2. Perspective view

2.1 Diesel engine and its significance

Diesel engines are imperative gear in open transportation, rock solid hardware, control age, agrarian and modern hardware attributable to their higher fuel-change profitability, higher power yield, higher torque limit, higher sturdiness, and higher trustworthiness than gas motors. Moreover they radiate lesser carbon monoxide

(CO), hydro carbons (HC) and carbon dioxide (CO_2) floods than diesel motors [16]. The utilization of fossil diesel in diesel motors passes on high NOx (nitrogen oxides) and buildup radiation that are unpleasant to both regular and human prosperity [17]. Diesel fumes is named harm causing to people by the International association for research on infection (IARC) in perspective on satisfactory evidence that its presentation is connected with an extended peril of lung threatening development while:

- Soot outflows can cause cardiovascular illnesses
- NOx present in diesel fumes is a central reason for exhaust cloud
- Ground level ozone
- Corrosive downpour
- Debilitated structure disorder
- Diesel engines offer un-paralleled fuel conversion efficiency, high torque capability at low engine speeds and durability.

Diesel engines are widely employed prime-movers for public transit systems, agricultural equipment, industrial implementations, power generation, construction and heavy machinery because of its un-matched fuel conversion efficiency, durability and torque capability [18]. The performance of diesel engines is usually higher than that of a gasoline engine of similar size. While the current state-of-the-art diesel engines are typically turbocharged with cooled EGR, equipped with common rail direct injection (CRDI) and after-treatment for soot and NOx, a larger population of diesel engines sold in agricultural and construction equipment during the last few decades in India include naturally aspirated stationary diesel engines [19]. These engines are widely used in the Indian agricultural sector to drive siphon sets to supply water for water system purposes [20]. The present quantities of these diesel driven siphon sets in the nation is about 14.42 million. As indicated by a study completed by the Indian Petroleum Conservation Research Association (PCRA), the yearly generation of these diesel driven siphon sets is 1.5 million with a normal yearly development of 7%. It is important to note that Indian agricultural sector recorded a consumption of 6 million metric tons (MMT) of diesel, which is about 8.55% of India's total diesel consumption (69 MMT) in the year 2012–2013. This statistic implies that a large population of farmers in India is severely exposed to the toxic diesel exhaust from these engines.

2.2 Crude oil and its demand

The burgeoning population, rapid industrialization and higher mobility have increased the demand and consumption of crude oil every year. The **Figure 1** shows the crude oil consumption in the year 2014–2015 across the world. The International Energy Agency (IEA) has predicted that the global crude oil demand will rise to 99 million barrels per day by the year 2035. Diesel extracted from crude oil by fractional distillation faces depletion in future. There is an estimate that the reserves of crude oil are gradually depleting at the rate of 2.1% per annum. Hence it is imperative that alternative forms of diesel engine compatible fuels have to be identified to improve energy security by the way of bio-based renewable sources. Instability in crude oil prices has an impact on the economies of countries without oil reserves

