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Review Article

Citrullus colocynthis Oil as Biofuel and its Performance in Engines: A Review

Nirupa Jain[1], Narpat Ram Sangwa[2], Yash Bansi Mathur[3], Krishan Kumar[4], Anshumala Sharma[5]

[1]M. Tech. Research Scholar (Renewable Energy), [2]Principal (Incharge), [5]Associate Professor, Manda Institute of Technology, Bikaner, Rajasthan, India.
[3]Associate Professor, Government Polytechnic College, Bikaner, Rajasthan, India.
[4]Assistant Professor, Department of Electrical Engineering, Manda Institute of Technology, Bikaner, Rajasthan, India.

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Corresponding Author:
Nirupa Jain, Manda Institute of Technology, Bikaner, Rajasthan, India.
E-mail Id:
nirupajn@gmail.com
Orcid Id:
https://orcid.org//0000-0001-9769-478X
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A B S T R A C T

Fossil fuel is not a renewable source of energy and its stocks will exhaust shortly. There is a need to explore the possibility of new sources of fuel, which may be used in existing vehicles so that there is no crisis in the future. The need for a clean source of energy has been highlighted by SDG 7. A large number of research studies have been carried out in this sector to explore the potential in the possibilities of the development of biofuel. Various vegetable oil has been tried and explored. *Citrullus colocynthis* oil has also been studied for biofuel. *Citrullus colocynthis* is called Thumba in India. Research studies have confirmed that it can be an important source of biofuel. Research studies have found that *Citrullus colocynthis* oil can be blended with diesel and can be used in existing engines. Considering the need for biodiesel, this review paper identifies previous studies on this resource to meet the growing demand for clean energy resources.

Keywords: Green Energy, Clean Energy, Biodiesel, Biofuel

Introduction

Energy is the most important resource for the development of any country. No economic activity can thrive without energy. It can be compared to the blood in a human body it is as vital in economy as blood is important in human body. Energy is essential for survival and development. However, the demand for energy is growing and there seems to be very limited options to meet this growing demand. There are limited resources in the form of fossil fuel based resources, which meet approximately 70-80% demand of energy at the present moment. There is a need to look beyond these resources to prepare a strategy for the future. The world need to invest in the development of alternative resources so that there is no energy crisis in the future. There is a need to intensify research on these sectors. This paper is an attempt to review the papers in this sector and identify the roadmap for the future. There is now an increasing interest towards new options for the development of energy. There are many research projects going on to explore new and improved options for alternative sources of energy. There is also an increasing interest towards environment protection. The sustainable development goal number 7, has now mandated it for every country to develop clean and environment friendly technologies for development of energy. Scientists[1], are developing methods of oxy fuel combustion to replace coal fuel combustion. These initiatives indicate that scientists are willing to explore options for environment friendly technologies.

Literature Review

Some scientists have found Phase Change Material (PCM) to be useful in energy storage. The research in the domain of energy has become the most important sector from the perspective of future development. Scholars and research studies[3] have now concluded that renewable sources of energy must be explored to replace fossil fuel based energy resources.

The data of world energy statistics[4] indicate that due to changing scenarios in the field of energy, the overall development of the countries is also changing. The changes in the energy sector will have long term implications on world geopolitics. There is a need to study these changes and derive lessons from these changes so that suitable actions are taken for the development of the energy sector. The share of the People's Republic of China in world energy production increased substantially from 7% in 1973 to 21.6% in 2016 and continues to rise. There is also a substantial rise in the status of middle east countries due to energy. The share of Middle East countries has increased from 0.8% in 1973 to 5.3% in 2016. The rise of emerging countries is primarily due to an increased focus on energy. Those countries, which have developed sources of energy, have become economic powerhouses also. Energy has today become the most important parameter in economic issues. The share of non-OECD Asian countries rose from 5.5% in 1973 to 13.2% in 2016 in world energy production and this has resulted in their increased economic prosperity. At the same time, the share of OECD countries in world energy has reduced from 61.3% in 1973 to 38.4% in 2016. Developing countries, particularly the countries from Africa are now emerging as the most promising economies. African countries are now overcoming their barriers and they are now experiencing a rise in their economic prosperity. The share of Africa in total world energy is also rising. It has risen from 3.4% in 1973 to 5.9% in 2016. In terms of share in world electricity generation, the share of China has increased from 2.9% in 1973 to 24.9% in 2016. China has increased hydroelectricity and solar electricity substantially.The share of non-OECD Countries in total world electricity has increased from 2.7% in 1973 to 11.7% in 2016. The share of Africa, the Middle East and non-OECD America has also increased but that of OECD countries has reduced from 72.8% in 1973 to 43.9% in 2016. Scientists had long ago[5] predicted that energy will become the most important factor in economic development. Many scientists had predicted that the renewable sources of energy will dominate the future and the world has to develop new sources of renewable energy to meet the challenges of the future.