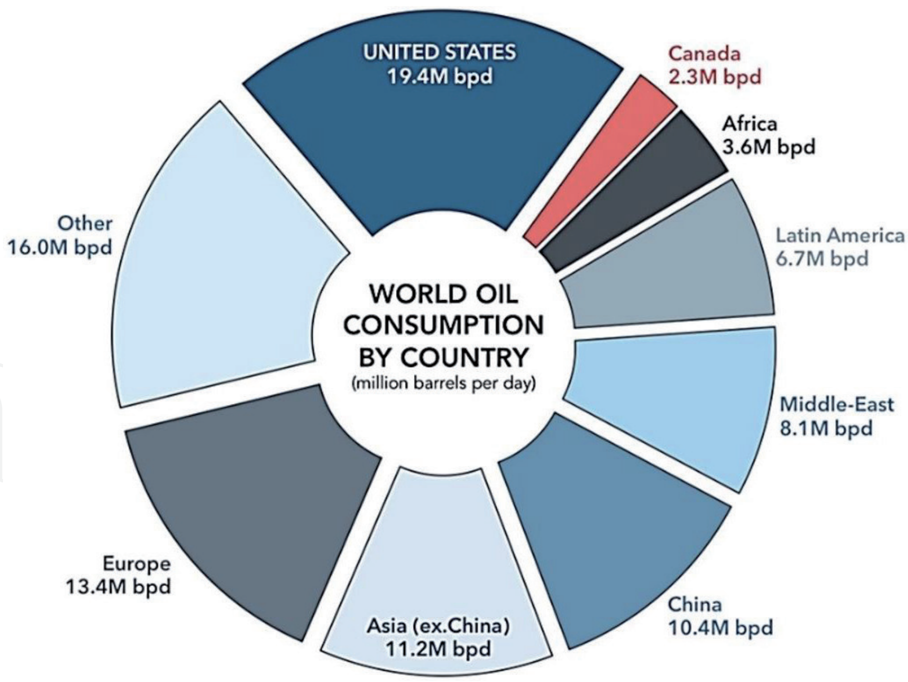

Figure 1.
Crude oil consumption in the year 2014–2015 [27].

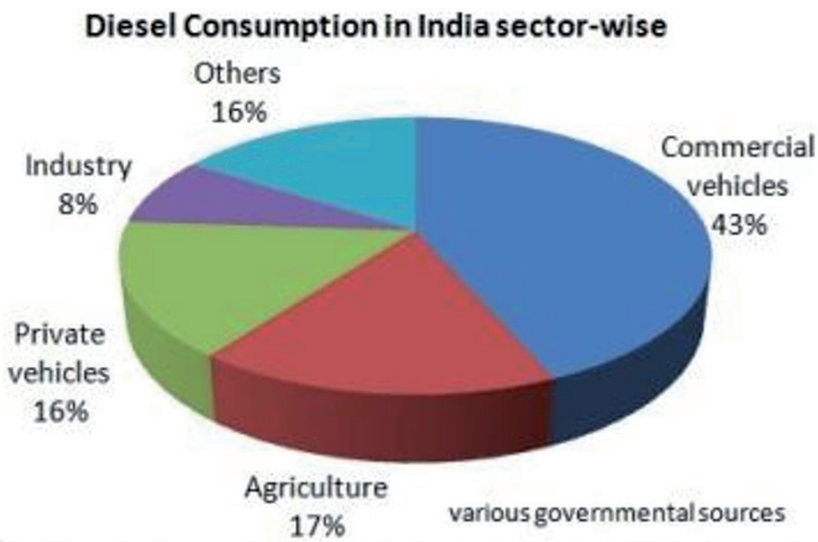

Figure 2.
Diesel consumption in India sector-wise [32].

and is heavily dependent on import. In the past 10 years, India relied heavily on imports to meet its increasing fuel demands [21]. High crude-oil imports suggest payments in dollars and depletion of foreign reserves which affects economy. India's domestic crude oil production plummeted for the fourth straight year in 2015–2016 which escalated India's import dependence to 81% in the last year from 78.5% in 2015–2016. Thus substitution of even a fraction of fossil fuel with a renewable biofuel will have positive impact on both the economy and environment. It has to be noted that India's fossil diesel consumption accounted more than that of gasoline. For instance, in 2012–2013, India consumed 69 million tons of diesel oil which is four times than that of gasoline. This consumption is primarily in transportation, industry and agriculture as shown in the graphic in **Figure 2**. The consumption in agriculture sector comprises tractors 17%, pump-sets for 7.5% and agriculture equipment 9.5%. All this indicates that a huge population is constantly exposed to hazardous gaseous emissions from diesel engines.

2.3 Hazards of diesel engine exhaust

Diesel engines emits high levels of oxides of nitrogen (NOx) and particulate matter (PM) into the atmosphere which are proven to be harmful to both human and environmental health [22]. Smoke in diesel engine exhaust is carcinogenic and cause a cardio-respiratory diseases. The diesel exhaust is classified as carcinogenic and continuous exposure can increase the chances of lung cancer [23]. The nano-sized particulate matter if inhaled is capable of trans-locating to the brain through olfactory nerves and can cause inflammation at deposition sites. In an experiment subjected 10 human volunteers to dilute diesel exhaust for an hour and showed that there is a functional effect in the human brain indicating a general cortical stress response [24]. Additionally, these smoke particles are also potential inducers of oxidative stress. The human brain is considered to be very sensitive to the damages caused by oxidative stress. Long term oxidative stress is found to be associated with diseases such as Alzheimer's and Parkinson's that leads to reduce cognitive function [25]. Further, when pregnant women are exposed to diesel fumes, adverse effect on fetal development is reported. NOx component present in diesel exhaust is a primary reason for smog, ground level ozone (1981), acid rain and sick building syndrome. NOx causes cyanosis and pulmonary diseases [26].

3. Alternative source

3.1 Prospective diesel engine fuels

Realizing a clean, affordable and safe energy future to address the growing concerns of fossil fuel dependence and the subsequent degradation of air quality by burning fossil fuels has been a challenge researchers relentlessly attempt to address [27]. Diesel engines could be perhaps fueled by a wide range of fuels like straight vegetable oil, biodiesel, biogas and bioalcohol adopting several strategies and modifications. The use of edible vegetable oils as diesel engine fuel threatens food security as the world community now embroiled in the "Fuel vs. Food" deliberation. Nonedible sources also have a concern. Their cultivation take up large land sources meant for food crop cultivation. Biodiesels are usually derived from edible and nonedible vegetable oils by transesterification which is a time consuming and expensive process. Biodiesels also presents the same concern as the vegetable oils because the feedstock they are derived from, takes up the acreage meant for the cultivation of food crop. Further the by-product of transesterification like glycerol poses another environmental challenge and has to be carefully disposed [28]. Biogas is typically a mixture of two potential greenhouse gases, methane and carbon-dioxide. Biogas is usually produced and used in as is where is basis because of the costs involved in its storage and distribution that require high pressure cylinders and safety measures to prevent leakage. Bioalcohols could be derived from both food and nonfood based feedstocks which makes them attractive [29]. Feedstock like lignocellulosic biomass which includes agricultural wastes (rice-straw, corn-stalks and sugarcane-bagasse), forestry wastes (wood-pulp, saw-mill and paper-mill rejects) and energy crops (switch grass, elephant grass and agave) that can be subjected to gasification, pyrolysis, steam reforming and bacterial fermentation to yield platform chemicals. Valorization of biomass to esteem included items and vitality is set to occur in biorefineries which could be viewed as similar to the present oil refineries [30]. For a nation like India with huge prolific grounds thriven by ordinary regular precipitation through rainstorm, there is a monstrous open door for gathering enormous amounts of lignocellulosic biomass and to ubiquitous diesel engines. The present study utilizes two such bioalcohols namely cyclohexanol and n-octanol derived from nonfood based sources to power diesel engines. Low carbon bioalcohols like methanol and ethanol which are popularly researched in gasoline engines are incompatible with diesel engines owing to their low energy density and low cetane number. Higher carbon bioalcohols like n-butanol, n-pentanol, n-hexanol, cyclohexanol and n-octanol can be appropriate possibility for diesel engine innovation. These bioalcohols can be made from glucose by development using planned littler scale living things or by getting ready lignocellulosic biomass using enzymatic hydrolysis and maturing, anaerobic digestion, gasification, pyrolysis and biocatalysis. **Table 1** exhibits the properties of some bioalcohols in examination with diesel and low carbon alcohols. It will in general be considered that to be the alcohols move higher, its cetane number, low warming quality, streak point, thickness and consistency increases while its oxygen content, vapor weight, dissolvability in water and unconventionality diminishes [31]. Also, the less vapor weight and less hygroscopic nature of high carbon alcohols offer better handling and storage. As a blend component, longer alkyl carbon chains also offer better miscibility with fossil diesel without any phase separation over a period of time.

3.2 Lignocellulosic biomass

Lignocellulose is the dry plant raw material that is abundantly available on the planet earth from which biofuels could be produced by processes like enzymatic and acid hydrolysis, pyrolysis, gasification, liquefaction and anaerobic digestion. Lignocellulose is composed of lignin—$(C_{31}H_{34}O_{11})_n$, cellulose—$C_6H_{10}O_5$, and hemicellulose—$C_5H_8O_4$. Lignin is the second most available natural material in the world after cellulose. It is a complex aromatic polymer which could be processed to produce platform chemicals for biofuel production. Lignin has the highest specific energy content among the three and constitutes up to 15–30% by weight and contains up to 40% by energy in a lignocellulosic biomass feedstock. The cellulose component is much easier to degrade and process to several platform chemicals from which high carbon alcohols like n-pentanol, n-hexanol, cyclohexanol, and n-octanol could be derived. **Figure 3** shows the structure and composition of a typical lignocellulosic biomass feedstock.

3.3 Production potential

The estimated global biomass production is 1.70×10^{11} tons per year. Global commercial lignin extraction is around 63 MMT (million metric tons) per year.