If all the possibilities are considered, world GDP will double by 2040. This will result in prosperity in developing economies. This will result in an improvement in overall living standards. It is expected that emerging countries like Brazil, Vietnam, India, China and Other Asia will be able to take advantage of the rising economic prosperity. If these countries invest in the development of alternative sources of energy, they can reap rewards of prosperity in the next few decades. Scientists have concluded[6] that the development of alternative sources of energy is essential now and those countries will be able to develop alternative sources of energy like solar, wind or other renewable sources that will be able to attain economic prosperity and improved living standards. It is a matter of solace that there is an increasing interest among investors and entrepreneurs towards green energy sector. Social entrepreneurs are now promoting investment in this sector. There is an increasing interest among entrepreneurs and investors towards new sectors of renewable energy.[7]

Many governments are coming forward to support renewable energy resources and this is a positive information for everyone. Take an example, the government of India has made extensive plans to boost biofuel and has announced its policy for promotion of biofuel and other forms of renewable energy. This will support renewable energy sector.[8] The government of India has published the draft national energy policy to promote discussions and deliberations on the energy sector. Participation of private sector will improve the opportunities and resources in this sector. Huge funds will be available for this sector. An example here is that Indian's energy sector reforms[9] have now opened this sector for private sector. Historically[10] the major investments have been in the conventional sectors but now the environmental issues are forcing everyone to move towards clean energy. The government of India[11] has introduced extensive energy sector reforms that have introduced the energy sector to the private sector players. A large number of people are debating these reforms because this will open the energy sector to the private sector. The first few decades after independence, the government was busy privatizing every company and many companies were asked to leave India. In this way, the present policies are a reversal of the policies before 1980. However, it has now been realized that to attain the required momentum in our growth, we have to undertake extensive privatization and invite every player to participate in the process of industrial development. There is a need to involve the private sector in the development of the energy sector. Government alone cannot achieve the gigantic goals of universal electrification and providing energy to everyone at affordable rates. There is a need to invite the private sector to participate in the development of energy and its distribution. Energy distribution in the government sector has been inefficient work. Electricity distribution companies in the government sector have suffered huge losses and they have not been able to contain electricity theft. They have not been able to recover their outstanding payments. Thus there is a need to transfer electricity distribution from government to the private sector so that this sector can also thrive. There is a need to invite the private sector in the transformation of electricity distribution. Companies like Torrent Power have transformed power distribution in Gujarat. They have proved that energy distribution through private sector participation can improve the access and affordability of the common people. The participation of the private sector to improve the overall efficiency and effectiveness should always be welcome.

The recent initiatives by governments to encourage private sector participation in the energy sector are being discussed widely in media[12] and many international companies are now planning to invest in India in the energy sector. Research and development will play a very important role in the next few decades. Research and development will enable the introduction of low-cost renewable energy. Every country should join international alliances for joint research and collaboration, for example, India[13] has become one of the founders of International solar alliance. If such initiatives are not taken, there will be energy crisis, which we are witnessing in many countries. Countries like Venezuela[14] are facing shortage of energy. Even developed nations like Australia are facing acute problems due to the energy crisis[15] their industries are getting adversely affected by this energy crisis. The energy crisis is now becoming a major problem in under developed regions and those regions which have a limited supply of fossil fuel based resources. South Asia is already experiencing an energy crisis[16] there is a need to introduce reforms to solve this problem. India and its neighboring countries are all experiencing an energy crisis. The demand for energy is far more than the supply. There is a need to under take major energy sector reform so that the private sector can play an important role in the development of new sources of energy. The governments have to come forward to invest in the development of alternative fuel so that this sector can become commercially viable, there after the private sector will also play an important role in the further development of this sector. There will be a very acute energy crisis in the years to come due to the rising population and increasing demand for energy. There will be difficulties in meeting the growing demand for energy due to an explosion in energy demand. Fossil fuel based resources are limited and they will get exhausted in the future. The world is primarily dependent on fossil fuel based energy resources at present. These resources are non renewable resources and they also cause substantial damage to the environment. There is a need to develop alternative sources of energy. Studies[17] have highlighted the importance of proper planning. The strategies, action and plan to meet the energy crisis will help in attaining the goal of a 1.5-degree global warming target.

The local Indian name of *Citrullus Colocynthis* is Thumba, it grows in desert regions in abundance. Oil extracted from *Citrullus Colocynthis* is similar to Jatropha oil. *Citrullus Colocynthis* oil is non-edible vegetable oil and *Citrullus Colocynthis* is also known as colocynth, looking similar to watermelon, it is an individual from the Cucurbitaceous family. Cucurbitaceous is a vast family that comprises almost 100 genera and 750 species, it's called *Citrullus Colocynthis* in Marathi, Indrayan in Hindi, Bitter apple in English and other locally called as *Citrullus Colocynthis*, Ghorumba, Kaurtumbaand Tumbi. It has also been called by its earlier name Citrullus vulgaris. It is mostly available in the north-western region of India particularly in Rajasthan and in Gujarat. In Rajasthan, it is most abundant in the Bikaner, Barmer, Jodhpurand Jaisalmer districts. *Citrullus Colocynthis* creeper plant is native of Turkey and it is broadly dispersed in the Sahara Arabian deserts in Africa and the Mediterranean area. It is local to the Mediterranean Basin and Asia. It is dispersed among the west shoreline of northern Africa, eastbound through the Sahara, Egypt until India and reaches likewise the north bank of the Mediterranean and the Caspian oceans. It becomes additionally in southern European nations as in Spain and on the islands of the Grecian archipelago. *Citrullus colocynthis* is found wild in the warm, dryand sandy parts in India. The creeper plant is through climbing (climber) plant and grows well in sandy loam, sandy soil, sub desert soilsand along sandy sea coasts with a pH range between 5-7.[8] The creeper plant can tolerate annual precipitation of 250-1500 mm and an annual temperature of 14.8ºC-27, 8ºC. The creeper plant grows from sea level up to 1500 meters above sea level. *Citrullus colocynthis* plants are highly xerophytic and grow well in areas with an annual rainfall ranging between 25-37 cm. The creeper plant has annular and unpleasant trunks, rough leaves which are 3-7 lobed, 5-10 cm long in the center. Flowers are monoecious and have yellow round natural fruits. The average yield is about 2500-3500 kg of seeds, ha with minimum inputs. The seeds of *Citrullus colocynthis* fruits are wellsprings of oil and protein with around 20-30% golden yellow, brown oil and up to 35% protein. The oil cake has great importance in the organic fertilizer industry. Presently all extracted raw *Citrullus colocynthis* oil is consumed by soap industries. *Citrullus colocynthis* creeper plant is mainly used as cattle feed by farmers. *Citrullus colocynthis* oil is also used as a laxative and anti-inflammatory drug. Citrulline is extracted from the fruit pulp, which is internationally marketed by Sigma and Emerc.

A large number of studies have been conducted on Jatropha, however, not much has been done on *Citrullus Colocynthis*. Mohammed et al. (2013)[18] carried out experiments in a four stroke diesel engine fuelled with Jatropha biodiesel with proportions of 10% (B10), 20% (B20), 30% (B30) and 50% (B50), compared the performance and combustion characteristics with baseline diesel fuel (B0) (Table 1). These are inferred that the combustion characteristics of Jatropha biodiesel blends were comparable to the B0 blend (mixture) without any engine modification. Peak pressure could be achieved with B10 and B50 blend (mixture) at lower and higher engine speeds. BSFC was found to rise with increasing proportions of biodiesel. B50 blend (mixture) exhibited the highest Exhaust Gas Temperature (EGT) and nitrogen oxides (NOx) emissions along with lowered CO emissions owing to the higher combustion temperature of the oxygenated biodiesel.

Table 1.Important Fuel Properties of Citrullus Colocynthis Oil

Properties	Diesel	Citrullus Colocynthis Oil
Specific Gravity at 20°C	0.835	0.905
Viscosity, cSt at 40°C	2.75	31.52
Calorific Value, MJ/kg	42.25	39.78
Flash Point, °C	66	201
Pour Point, °C	-20	-5
Free Fatty Acid, %	-	> 1
Cetane Number	47	45

A study[19] evaluated the suitability of Jatropha biodiesel as an effective alternative fuel for an unmodified diesel engine. Experimented by varying percentages of biodiesel with diesel fuel (5%, 10%, 20%, 30% and 100%), compared with diesel fuel. Reductions of HC, CO and smoke emissions and increased NOx emissions were observed for biodiesel blends. It can be inferred from the study[5] that Jatropha and *Citrullus Colocynthis* biodiesel and its blends (mixtures) can be used in an unmodified diesel engine for lowering the dependency of fossil fuels.

A study[20] studied the emissions and overall performance of a diesel engine fuelled with oxidatively stabilized Jatropha curcas biodiesel. Experimental trials revealed that Brake Specific Fuel Consumption (BSFC) of Jatropha biodiesel with antioxidants was lower than biodiesel without antioxidants. Antioxidants were observed to have minimal influence in combustion characteristics, while emissions such as HC, COand NOx showed significant reductions. The studies concluded that the addition of antioxidants protects the biodiesel from deterioration for a longer period (up to 6 months) in comparison with un stabilized fuel.

A study[21] performed a comparative study on a diesel engine fuelled with Jatropha curcas Biodiesel (JB) Chinese pistache Biodiesel (CB). The thermal efficiency of JB, CB were higher than diesel fuel on an average of 10.4%, while HC, CO emissions of both JB, CB were closer to each other lower than diesel fuel at higher loads. NOx, smoke emissions of JB, CB were mostly lower than diesel fuel throughout the engine load conditions.

A study[22] investigated emulsified Jatropha biodiesel in a 10.3kW, single cylinder diesel engine. JB10 with a 10% water fraction exhibits similar combustion characteristics with that of diesel fuel. Ignition delay was found to rise for JB10 with 20% water fraction at higher engine loads. Brake Thermal Efficiency (BTE) of emulsified blends increased by 3.4% in comparison to non-emulsified blends owing to the occurrence of micro-explosion. HC, CO and NOx emissions of emulsified fuels were lowered by 7%, 31.5% and 3% respectively.