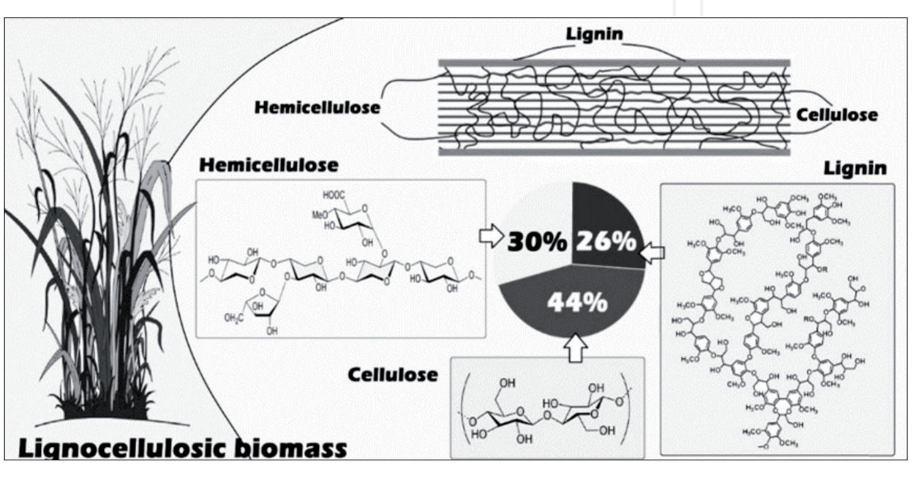

Figure 3.
Lignocellulosic biomass—Structure and composition.

Lignocellulosic biomass is abundant in nature and is available at low cost and could easily form a new class of second generation biofuels. The production of high carbon alcohols using catalytic synthesis could be scaled up with much of the research required in engineering the reactor, process design and economic viability.

3.4 Production pathways

The present study utilizes biofuels that could be possibly derived from nonfood-based feedstock. Biofuels that could be derived from biomass feedstocks using microbial production include high carbon alcohols, biodiesels, jet fuels, and biogasoline [31]. As of now, mechanical microorganisms (like *Escherichia coli* and *Saccharomyces cerevisiae*) and photosynthetic life forms like cyanobacteria are built to follow up on non-sustenance-based sources and create petroleum like derivatives, called "progressed" or "drop-in" biofuels. The different pathways for the combination of biofuels derived from lignocellulosic biomass feedstock are presented in **Figure 1**. The current study utilized bioalcohols like n-octanol and cyclohexanol that could be derived from lignocellulosic biomass feedstock. n-Octanol is an aliphatic straight chain alcohol that has superior cetane number, calorific value, oxygen content, and solubility with diesel [32]. Cyclohexanol is an aromatic ring chained alcohol. Cyclohexanol has superior oxygen content but slightly lower cetane number and energy density than n-octanol. Both these bioalcohols are excellent biofuels that has huge prospects for synthesis in biorefineries. Cellulose and hemi-cellulose can be subjected to enzymatic or acid hydrolysis to be broken down to sugars. C_5-C_6 sugars could be dehydrated to platform chemicals like furfurals, levulinic acid. Selective microbial fermentation of C_5-C_6 sugars can be employed to extract high carbon alcohols using engineering micro-organisms like *E. coli*. During the past 3 years, microbial production of n-octanol has gained the interest of researchers and extended the n-butanol pathway to obtain a yield of 70 mg/L of 1-octanol using the *Clostridium* species. Several pathways were later developed with improved yield of n-octanol. Biosynthetic pathway employing multi-functional catalysts to derive linear C8 products like 1-octanol and di-octyl ether from lignocellulose. A yield of up to 93% of linear C8 alcohol products was achieved using this innovative route. Subramanian et al. proposed 1-octanol as a biofuel with diesel-like properties and engineered a biosynthetic pathway to extract it from *E. coli*. Recently, they developed an energy-efficient catalytic system that could produce a highest yield of 1-octanol (62.7%) from biomass-derived furfural-acetone and synthesized phenolic compounds like cycloalkanes, cyclohexanol and linear alkenes from a pyrolytic lignin-oil fraction using catalytic valorization through hydro-treatment [32]. Cyclohexanol can also be obtained from guaiacol which is one of the most abundant lignin de-polymerization products. They introduced an in situ catalytic hydrogenation system to convert lignin-depolymerized compounds like guaiacol and phenol to cyclohexanol using Raney nickel catalyst and devised another highly efficient hydrothermal conversion of biomass derived cyclohexanone to cyclohexanol with high yield and high selectivity using in situ hydrogenation in the presence of a copper catalyst. It achieved more than 97.74% of guaiacol conversion with 100% cyclohexanol selectivity in the presence of 20% Nickel/Magnesium-oxide catalyst. Recently, they achieved highly efficient hydrogenation of a lignin-derived monophenol (4-ethylphenol) to cyclohexanol over Pd/γ-Al_2O_3 (Palladium/gamma-Alumina) catalyst with selectivity up to 98.6%. Lignin can also be biodegraded to renewable biofuels using genetically modified microbes. Bacterial lignin degradation activity has been best characterized in actinobacteria. The use of microbes like *Pseudomonas stutzeri* to breakdown lignin to aromatic monomers has been identified already. The utilization of biocatalysts could address every ones issues for high profitability and high prospects for feasible cyclohexanol process advancement.