A study[23] carried out experiments in a single cylinder diesel engine fuelled with PBJB5 (5% palm biodiesel+5% *Citrullus colocynthis* biodiesel+90% diesel), PBJB10 (10% palm biodiesel+10% *Citrullus colocynthis* biodiesel+80% diesel) and neat diesel. The calorific value of PBJB5 was closer to diesel fuel at about 45.8 MJ/kg and both PBJB5, PBJB10 had higher flashpoints in comparison with diesel fuel. HC emissions of PBJB5, PBJB10 were lesser in comparison to diesel fuel by 3.69% or 7.81%, while carbon emissions reduced by 9.53% or 20.49%. Both the blends exhibited higher NOx levels in comparison with diesel fuel. Also, the average sound levels developed by an engine with PBJB5 and PBJB10 were lower than diesel fuel by 2.5% or 5% respectively.

A study[24] carried out experiments in a 4 cylinder diesel engine fuelled with 10%, 20% palm biodiesel (PB10 and PB20), with 10%, 20% Jatropha biodiesel (JB10 and JB20), compared the performance and emissions with standard diesel fuel. The speed range of experimentation was varied from 1000-4000 pm. Results indicated that there is a reduction in Brake Power (BP) on an average from 2.3% to 10.7% when operated from 10% to 20% blend (mixture) ratios of both biodiesels. With an increasing percentage of biodiesel concentration, there resulted in average higher BSFC levels from 19.0% to 26.4% (for both biodiesel blends) owing to higher viscosity, densityand cetane number characteristics of biodiesel. On emission front, an increasing percentage of biodiesel tends to reduce the percentage of HC and CO emissions of both JB and PB blends in comparison with diesel fuel owing to higher cetane number and higher oxygen content of biodiesel. A further rise in engine speeds tends to lower the exhaust emissions significantly. NOx emissions of Jatropha biodiesel blends were higher than palm biodiesel blends throughout the engine load. They concluded that a 20% biodiesel blend (mixture) can be utilized in the engine as a suitable alternate without any engine modifications.

A study[25] analyzed the influence of idling on fuel consumption and emissions of a diesel engine fuelled with Jatropha biodiesel-diesel blends. Experiments were conducted at higher idling conditions (lower load accompanied by lower-rated speed), where the engine cannot run at peak working conditions Normally when an engine running at the high idling condition with diesel fuel, HC and CO emissions increases owing to incomplete combustion more fuel residues. However, operating with Jatropha biodiesel-diesel blends, the results were interesting as the HC, CO emissions were lowered along with marginal increments in NOx emissions. In comparison with diesel fuel, the fuel consumption range was higher for biodiesel blends at high idling conditions which further increased with a rise in biodiesel percentages.

A study[26] investigated the regulated and unregulated emissions of a 4 cylinder, 4 strokes, Common Rail Direct Injected (CRDI), diesel engine fuelled with Jatropha bio diesel at proportions of 5%, 10%, 20%, 50% and 100% (volume fraction) respectively. NOx, CO, HC and smoke emissions were considered for regulated emissions, while formaldehyde, acetaldehyde, acetoneand toluene were analyzed for unregulated emissions. These are reported that NOx emissions rise with increasing biodiesel concentration. The higher viscosity of biodiesel resulted in a high mean peak temperature followed by a higher NOx profile. CO emissions rise with increasing biodiesel concentration at lower loads while it remains unaffected at higher loads. For all the loads, HC and smoke emissions reduce with increasing bio diesel concentration. In the case of regulated emissions, all the bio diesel blends except the B20 blend (mixture) has higher formaldehyde emissions in comparison with diesel fuel. Similarly, acetaldehyde emissions of B10, B20 blend (mixture) are in a lowered trend. Even though acetone emissions of biodiesel blends are higher than diesel fuel, the range lies only below 3ppm which is acceptable. However, toluene emissions found to reduce with an increasing percentage of biodiesel which indicates the lowered aromatics emission with the usage of Jatropha biodiesel. Concluded that the B20 Jatropha blend (mixture) can be an optimum blend (mixture) that can simultaneously lower the regulated as well as unregulated emissions when fuelled in diesel engines.

A study[27] analyzed the in cylinder combustion, spatial sootand spatial flame temperature distribution of diesel, JB20, JB100 blends at a constant speed diesel engine with varying engine loads using the endoscopic visualization technique. They found that the JB100 blend, owing to its higher fuel oxygen content combusted rapidly and resulted in higher peak in cylinder pressure and HRR in comparison to JB20, diesel fuel. Flame temperature distributions for all the test fuels were found to rise with increasing engine loads. Endoscopic investigations also revealed that the JB100 blend (mixture) exhibits the lowest soot generation and lowered flame luminosity owing to higher oxygen content. Combustion behavior indicated that diesel fuel showed more active combustion regions where there are maximum temperature distributions, in comparison to JB20 and JB100".

A study[28] investigated the emissions of two cylinder Kubota GL700 diesel engine generator fuelled with BDE (biodiesel-Diesel Ethanol), with varying ethanol concentrations namely 3% (BDE3), 5% (BDE5), 15% (BDE15) and 25% (BDE25) while maintaining equal proportions of biodiesel and diesel. The biodiesel employed for experimentation was waste cooking oil which was transesterified for its application in a generator. Experiments revealed that the emissions were dependent not only on engine operating conditions but also on fuel blends concentrations. It was found that with increasing concentration of ethanol in BDE, there was a rise in HC and CO emissions while a reduction in NOx emissions owing to the oxygen content of alcohols lowering the in-cylinder temperatures at lower loads. At higher engine loads of 70% and more, the emission levels of BDE and diesel were in par owing to very high cylinder temperatures which could not inhibit the cooling effect.

A study[29] carried out experiments on a 4 cylinder heavy duty diesel engine fuelled with BDE blends with premixed Low Temperature Combustion (LTC) achieved using moderate levels of Exhaust Gas Recirculation (EGR). Experiments were conducted with BD10 (10% biodiesel, 90% diesel), BDE10 (10% biodiesel + 80% diesel + 10% ethanol) and BDE20 (10% biodiesel + 70% diesel + 20% ethanol). On experimentation, simultaneous reductions of NOx and smoke emissions were achieved for BDE blends. Increasing ethanol concentration in the BDE blend (mixture) increased maximum HRR occurring farther from TDC owing to a prolonged delay period. HC, CO emissions were higher due to the presence of ethanol in BDE. These are inferred that 20% ethanol addition in the BDE blend (mixture) can lower the exhaust emissions and improve the BTE in LTC mode with advanced fuel injection timing in comparison with diesel fuel.

A study[30] investigated the effect of ternary blends based on ethanol (biodiesel-diesel-ethanol), methanol (biodiesel-diesel-methanol) in a 2 cylinder, Kubota GL-7000 diesel engine generator. The test fuels employed were standard diesel, BDM20 (40% biodiesel+40% diesel+20% methanol), BDE20 (40% biodiesel+40% diesel+20% ethanol) and BDE10 (45% biodiesel+45% diesel+10% ethanol), respectively. The study[16] concluded that both ethanol and methanol blends exhibited lowered BSFC in comparison with diesel fuel. BDE blends were found to exhibit lowered BSFC in comparison with BDM blends. With increasing ethanol concentration in BDE blends, there was a reduction of NOx emissions with a rise in HC, CO emissions. On the contrary, with increasing concentration of methanol in BDM, a higher level of NOxand lowered HC and CO emissions were observed. The research concluded that to get reduced NOx, the BDE blend (mixture) should be adopted and for reducing HC and CO emissions, then the BDM blend (mixture) should be adopted.

A study[31] conducted experiments in a 4 cylinder 46.5kW diesel engine fuelled with diesel, D85B10E5 (85% diesel +10% rapeseed biodiesel+5% ethanol), D70B25E5 (70% diesel+25% rapeseed biodiesel+5% ethanol) and D80B10E10 (80% diesel+10% rapeseed biodiesel+10% ethanol). The performance of ternary blends in terms of BTE was inferior throughout the engine load condition. CO emissions were lowered for D80B10E10 blend (mixture) at lower and part loads while at higher loads CO emissions of D85B10E5 were found lowest (0.234% vol.) in comparison with diesel fuel (0.57% vol.). NOx emissions increased at medium and higher engine loads while HC emissions of ternary blends were lower than diesel fuel throughout the engine load. D70B25E5 blend (mixture) showed the lowest HC profile, while the highest HC emissions were observed for D80B10E10. Smoke emissions of ternary blends were lower than diesel fuel throughout the engine loads. The study[17] confirmed that at full load, 27.6% smoke reduction was achieved with D70B25E5 blend (mixture) while 50.3% smoke reduction was achieved with D85B10E5 blend (mixture) owing to lowered fuel accumulation at fuel rich zones inside the combustion chamber.

A study[32] conducted a review of the utilization of binary blends (diesel, biodiesel), ternary blends (diesel, biodiesel,ethanol), on diesel engine emissions. Studies highlighted that both binary and ternary blends were useful in lowering HC, CO emissions along with increased CO_2 emissions owing to higher oxygen content of both biodiesel and ethanol there by improving the combustion rate. Detailed on increased NOx emissions owing to peculiar fuel properties like higher cetane number and improved oxygen content. The studies enumerated on a significant reduction in Particulate Matter (PM) emissions of ternary blends due to the presence of lower aromatic compounds and higher levels of oxygen content. The study finally concluded that the addition of 5-10% ethanol, 20-25% biodiesel with raw diesel can be an efficient alternative fuel mixture with lowered regulated emissions.

A study[33] reviewed the effect of mixed blends of diesel, biodieseland ethanol fuels on the diesel engine's performance and emission characteristics. Summary of the findings was, emissions are strongly dependent on engine operating conditions and the percentage of bio-fuel; Diesel-biodiesel-ethanol blends in diesel engines can be used to simultaneously lower the NOx and HC emissions; with an increasing percentage of ethanol in ternary blends, higher smoke reductions are evident. Using ternary blends in a diesel engine can be effective in lowering the PM emissions. Ethanol addition in biodiesel-diesel blends can lower both particle number concentration and particulate mass emissions, however with a penalty of increased fuel consumption rate in comparison with diesel fuel.