4. Background

Smoke and NOx emissions in diesel engines have an inherent exchange off connection among them and in this way endeavors to limit one of them would normally bring about expanding the other. To add to this hopelessness, endeavors to decrease outflows would regularly result in misfortune in execution of the engine. This is because efficient combustion often results in high cylinder temperatures and reduces smoke but promotes NOx formation. On the other hand, lowering the combustion temperature results in incomplete combustion and favors NOx emissions but increases smoke formation and reduce engine performance. Adding oxygenated biofuels like bioalcohols to diesel reduces smoke emissions by the way of providing additional oxygen during combustion in fuel-rich zones via fuel-bound oxygen content. However this often results in higher NOx emissions. Exhaust gas recirculation (EGR) is a NOx reduction technology which involves bypassing a percentage of the combusted gases back to engine cylinder along with the intake charge that reduces peak combustion temperatures responsible for NOx formation by the way of its thermal, chemical and dilution effects. However, EGR causes a drop in engine performance as it disturbs the normal combustion process. Modifying the injection timing also affects the emission and performance characteristics. Delaying the injection up to the TDC causes low combustion temperatures and reduces NOx emissions and engine performance. Early injection improves air-fuel mixing and promotes complete combustion. This increases peak combustion temperatures and reduce NOx emissions. Hence it could be inferred that optimization of parameters like oxygenate composition in diesel, EGR and injection timing could achieve low emission and high performance in a diesel engine.

5. Conclusion

Higher alcohols are second/third era biofuels that can be gotten from lignocellulosic biomass utilizing maintainable way and absent much any dependence on sustenance crops. As run of the mill biofuels, they are equipped for tending to the two dimensional issue of natural debasement and vitality weakness. The accompanying ends can be drawn after this broad study concerning the utilization of 3-carbon propanol to 20-carbon phytol in diesel engines.

Alcohol expansion drags out the start postponement of the mix. Higher alcohol/diesel mixes show higher pinnacle chamber weights and higher pre-blended warmth discharge rates contrasted with diesel. The more extended the length of the carbon chain of the alcohol, the more ignitable the alcohol is. BTE of the engine energized with alcohols like propanol and butanol for the most part demonstrated improved execution:

- Higher level of premixed burning
- Low cetane number of propanol and improved shower attributes
- Decline in consistency and thickness of the mixes.

BTE drops with the use of pentanol and other higher alcohols in diesel engine. Longer chain fatty alcohols like hexanol, octanol and dodecanol are prevalently utilized as surfactants to balance out lower alcohol/diesel mixes and diesel oil miniaturized scale emulsions.

NOx emissions for the most part diminished with expanding propanol or butanol substance in the mix. In any case, alcohols including pentanol and higher, expanded NOx discharges directly with their substance particularly at high loads. This variety is because of the distinction in mastery between the impacts of higher warmth of vaporization and cetane number. This fragile adjusting likewise relied upon the particular motor and its working conditions.

Abbreviations

ASTM	American Society of Testing and Materials
BDC	bottom dead center
Bmep	brake mean effective pressure
BP	brake power
BSEC	brake-specific energy consumption
BSFC	brake-specific fuel consumption
BTE	brake thermal efficiency
But	n-butanol
CA	crank angle
CCI	calculated cetane index
CI	compression ignition
CR	compression ratio
CRDI	common rail direct injection
EGR	exhaust gas recirculation
Eth	ethanol
Hex	n-hexanol
HRR	heat release rate
LHV	low heating value
Meth	methanol
MMT	million metric tons
Oct	n-octanol
Pen	n-pentanol
ULSD	ultra low sulfur diesel

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