A study[34] conducted a review on diesel engine performance and emission characteristics when blended with biodiesel and ethanol. Findings confirmed that the blending of biodiesel in diesel, ethanol blends acts as a mixture stabilizer and improves the physico-chemical properties of the ternary blends and can be effective in replacing the fossil fuel to a great extent. The studies also observed that the property of the resulting mixture of ternary blends can be a match with diesel. The ethanol concentration in ternary blends played a vital role in the blend (mixture) preparation and it was kept as low as possible (up to 5-10%). The use of ternary blends in diesel engines increased the BSFC, as observed in most of the studies. However, as a compromise, HC, PM, smoke and soot emissions were considerably lowered in comparison with diesel fuel. While CO, CO_2 and unregulated emissions of ternary blends were almost in par with diesel fuel, NOx emissions were always in increasing trend and found not satisfying. Presented that, ternary fuels can be utilized in diesel engines along with the adoption of certain NOx mitigation strategies such as EGR, water in emulsion, fuel borne additivesand retarded IT which can simultaneously lower the exhaust emissions and replace the fossil fuel to a great extent.

A study[35] conducted a theoretical feasibility study of using diesel-biodiesel-ethanol blends in existing un-modified diesel engines by reviewing more than a hundred studies dealing extensively with ternary blends. Some of the key conclusions observed are as follows; Density, viscosity, cetane number and lubricity values of ternary blends lie within the standard limits and are comparable with standard diesel fuel; Ternary lends can affect the cold starting of an engine at lower temperatures due to phase separation. With increasing ethanol concentration in ternary blends, the heating value of mixture drops significantly which caps the ethanol blending limit (up to 10% maximum); Using ternary blends with biofuel (biodiesel and ethanol) can replace fossil diesel by about 25-30% saving almost 30% diesel fuel worldwide; Appending additives in ternary blends can improve the safety and transportation characteristics of the blend (mixture), improve its mixture stability for a longer period.

A study[36] studied the puffing and micro-explosion of a ternary blend (mixture) composing diesel, rapeseed biodieseland ethanol at various compositions using high-speed backlight imaging method. The study[22] method uses a glow plug heater which ignites the suspended fuel droplets on a thermocouple which detects the temporal variations of the expected droplet area and characterizes the fuel into smooth burning, puffingand micro-emulsion. Based on the composition of biodiesel, dieseland ethanol, a ternary diagram was plotted for identifying conditions suitable for micro-explosion. Detailed that the presence of ethanol at a range of 10-40% in a ternary blend (mixture) favored micro explosion, while a further rise in the percentage of ethanol blending resulted only in puffing and there was an absence of micro-explosion. The study[22] revealed that after puffing and micro-explosion of primary droplets there was a further explosion of secondary droplets. Indicated that a minimum in cylinder temperature was required for initiating puffing and micro-explosion (via superheating and ethanol evaporation) typically around 800K. Findings from a study[37] demonstrating that increasing pressure inside the combustion chamber can promote micro-explosion of ternary blends, especially during the pre-combustion phase. Finally, it concluded that the addition of biodiesel in a diesel-ethanol blend (mixture) was sufficient to result in a fuel mixture without phase separation.

A study[38] investigated the effect of combustion characteristics and particulate emissions of a diesel engine fuelled with DBE (diesel-biodiesel-ethanol) blends. Blended (mixed) ethanol at ratios of 5%, 10%and 15% with diesel-biodiesel blends and fuelled them in a 4 cylinder diesel engine operated at five different loads. Experimental studies revealed that DBE blends resulted in higher in cylinder pressure and HRR than diesel fuel owing to more fuel burnt in the Premixed Combustion Phase (PCP) as a result of ethanol blending which prolongs the ID period. With increasing ethanol concentration in DBE, the Diffusion Combustion Phase (DCP) gets lowered and less fuel mass gets burnt in the diffusion phase thereby retarding the start of combustion for DBE blends in comparison with neat diesel and 100% biodiesel. DBE in diesel engines can effectively lower the particulate emissions, which were associated with diffusion combustion phase and the particulates are lowered both by mass and number because of lowered fuel mass burnt at diffusion combustion phase along with lowered aromatics and sulfur. They concluded that DBE blends can be effective in lowering the NOx emissions along with particulates in comparison with diesel fueland this was an important finding as it weakened the NOx-PM trade-off.

A study[39] studied the current scenario of biodiesel. The study found that there was a need of developing alternative fuel to meet the growing need for fuel (diesel). Limited resources and environmental concerns have forced the world to focus on biodiesel because these are environment-friendly and renewable sources of energy. Governments all over the world are therefore investing substantially into the development of this sector in an attempt to replace fossil fuels. Triglycerides and their derivatives were used as viable alternatives for diesel fuels. The study[44] found that there are many problems in using vegetable oil including ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. Hence, a suitable modification was carried out to lower the viscosity to get rid of the problems. This research work helped the researcher in preparing a benchmark to start the research project.

Usta et al. (2015)[40] conducted a study on Biodiesel and found it a good substitute. They used the transesterification process for the optimization of biodiesel produced from Citrullus colocynthis oil. They studied parameters like molar ratio, stirring speed, KOH concentration, temperature, time of the transesterification process, etc. It was found that the maximum yield of Citrullus colocynthis methyl ester was obtained at 6:1 molar ratio, 0.75% of KOH, at 65°C temperature with 250 rpm and 70 minutes of reaction time.

A study[41] found that Diesel engines would remain popular in the agricultural and transport sectors. The study[27] found an optimum compression ratio for the variable compression ratio diesel engine fuelled with diesel fuel. The findings validated that the compression ratio 17 was optimum as it exhibited superior performance and reduced emissions.

A recent study[42] conducted an experimental investigation to depict the effects of varying loads at various compression ratios using Citrullus colocynthis methyl esters. The study found the optimum performance and emission characteristics as 20% Citrullus colocynthis-diesel blend, at a compression ratio of 18 at maximum load. It was found that the optimum values of BSFC, BTE, HC, CO and NOx were 0.456 kg/kWh, 19.725%, 38.432 ppm, 0.026% and 348.744 ppm respectively at the load of 10 kg, CR of 18 and blend (mixture) percentage of 20. This study suggested that similar type diesel engine parameters using Citrullus Colocynthis (Citrullus Colocynthis oil) blend (mixture) can be explored without engine modification.

With the rapid rise in energy requirements and problems regarding atmosphere pollutions, renewable biofuels are the better choice for the internal combustion engine to partially or replace the pollutant petroleum fuel. In an experimental study[29] Citrullus colocynthis (Citrullus colocynthis) non-edible vegetable oil was used for the production of biodiesel and examine its possibility as diesel engine fuel. In an experimental study[43] transesterification process was used to produce biodiesel from Citrullus colocynthis non-edible vegetable oil. Citrullus colocynthis biodiesel (TBD) was used in the study to prepare five different volume concentrations (blends) with neat diesel (D100), such as TBD5, TBD15, TBD25, TBD35 and TBD45 to run a single cylinder diesel engine. The diesel engine's combustion parameters such as mean gas temperature, in cylinder pressure, rate of pressure rise, cumulative heat release, net heat release rateand mass fraction burnt analyzed through graphs and compared all Citrullus colocynthis biodiesel blends result with neat diesel fuel. The mass fraction burnt start earlier for Citrullus colocynthis biodiesel blends compared to diesel fuel because of less ignition delay while peak in cylinder pressure, maximum rate of pressure rise, maximum net heat release rate, maximum cumulative heat releaseand maximum mean gas temperature have found decreased results up to 1.93%, 5.53%, 4.11%, 4.65%and 1.73% respectively for Citrullus colocynthis biodiesel.

A study[44] investigated the performance (BThE) and emission (UHC, NOx) of Citrullus colocynthis biodiesel at varying load percentages to diesel. The experimental study was carried out in an IDI CI engine at 34, 67, at constant 1500 rpm at 100% load conditions. Three blends were used for the experiment. The first blend (mixture) was 100% diesel (PD), the second blend (mixture) was Citrullus colocynthis biodiesel 10% diesel 90% (Blend 1), the third blend (mixture) was Citrullus colocynthis biodiesel 20%, diesel 80% (Blend 2).

An experimental study[45] investigated the significance of biodiesel replaced for diesel. The biodiesel was obtained by two intrinsic methods from Citrullus colocynthis, one with methyl ester and other with enzymatic lipase-based methyl ester transesterification process. The process used Fe3O4+ thermomyces lanuginosus lipase as a catalyst for transesterification.

An experimental study[46] was performed to evaluate the physicochemical characterization and exhaust gas emissions of algal oil methyl ester blends (biodiesel+diesel), pure diesel fuel on a single cylinder, VCR diesel engine using different loads (0, 3, 6, 9 and 12 Kg), with different CRs conditions (13, 14, 15, 16 and 17).

Diesel fuel blended (mixed) with non edible Vegetable oil, fatty acidand fried oil. Using oil blends converts as Biodiesel. Biodiesel is oxygenated fuel and it can be produced at a lower cost. It is an eco friendly product and it is produced from local resources. The world has been now facing major problems like fossil fuel depletion and environmental damage. Fossil fuel oil soon will become rare due to its oversimplified extraction and consumption. Hence considered biodiesel has a promising option that they are squeaky clean renewable fuel oils and best substitute for diesel fuel oil in any IC engine. A study[47] was conducted on characteristics of emission and combustion of blends in the VCR engine.

Vegetable oils are found suitable alternate of diesel fuel as per the results of short run studies. Long run studies with vegetable oil as a fuel pointed out the problems related to wear and maintenance of the engine. In an experimental study,[48] a single cylinder, variable compression ratio diesel engine was examined for 512h (32 cycles of 16h per day) to study longevity implications of using Citrullus colocynthis vegetable oil. The results of the study revealed that very little damage was observed over the running surface of the cylinder liner, piston rings, valvesand valve seats. Wear in the piston outer diameter was observed to be 13-30 microns. Cylinder wear was about 80 microns. The closed gap in the oil piston ring increased up to 200 microns. Heavy carbon deposition was found on different internal parts of the engine, which indicates poor combustion of fuel. The amount of copper (66 mg/kg), silicon (112 mg/kg), dissolved in the lubricating oil was found more than permissible limits (Cu 50 mg/kg, Si 25 mg/kg), after 450h engine test run. But all the dissolve materials remain in allowable limits when the durability test conducted with diesel. Smoke, CO, HC and NO_x emissions were found to rise initially then decrease in the further engine running hours. But these emissions were found inferior to the engine emissions fueled with diesel in all the running hours. CO_2 emissions were found superior throughout the test with the pre-heated T20 Citrullus colocynthis oil blend (mixture) than diesel. The maximum reduction in the viscosity of the lubricating oil, during endurance testing, was found 60 centipoises but it was found 25 centipoises when the test conducted with diesel.

A study[49] was conducted to find the effects of varying loads at various Compression Ratios (CRs) using various Citrullus colocynthis oil-diesel blends on a Variable Compression Ratio (VCR) engine.

An experimental study[50] was conducted to identify characteristics of a direct-injection diesel engine fuelled with Mahua methyl ester and Diethyl ether as an additive, with two input parameters (load and fuel), for nine response parameters (exhaust gas temperature, brake specific fuel consumptionand brake thermal efficiencyand emissions of hydrocarbons, carbon monoxide, carbon dioxide, oxygen, nitrogen oxidesand smoke). The study concluded that Mahua methyl ester+10% Diethyl ether as the fuel at 30 kg load was the best solution.

A study[51] was conducted on combustion and exhaust emissions of a single-cylinder, air-cooled, direct injection (DI), compression ignition engine using biodiesel from the non-edible feedstock. In this study,[37] biodiesel (B100) was used in the study. Citrullus colocynthis L. methyl ester (CCME), its blends B30 with diesel fuel were used in the study. The biodiesel was produced via an alkaline-catalyzed transesterification process using methanol (6:1 M ratio), 1% of sodium hydroxide at the reaction temperature of 60°C for 1 h. The important physical and chemical properties of Citrullus Colocynthis L. Methyl Ester are close to those of diesel fuel. Fuels (diesel fuel, B100and B30) were tested on a DI diesel engine at 1500 rpm for various power outputs. The results indicated that B100 and B30 exhibit the same combustion characteristics compared to diesel fuel. However, B100 and B30 display earlier start of combustion. At lower engine loads, the peaks of cylinder pressure and Heat Release Rate (HRR) were higher for B30 than B100 and diesel fuel during the premixed combustion period. At higher engine loads the peaks of cylinder pressure were higher for B100 than B30 and diesel fuel, but the HRR during diffusion combustion was more considerable than diesel fuel. The Brake Specific Fuel Consumption (BSFC) was higher for B100 than diesel fuel at all engine loads while B30 exhibited comparable trends. The thermal efficiency was slightly higher for B100 than B30 and diesel fuel at low loads and rise for B30 at full loads. B30, B100 provided a higher reduction of hydrocarbons emissions up to 50% for B100. Nitrogen oxides and particulate matter emissions were also reduced.

Development of biodiesel-diesel blend[52] was studied to transesterify the CCO in the presence of Candida Antarctica lipase as catalyst and methanol and during the study, the optimum blend was obtained through the experimental process. The findings summarized that the physicochemical parameters/fuel properties of the Citrullus Colocynthis Methyl Ester (CCME) were assessed and compared. The fuel properties of Citrullus Colocynthis L. Methyl Ester were within the limits of the ASTM D6751 and EN14214 standards. Furthermore, Citrullus Colocynthis L. Methyl Ester showed good oxidative stability and a long shelf life due to its high natural antioxidant content. Citrullus Colocynthis L. Methyl Ester showed better fuel properties and long-term storage stability due to which it can be used as a potential alternative fuel.

Discussion

The result of an experimental study[53] showed that the low concentration of Citrullus colocynthis oil blends with diesel can be used successfully in diesel engines without any hardware modifications and without posing any problems related to combustion and engine knock. Citrullus colocynthis oil blended (mixed) with diesel up to 30% levels can be used successfully in diesel engines with no major reduction in engine performance and reduced tailpipe emissions.

In an experimental study[54] CFD analysis of biodiesel fuel combustion was carried out using ANSYS FLUENT R14.5 software to study the effect of blending ratio on the combustion characteristics in Compression Ignition (CI) engine and parameter such as in-cylinder pressure, temperature, heat release rate, etc. were determined. The fuel considered in the study were pure diesel, 10%, 20% and 30% blending of biodiesel derived from Citrullus colocynthis oil (Citrullus Colocynthis) with pure diesel. The study revealed that peak cylinder pressure of the engine running on biodiesel blend (mixture) was slightly higher than the engine running on pure diesel. Citrullus colocynthis biodiesel blends had a lower heat release rate compared to diesel during the premixed combustion phase. The peak of heat release rate for diesel during the premixed stage was about 35.03%, during the mixing, the stage was about 1.09% higher compared to B20. The review of research papers confirms that there is a scope for development of biodiesel and that this biodiesel can be used in existing engines without any engine modification. Thus there seems to be a scope for exploring commercial viability of this project, which can indirectly help in promotion of green energy and help in attainment of SDG7 (development of clean sources of energy).

Conclusion

The research studies have found that biodiesel blended with diesel can be used in existing engines (without any modification). This finding can indicate the possibility of greater use of biodiesel considering the rising cost of diesel and reducing stocks of fossil fuel based sources. This review of research studies can take us to conclusion that in the future, there will be greater use of biofuel, which will help mankind in over coming the energy crisis and enable development of alternatives to fossil fuels, which will eventually exhaust. There is a need to undertake commercial viability analysis of development of biofuel so that some entrepreneurs can explore this field of study.

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